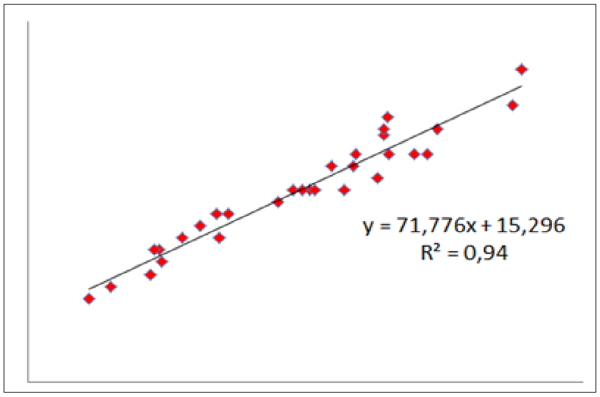
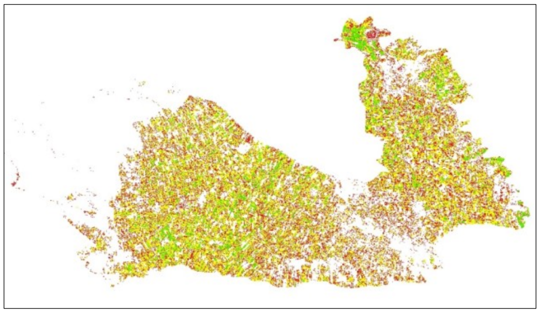
Master of Environmental Sciences

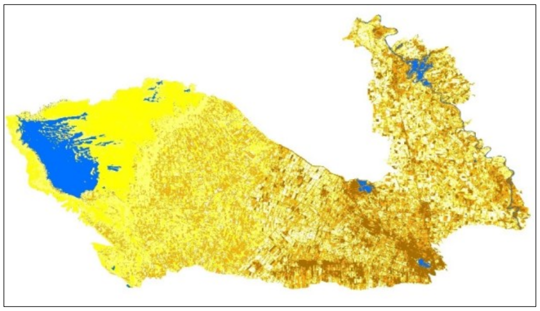
Master Thesis Report: MES-2019-09

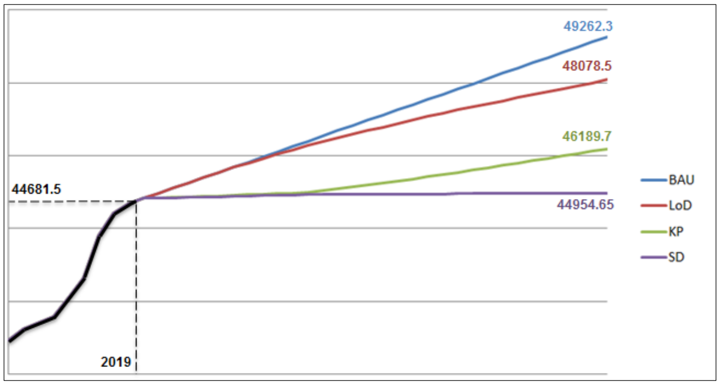
Assessment of desert extension and soil salinity in Mirzachul Steppe, Uzbekistan

Sayidjakhon Khasanov









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Assessment of desert extension and soil salinity in Mirzachul Steppe, Uzbekistan

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"Erosion, desertification and pollution have become our lot. It is a weird form of suicide, for we are bleeding our planet to death."

Gerald Durrell

Acknowledgement

I express my deep gratitude to several people who have supported me throughout my studies in Wageningen University and Research. First of all, I wish to thank Mr. Ulugbek Islamov from the UNDP project called Sustainable Management of Water Resources in rural areas in Uzbekistan who supported me to study at this university by covering my first-year invoice. Special gratitude is also addressed to Ms. Marjo Lexmond for gratuitous help to apply for Wageningen University Fellowship Program to receive a grant to reimburse the second year tuition fee. I express my gratitude to Alim Pulatov for all his advice and ideas on choosing the thesis topic and providing me with a beautiful learning experience which made me ready to study at this university. I thank a lot to André van Amstel and Harm Bartholomeus for their supervision and the feeling of confidence they gave me. I wish to thank also to my chingones and friends, Elie, Enya, Erich, Job, Joost, Teun, Vince, Umidkhon and others for their amazing friendship. Last but not least, I express my thankfulness to my family, especially for you mom!

Онам! Хаммасига сизни қилган узоқ дуоларингиз билан етишдим. Ёшлигимдан орзу қилар эдингиз чет давлатда ўқиб қайтишимни, мана, ниятингизга етказганимдан беминнат хурсандман. Илтимос, дуодан қўйманг ва бундан хам каттароқ ютуқларга эришганимда хар доим ёнимда бўлинг. Умрингиз узоқ бўлсин.

Abstract

Uzbekistan has an arid climate and 85% of its territory consists of desert. This makes Uzbekistan vulnerable to desertification (desert extension). The consequent high evaporation rate of saline irrigation water and mineralized groundwater increases soil salinization. This salinization expands the deserts and these results in many complaints to the government on loss of arable land from the local farmers. As a response, the responsible institutions sent scientists to carefully study this situation. Their studies, however, neither quantified nor estimated the severity of this desert extension. Salinization damages crops and this has hampered the country's economy. Approximately one 1 billion US dollars are lost each year. In addition, the responsible institutions still use a time-consuming, costly and non-spatially specific in-situ soil salinity assessment method as their primary method. Therefore, I did two experiments that consider all of the above-mentioned aspects. The first experiment assesses the desert extension by monitoring sand dynamics in the Mirzachul Steppe by using GIS and remote sensing tools, and by applying scenarios that tackle the desert extension. The second experiment assesses soil salinity and compares in-situ and GIS-based methods by applying a multi-criteria decision analysis to identify the current perception of the responsible institutions.

To assess the desert extension, satellite images were downloaded to create a preliminary map of soil mechanic content. This analysis was conducted for the period 1994 to 2018 and the average annual rate of desert extension was determined. This rate accounted for 143.2 hectares of desertification per year. I then formulated different scenarios to quantitatively project future states and expected changes till 2050. In total, four scenarios were created in which agroforestry was the main mitigation measure. The gap between these scenarios was a loss of 5,000 hectares of arable land. Narrative storylines were based on these scenarios to visualize the influence of mitigation measures on climate change and soil reactions. The scenario analysis showed that agroforestry can stop the desert extension by reducing future wind speed.

The soil salinity maps from the GIS-based assessment method were compared with the in-situ data maps. August was selected to map soil salinity since this indicates the maximum of the growing season for cotton, which is the area's main crop type. The maps proved visually very consistent and this impression was then statistically tested. The NDVI-GIS approach correlated almost 96% with the in-situ soil-quality-index values (R^2 is 0.84). This enabled me to apply a multi-criteria decision analysis to ascertain the most preferred soil salinity assessment method by scoring and ranking selected criteria. This analysis showed that the GIS-based approach outweighed the in-situ one. This initiated a discussion among representatives of the governmental institutions that use the in-situ soil salinity method as a primary method. They endorsed the GIS-based approach, but they stated that the GIS-based method cannot determine the chemical soil salinity types, which serve help organize salt-leaching measures. I assumed that GIS indeed potentially can assess the degree of soil salinity, but the first step to formulate such approach is to assess the chemistry type of soil salinity.

List of used acronyms

ANOVA – Analysis of variance

DE – Desert extension

ESA – Environmental systems analysis

GIU – Governmental institution of Uzbekistan

GIS – Geographic information systems

LD – Land degradation

MAWR – Ministry for Agriculture and Water Resources

MCDA – Multi-criteria decision analysis

NDVI – Normalized difference vegetation index

RQ – Research question

RS – Remote sensing

SAVI – Soil-adjusted vegetation index

SQI – Soil quality index

UNCCD – United Nations Convention to Combat Desertification

Uzgeocadaster (SCLRGCSCRU) – State Committee for Land Resources, Geodesy, Cartography and State Cadasters of the Republic of Uzbekistan

Uzsoilscience (SSRISSAC) – State Scientific Research Institute of Soil Science and Agro Chemistry

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1. GENERAL INTRODUCTION

Land degradation (LD) is considered as one of the major challenges for the quality of life and environment across the world (Dubovyk, 2017). Nowadays, 33% of soil resources in the world are being degraded. Amongst them, steppes and croplands of degraded land accounts for 40%. Over 1 billion people are highly dependent on these degraded lands in the world. At the same time, 12 million hectares of land are likely to be lost for crops annually (FAO and ITPS, 2015; FAO, 2017), despite taking significant actions and measures towards the LD issue. In the past, when the impact of LD was slowly increasing, the advanced apprehension of the world on LD had driven the United Nations into the proclamation of the Convention to Combat Desertification (UNCCD) in 1994 which mainly aimed for a reduction of the severity of LD in all affected countries (Dubovyk, 2017; UNCCD, 2014). In addition to this, 17 Sustainable Development Goals of the 2030 Agenda for Sustainable Development were embraced in September of 2015 by most world leaders to create a more sustainable world (Nkonya et al., 2016).

LD is interpreted as the reduction or loss of the biological productivity or economic value of land (i.e. its ecosystem) (UNEP, 1994). LD comprises of eight different soil threats. These are soil salinization/sodification, soil erosion, loss of soil organic carbon, loss of soil biodiversity, soil contamination, soil acidification, soil compaction and soil sealing (Bai et al., 2015). These threats occur due to climate change and other human-induced activities, and contribute to desertification (Stolte et al., 2016). My thesis report focuses on desertification as a LD type and soil salinization as a LD threat in drylands.

According to the definition of desertification the United Nations, on the one hand, officially affirms that desertification is LD in typically dry areas (arid zones) resulting from various factors, including climatic variations and human activities (UNCCD, 2006). However, Prince (2004) and many other scientists studying desertification were critical of this and considered this definition too broad (Herrmann and Hutchinson, 2005). On the other hand, Merriam Webster's Collegiate Dictionary (2003) defines the term desertification as, 'the process of becoming a desert'. Early experts on the subject promoted the idea of the 'encroaching desert', 'moving desert' or 'advancing desert' to illustrate desertification (Adu, 1982; Mainguet, 1994) with the latter citing several earlier studies related to this aspect of desertification. This 'expansion of the desert' theory culminated in the assertion by Lamprey (1975) that the Sahara as one example for arid zones was marching at a rate of 5.5 km per year. Central Asia as another example for arid zones is famous amongst other Asian countries with its huge deserts, namely Kizilkum, Karakum and Aralkum. The Aralkum Desert appeared after the crisis of the Aral Sea and the territory of this desert is still extending (UNCCD, 2014). These deserts currently account for roughly 85% of Uzbekistan's total area (Simonett and Novikov, 2010), threatening human economic activities and the natural processes of arable land. For that reason, the term desertification will be used to signify '*desert extension*' hereinafter in my research to test the likelihood of the deserts to trespass onto arable land in Uzbekistan.

An increasing population of the world is placing massive stress on agricultural products, as such unsustainable agricultural practices, like commercial cultivation and irregular crop rotation, have led to soil degradation. From the other side, incorrect fertilizer management in agriculture has caused the groundwater nitrate level to rise, resulting in land and yield losses (Ivushkin, 2019; FAO, 2003). These drivers create favorable conditions for the soil salinization processes taking place within the top-soil. *Soil salinization*, which is the process of salt accumulation in soils, is more common than other soil threats in the arid zones of the world (Rhoades and Chanduvi, 1999). With an increasing degree of soil salinity, roots dissolve the salts and the natural flow of water in the plant organism is disturbed, causing the plant stomata to close. Additionally, the severe concentration of salts in soils restricts the ability of crops to absorb water from the soil (Ochieng et al., 2013; Gorji et al., 2015). Two factors, salty irrigation water (Figure 1a) and mineralized groundwater (Figure 1b), can directly result in soil salinization (Brouwer et al., 1985).

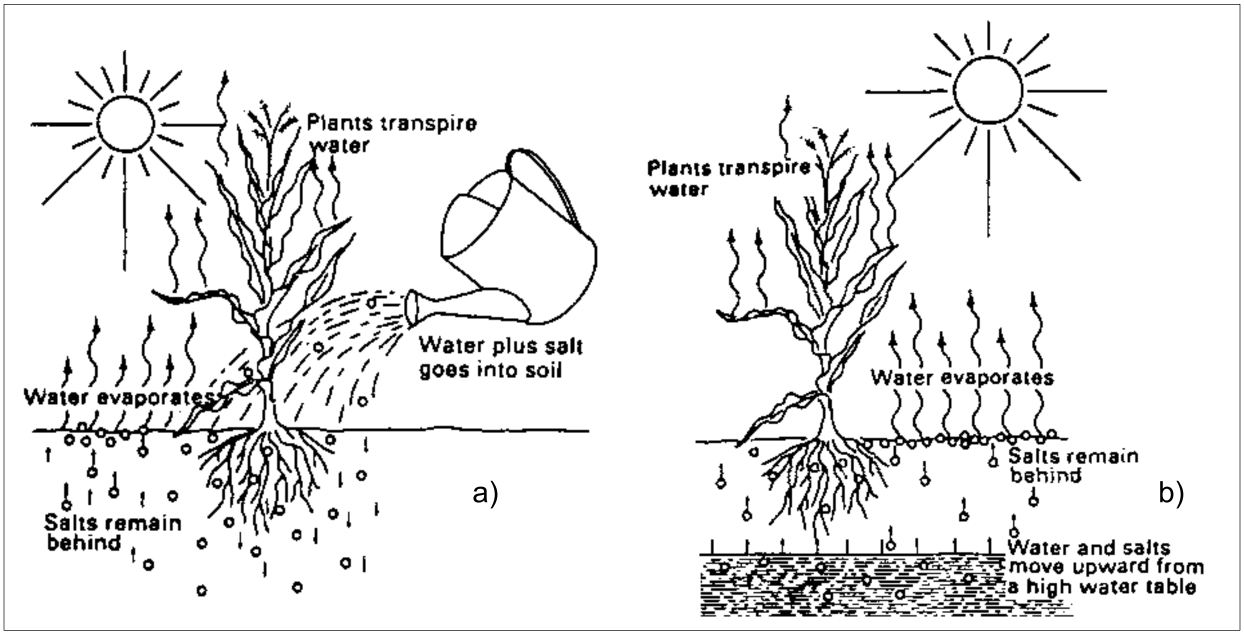

Figure 1. Salinization caused by irrigation water (a) and a high water table (b) (Brouwer et. al., 1985)

As a matter of fact, more than 20% of irrigated lands worldwide are now affected by salts to different degrees (Ghassemi et al., 1995). In general, salt-affected areas are moderately spreading at the rate of around 2 million hectares per year (Abbas et al., 2013). These areas nowadays counterbalance the considerable amount of agricultural production. This amount is otherwise attainable by using the best and most sustainable land and water management practices at the country-wide area.

The Center for Economic Research (2015) stated that the agricultural economic strategy of Uzbekistan mainly relies on agricultural production, which consists of 17.6% of the total Gross Domestic Product (GDP), and the employment rate in agriculture was 27.2% in 2013. In fact, Uzbekistan only uses roughly 11% of its territory for agricultural purposes (FAO, 2009). The State Scientific Research Institute of Soil Science and Agro Chemistry (hereinafter Uzsoilscience) (SSRISSAC, 2014) found that 46.7% of arable land was at different levels of soil salinity. The annual economic damage of soil salinization accounts for approximately one billion US dollars and is a burden for the developing economy of the country (Akramkhanov et al., 2011). Dry soils of Uzbekistan commonly have a moderate salt concentration which is only leached and deposited into local groundwater systems through massive irrigation.

Considering this background information, two topics discussed above, desertification (desert extension, DE) and soil salinization, are critical issues in the context of Uzbekistan. The overall goal of this research is to contribute to the methodology development for desertification and soil salinity assessments. Therefore, this thesis research employed two separate experiments for each topic which were undertaken through Geo-Information Systems (GIS) and Environmental Systems Analysis (ESA) tools. The report is then structured as following (Figure 2).

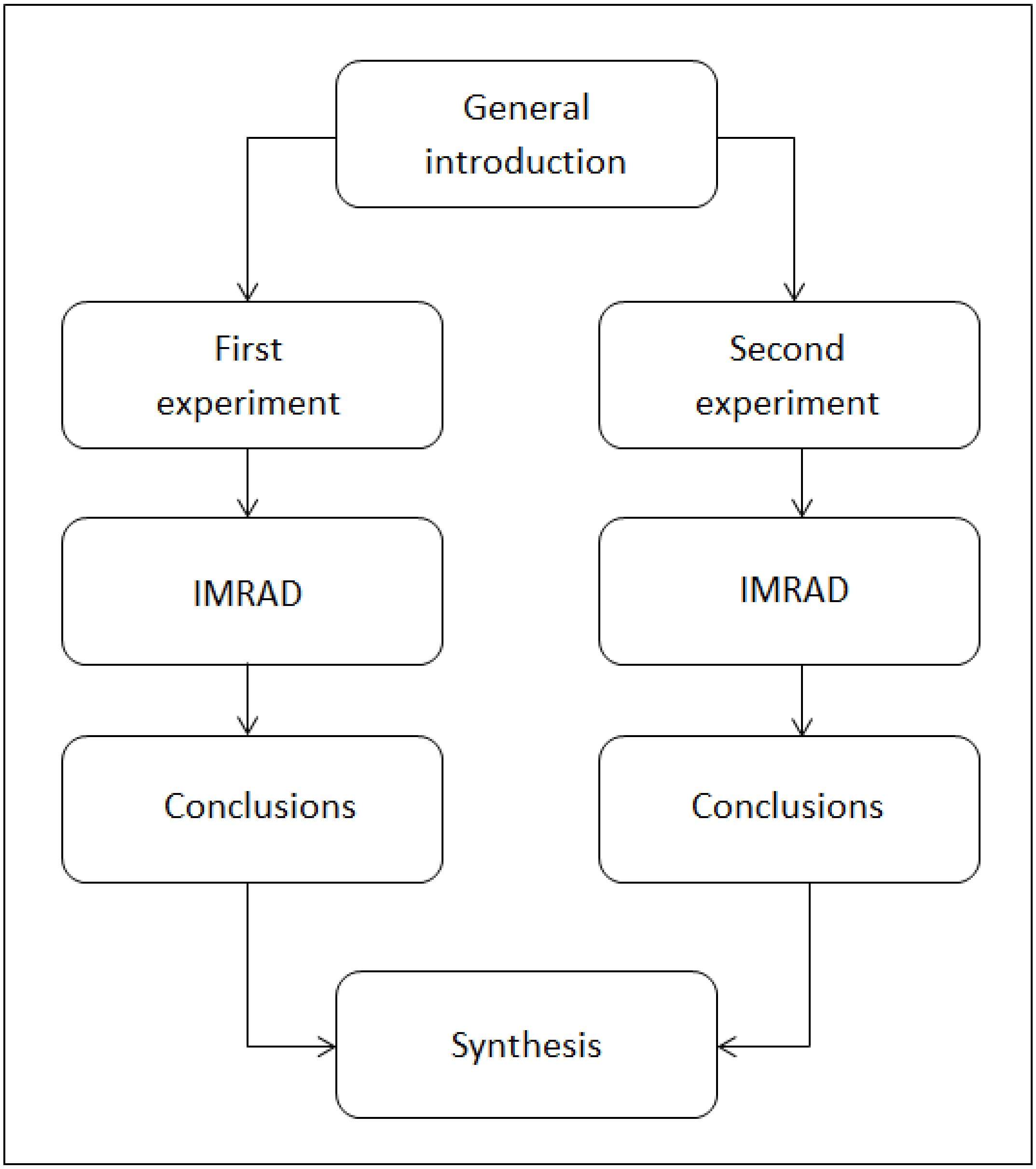

Figure 2. Structure of the report

This structure sandwiches two experiments, which were done by the Introduction Methodology Results And Discussion (IMRAD) approach as well as conclusions, between the general introduction and the overall synthesis. This structure gives a straightforward understanding of and ensures an appropriate focus on the contents of each experiment, reducing the likelihood of confusion that can be occur as the reason behind the traditional approach on structuring the research.

2. EXPERIMENT 1. THE ASSESSMENT OF DESERT EXTENSION

2.1. Introduction

According to Simonett and Novikov (2010), more than 85% of the territory of Uzbekistan consists of deserts and semi-deserts. The mid-latitude desert located in the western part has long, hot and dry summers with mild winters. The eastern part of the country is semi-arid grassland with mountains surrounding the northern and southern borders. Around 47% of the total territory consists of meadows and pastures, another 10% is arable, and 1% has permanent crops. There are two main rivers, namely the Amu Darya and the Syr Darya, which both end in the Aral Sea. Over 30 major tributaries are located in these two watersheds as well as more than 50 large and mid-sized water reservoirs and 60 canals in different sizes, which have been constructed in these watersheds to promote intensive irrigated agriculture since the 1950s (Saigal, 2003).

Sadly, the intensive agriculture during the Soviet period led to some cataclysmic environmental problems, for example, the Aralkum Desert intruded on the territory of the Aral Sea. The Aralkum Desert is the youngest desert in the world, appearing after anthropogenic disturbances. The loss of the southern part of the Aral Sea has influenced the emergence of areas overloaded with toxic sand particles and pollutants from eroding ships (Breckle and Wucherer, 2012; Opp et al., 2019). The extension trend of the Aralkum Desert is increasing day by day, occupying an area of 45,000 km^2 in Uzbekistan nowadays. It was concluded that it is difficult to rehabilitate the ecosystem and bio-productivity of this area (Nachtnebel et al., 2006; Breckle and Wucherer, 2012).

With respect to the Aralkum Desert, it has newly appeared in Uzbekistan and scientists tend to conduct scientific researches on this field with innovative technologies. But, relatively less attention is paid nowadays to the impacts of other deserts in Uzbekistan (Saigal, 2003). Therefore, there is a high demand for studies, collaborating with Governmental Institutions of Uzbekistan (GIUs), introducing satellite monitoring of climate conditions and soil reactions, to understand how global warming interacts with the changes of soil dynamics and indirectly affects the desertification processes.

There is only one responsible GI, the State Committee for Land Resources, Geodesy, Cartography and State Cadasters of the Republic of Uzbekistan (SCLRGCSCRU or hereinafter Uzgeocadaster), which is ready to cooperate with local and international scientists on desertification issues in Uzbekistan (YGK, 2019). The main objectives of Uzgeocadaster are: to develop and implement state programs on the rational use of land resources, to ensure the safety and protection of land from human-induced environmental changes, to increase soil fertility and to enhance the effectiveness of geodesic and cartographic activities (YGK, 2019). Another objective, which does not directly address desertification issues, is collaboration with scientists and cooperation towards wider goals. This type of work, however, is still essential for finding potential desertification solutions through the promotion of research quality.

2.2. Problem definition and research questions

Representatives of Uzgeocadaster announced in their national report that local municipalities have received too many complaints from the farmers and smallholders, mainly on the loss of private gardens and farm-yards, in the past decade (SCLRGCSCRU, 2016). After having analyzed the complaints (Table 1), representatives determined that these yards were formerly located close to the deserts.

Table 1. Distribution of the received complaints from farmers on arable land loss per province in Uzbekistan (SCLRGCSCRU, 2016)

Provinces	Bukhara	Jizakh	Karakalpakstan	Kashkadarya	Khorezm	Navai	Samarkand	Sirdarya	Tashkent	TOTAL
%	14.8	13.4	18.5	10.7	8.1	18.9	6.1	9.2	0.3	100.0

Referring to the percentage of public complaints on land loss, 22.6% of the total complaints (738) were received by the municipalities of Jizakh and Sirdarya provinces which are considered as agricultural provinces in Uzbekistan (SCLRGCSCRU, 2016). The loss of these productive areas, in the two mentioned provinces, will be economically significant to the agricultural sector of the republic, since the main crop type is cotton in these provinces, which provides half of the revenue of the agricultural sector (SCLRGCSCRU, 2008).

Therefore, groups of scientists from ecological and land-use and management departments of Uzgeocadaster were organized to conduct field research on lost areas. Within the short period, scientists undertook an observation on the lost agricultural fields and the results were shortly described as, "It occurred due to the desert extension" (p. 47, SCLRGCSCRU, 2017). Scientists did not eventually provide their interim report with the specific data, neither on the actuality of the DE rate nor of the desertification maps, because they restricted themselves to only use the conventional methods of the research (SCLRGCSCRU, 2017), without including GIS techniques. Based on the short conclusion of the scientists quoted above, it is slightly difficult and uncertain to foresee the future state of the DE and describe required precautionary measures towards the DE in Uzbekistan. These difficulties and uncertainties in the DE assessment were the reason behind a lack of methodology development.

Considering all aspects of desertification in Uzbekistan, the first experiment aims to monitor sand dynamics in Uzbekistan by using GIS and Remote Sensing (RS) tools and applying proper scenarios against the DE by answering the following research questions (RQs):

RQ1. How can ground truth be used in combination with satellite images to estimate the average "desertification" (desert extension) rate per year over the period 1994 to 2018?

RQ2. What types of scenarios could be applied in this circumstance to describe the future situation from 2019 to 2050?

RQ3. Which scenarios are possible to describe the expected changes in the situation between 2019 and 2050?

RQ4. Which storylines are needed for these scenarios on climate change and soil reactions to cover the future up to 2050?

In RQ1, the annual average area loss due to the DE will be determined by analyzing satellite images. Hereby, the only atlas map published in 1994 characterizing the soil classification will be used as reference data. Then, the results of RQ1 will serve as an input for RQ2 to decide the type of scenario. After having determined the type of scenario, next, appropriate scenarios including potential measures to reduce the DE rate will be detailed to envision changes in the future period. Lastly, storylines will be selected to describe possible impacts of these scenarios from climate change, and the subsequent soil reactions, in the future period.

2.3. Methodology

2.3.1. Study area

Uzbekistan is a land-locked country which is located in Central Asia (Figure 3) between the Syr Darya and the Amu Darya rivers. The total territory of the republic is 447,400 km^2, in which just less than 43,000 km^2 is used for agricultural purposes. Large valleys and deserts, foothills and mountain regions characterize the landscape of Uzbekistan. Due to the geographical location of Uzbekistan, dry and continental weather can be observed at any time of the year and it is considered as a (semi-)arid zone (Sluijter et al., 2011). Uzbekistan has a unique climate condition consisting of long, dry and very hot summers, cool and wet autumns and very cold winters with thaws (FAO, 2012). The average temperature during the peak summer time (July) is 28°C while the mean temperature is 1°C in the peak winter time (January). The mean annual sum of the precipitation is 424 mm (Advantour, 2019).

Figure 3. Map of Uzbekistan (US Embassy in Uzbekistan, 2019)

The study area is Mirzachul Steppe (in Russian – Голодная Степь, transliteration - Golodnaya step, hereinafter, Mirzachul), which lies on the territories of Sirdarya and Jizakh provinces as well as includes a negligible part of Tashkent province (Figure 4). The coordinates of the study area range from latitude: 41° 45’ 54’’ N, longitude: 067° 42’ 07’’ E to latitude: 40° 20’ 17’’ N, longitude: 067° 14’ 23’’ E. Mirzachul is a steppe-arable land and its borders were first identified in the official map of Uzbekistan in 1994 (Atlas of Uzbekistan, 1994). In the same year, the total area of Mirzachul was calculated and it was just above 1 million hectares (including territories in Kazakhstan). Mirzachul shares borders with the Kizilkum desert. There are two windy seasons, starting at the beginning of March until May and from the end of September to the middle of November (Encyclopedia of Uzbekistan, 2002), which might be the main driver of the DE. According to the data provided by the Hydro-meteorological Service (Uzhydromet, 2010), sandstorm weather conditions such as sandy rain and sand-storm have been registered several times in Mirzachul.

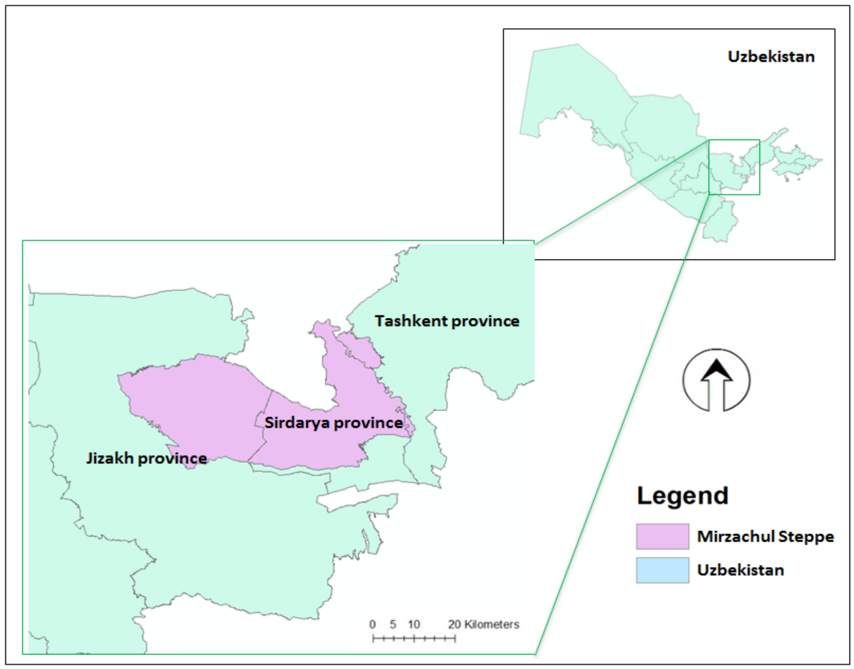

Figure 4. Map of Mirzachul Steppe in Uzbekistan

2.3.2. Importance of geo-information systems to assess the vulnerability of desertification

As mentioned above, gardens and farm-yards near the deserts have been lost in the republic, it is now important to apply GIS and RS tools and techniques to instantly assess the dynamics of this DE at the wider spatial resolution, rather than spending more time on the in-field research. These tools have a great potential to monitor and evaluate soil dynamic processes including the DE (Hostert et al., 2001).

Walker and Robinove (1981) first started to locate, assess and monitor the DE with GIS and RS techniques. They claimed that GIS and RS-based data provide a permanent record of the land condition in such a format that records measurable changes, occurring in land features and condition. Hostert et al. (2001) considered that the RS approach towards desertification plays an important and key role as one of the major sources of state-of-the-art and physically-based information, whereas GIS provides the toolbox that improves the ability of data integration, data analysis and data extraction from the source.

Some scientists claim that desertification can be assessed by using RS tools like Normalized Difference Vegetation Index (NDVI) and Soil-Adjusted Vegetation Index (SAVI) and that it might provide a basis for an early warning of desertification. NDVI and SAVI, calculated using satellite images, have revealed the capability of RS for systematic, reliable and spatially extensive monitoring of desertification (Diouf and Lambin, 2001; Nicholson et al., 1998; Prince and Justice, 1991; Prince, 2004; Bannari et al., 1995).
Recent studies have also shown that the integration of GIS and RS can investigate temporal and spatial dynamics of desertification, analyze potential changes occurring amid land cover features and develop the baseline maps of desertification (Higginbottom and Symeonakis, 2014; Miehe et al., 2010). In regard to these studies, RS implies either satellite images or aerial photography in order to perform a trend analysis for future scenarios and create trend maps showing the possible changes in land cover condition over a certain time period (Masoudi et al., 2018).
Only one study has been carried out in Central Asia to assess the vulnerability to the DE by Liu et al. (2005). They determined the extension by using desertification indices in RS from 1995 to 2001. Interestingly, there was a moderate change of the soil type in Uzbekistan according to their results, which can be replicated and observed by using GIS and RS techniques.

2.3.3. Application of scenarios to desertification

The outcomes of the GIS-based trend analysis of the DE serve a strong basis to apply potential scenarios by implementing scenario analysis to foresee the future severity. Scenarios are crucial to delineate the future state of a certain problem consistently, coherently and plausibly (Carter et al., 2001). Referring to Alcamo (2008), the application of the scenario analysis is valid when the uncertainty is high and the complexity or controllability is low.
Scenario analysis mainly produces results which are relevant to the science because of its iterative procedure that allows scientific experts to obtain scenarios fitted to their objectives. Scenario analysis also generates credible results since it can be handled by using ultra-modern computer models to derive numerical information about the dynamics of environmental changes (Alcamo, 2008; Alcamo, 2008b).
Several scenarios, modeled on the Intergovernmental Panel on Climate Change (IPCC), are globally used to provide information in the Millennium Ecosystem Assessment (MEA, 2001), an international scientific assessment of the consequences of changes on ecosystems for human well-being, by the request of international partners such as UNCCD. Regionally, some scientists conducted research using GIS techniques in Eastern Asia and Northern Africa to check how climate factors such as wind speed and precipitation would affect the DE (Feng and Fu, 2013; Ci et al., 2002; Herrmann et al., 2005; Miao et al., 2015). It was concluded that the applied scenarios revealed that the near future (2025-2030) would become slightly hot in the drylands in Asia and Africa. The findings of this research were also identical to those which the IPCC described (Miao et al., 2015).

2.3.4. Data collection

The Atlas of Uzbekistan published in 1994 contains the only paper map of Uzbekistan after the independence in which the territory of Mirzachul (in Russian – Голодная Степь) was firstly and, lastly illustrated. This atlas map was taken as the primary data source. For that reason, the base

year of the analysis in the first experiment of this research is 1994. This map was then digitized in order to extract Mirzachul for further analysis.
Furthermore, the soil map of Mirzachul is also important to observe the distribution of soils in that area. Therefore, the soil map of Mirzachul was derived from the same atlas (Figure 5) so as to set up the reference digital map created by using the satellite images.

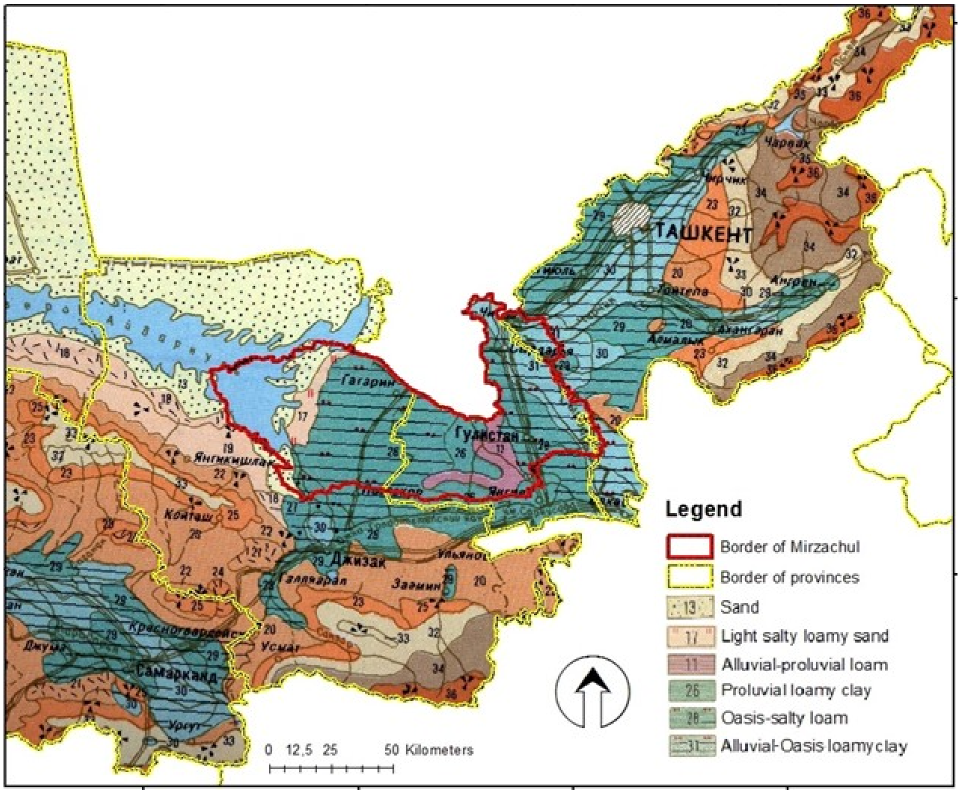

Figure 5. Soil map of Mirzachul published in Atlas of Uzbekistan in 1994

As for secondary data, satellite images taken especially in the middle of November were downloaded from the open source databases Earth Explorer and Glovis (www.earthexplorer.usgs.gov; www.glovis.usgs.gov). This time period was used, as in the study area, there are two windy seasons which terminate in the middle of November in each year. For this reason, the mid-days of November are the best to observe the dynamics of sand migration in the study area. Regarding the sensors of satellite images, Landsat TM 5, Landsat ETM+ 7 and Landsat 8 OLI (for further information on Landsat sensors, see CRISP) were used. The temporal resolution of the selected sensors is 16 days, whereas, the spatial resolution of images is 30 meters, which means one pixel of the image covers 30 meters x 30 meters of land surface. The full list of downloaded satellite images can be found in Annex 1.

2.3.5. Data analysis

The analysis of the DE required several steps to interpret the results. Firstly, some pre-processing steps and operations on satellite images (e.g. atmospheric and geometric corrections, outlier removal and mosaicking) were undertaken which directly improved the quality and the accuracy of the RS maps (Richter, 1990; Liang et al., 2001; Kardoulas et al., 1996; Irish et al., 2006; Fedorov et al., 2003). The analysis of the DE was conducted by using

ArcGIS and Erdas Imagine software packages. Then, a GIS tool called "Resample" was used in order to change the actual pixel size of the satellite images to 150 meters x 150 meters to speed up analyses, return an enhanced visualization and reduce the size of the RS images to ensure proper data storage.

Afterwards, the Normalized Difference Vegetation Index (NDVI) was applied to remove the canopy cover from the satellite images. The NDVI ranges from -1 to 1 and assesses whether the target being analyzed contains photosynthetically active vegetation or not by using Equation 1 (Bannari et al., 1995):

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad \text{(Equation 1)}$$

Where:

NIR is the near Infrared band of Landsat sensor (band 4 for Landsat TM 5 and Landsat ETM+ 7; band 5 for Landsat 8 OLI); and

RED is the red band of Landsat sensor (band 3 for Landsat TM 5 and Landsat ETM+ 7; band 4 for Landsat 8 OLI).

Once the NDVI was calculated, vegetation cover above 0.3 NDVI was removed from each satellite image (Ivushkin et al., 2017; Platonov et al., 2015) in order to improve the accuracy of the Soil-Adjusted Vegetation Index (SAVI) values ranging from -1.5 to 1.5. The SAVI enables the sufficient description of the soil-vegetation system and soil type classification by using Equation 2 (Huete, 1988; Bannari et al., 1995).

$$SAVI = \frac{(NIR - RED)}{(NIR + RED + L)} \bullet (1 + L) \qquad \text{(Equation 2)}$$

Where:

L is a soil adjustment factor (according to Huete (1988), L = 0.5)

When a potential RS tool, SAVI, was found to describe the soil system and reflection, the soil type of Mirzachul was classified for all years (1994-2018) by using the proposed values for the arid zone indicated in Table 2.

Table 2. Soil type classification based on the SAVI values (Huete, 1988; Fox et al., 2004; Mobasheri et al., 2010; Poggio et al., 2013; Yoshino et al., 2015; Zeraatpisheh et al., 2017)

Soil type	SAVI values
Sand	0.00 – 0.10
Loamy sand	0.11 – 0.15
Sandy loam	0.16 – 0.20
Loam	0.21 – 0.40
Loamy clay	0.41 – 0.60
Clay	0.61 <

When soil maps were created for all years, the dynamics of the sand close to the study area were showing whether the actual area of the desert extended or reduced. As far as the desert extended, the above-mentioned step-by-step methods were enough to tell the average annual DE rate in Mirzachul which was a response to RQ1 in the first experiment.

In order to justify this, the accuracy of the GIS results was determined by comparing the GIS results with the reference data on the soil type classification performed by Uzgeocadaster (SCLRGCSCRU, 2017) through in-field research. Then, a simple correlation analysis was performed using R software for all soil classes to see how soil types correlated with each other and how sand was correlated with wind speed. Data on wind speed were recorded (Annex 2) in two different meteo-stations, Dustlik and Jizakh, located in Dustlik district and Jizakh city which are close to the desert (Annex 3) in Jizakh province. The wind speed data were retrieved from the Hydro-meteorological Service (Uzhydromet, 2019). Also, to statistically prove the correlation between other soil types and sand with wind speed, a simple linear regression analysis was undertaken in MS Excel to check the *p-value* of all variables, especially for sand, in order to find the statistical significance of the increase or decrease ($p > 0.05$ – statistically insignificant; $p < 0.05$ – statistically significant).

The remaining RQs were answered by the implementation of scenario analysis. The statistically proven GIS results, which helped to decide on the type of scenario used (RQ2), served as an input for the initial stage of the application of scenarios. Regarding the elements of scenarios (Alcamo, 2001; Leemans, 2018; Kok, 2018), the base year for scenarios was 2019 and the end point in time of the scenario was set for 2050. Scenarios were formulated at the regional extent since Mirzachul lies between three provinces. Four different scenarios, as recommended by Van der Heijden (1997) and Leemans (2018) as an ideal number, were used to illustrate the future change in different time steps such as up to 2030 – short term, 2040 – mid-term and 2050 – long term (RQ3). The future impacts of these scenarios on climate change and soil reactions were thereafter portrayed by repeating the same procedure with different storylines (RQ4).

2.4. Results

According to the RQs to conduct the first experiment, this section consisted of several step-by-step sub-sections, starting with the GIS-based results and their validation and terminating with the potential storylines for the various scenarios.

2.4.1. GIS results

In total, 22 satellite images from 1994 to 2018 (excluding 1998, 2006 and 2012, since the images in these years were taken during undesirable weather conditions which directly disabled their workability) were downloaded and analyzed. Firstly, after having taken out the vegetation cover by using the NDVI tool during the analysis of the satellite image for 1994, SAVI was applied by using the SAVI soil type classification table (Table 2) in order to find the first similar patterns through comparison with the actual soil map of Mirzachul in 1994 (Figures 5 and 6).

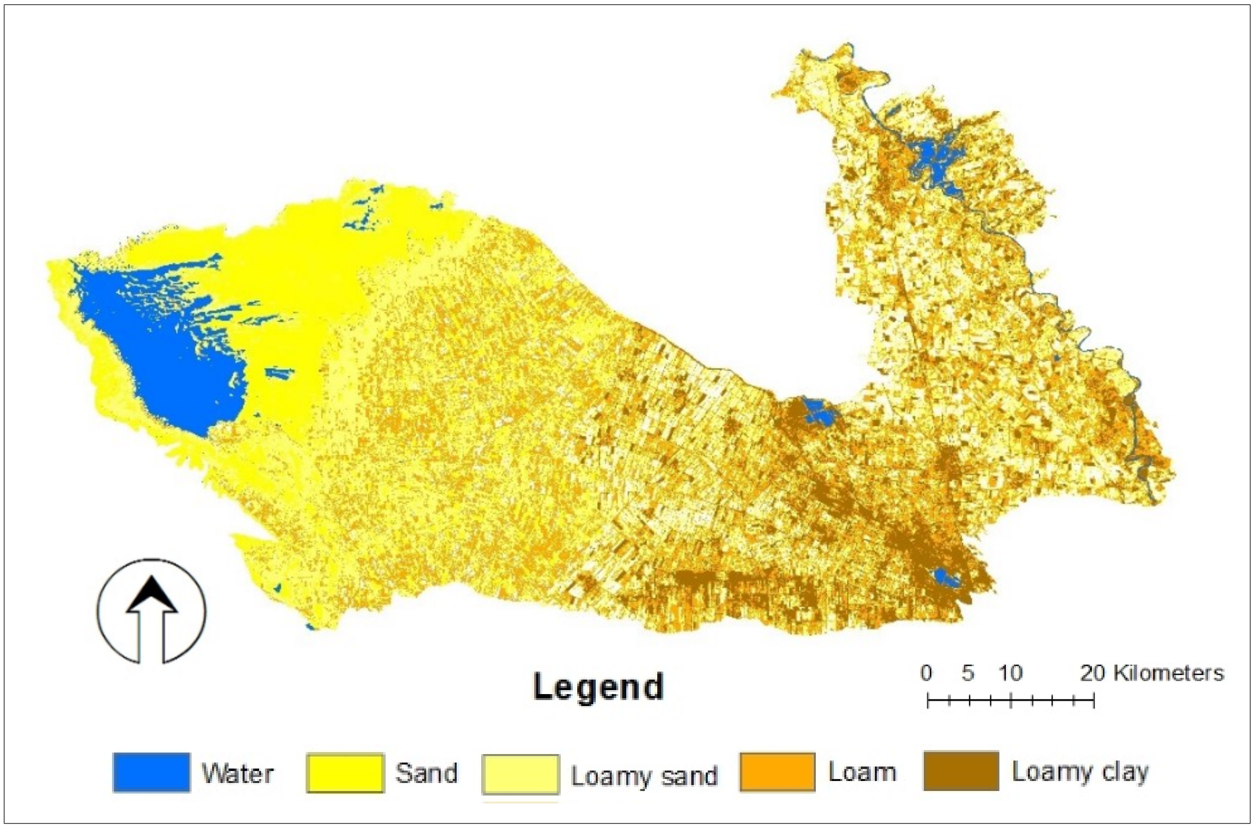

Figure 6. SAVI-based soil map of Mirzachul in 1994

As can be seen, patterns in Figure 6 on the soil types were visually satisfactory and similar to the actual map. As such, it was valid to perform this operation for all satellite images. Some of the GIS-based soil maps are given below in Figure 7 and the rest of them can be found in Annex 4.

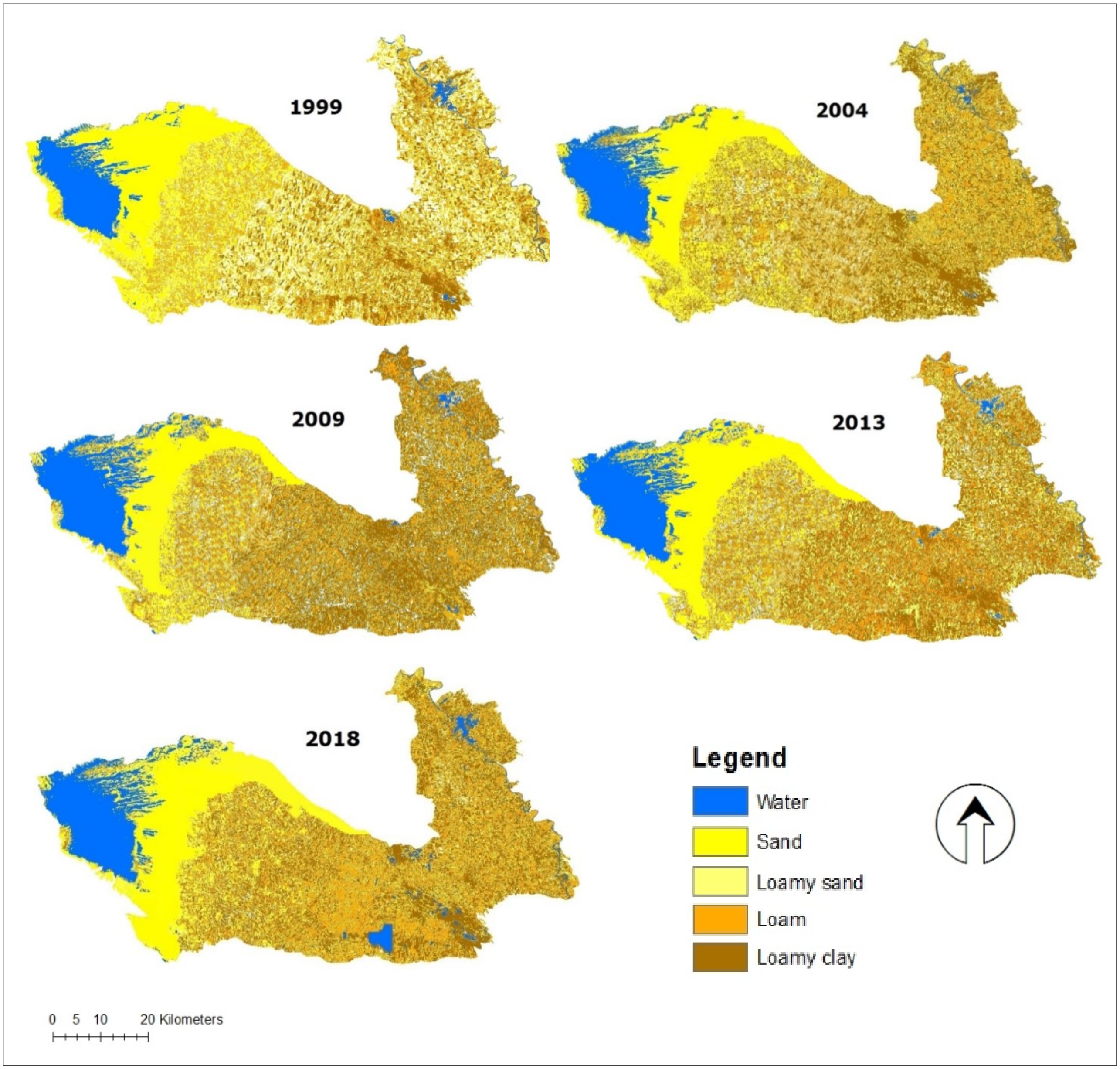

Figure 7. SAVI based soil maps of Mirzachul for the years 1999 to 2018

The sandy area had noticeably extended to the eastern side and sand had also migrated from the north. It is interesting to note that the territory of water in 1994 increased significantly at the end of 2018. With regards to the distribution of other soil types, they were also dynamic throughout the time period. While loamy clay was the dominant soil type in the eastern part of Mirzachul in 2009, the combination of loam and loamy sand dominated in other years. Thereafter, in order to derive quantitative values on the distribution of each soil type and water, the "Reclassify" operation was performed in ArcGIS software to transfer the qualitative data into quantitative. The result of this operation is displayed in Table 3.

Table 3. Soil and water dynamics of Mirzachul over the 24-year period in hectares

Year	Water	Distribution of soil types				Vegetation	Total
		Sand	Loamy sand	Loam	Loamy clay		
1994	34161.3	41304.8	15468.2	53055.5	68351.1	46845.4	259651.3
1995	36781.8	39821.2	15733.1	50349.3	65742.8	51223.1	
1996	38315.3	38733.1	12539.5	48499.8	67694.5	53869.1	
1997	43216.5	35169.6	12046.7	56822.5	63248.2	49147.8	
1999	43988.3	35571.3	12184.1	45360.5	65033.4	57513.7	
2000	44159.8	36078.1	10964.4	77894.6	51880.1	38674.3	
2001	43825.1	36713.4	10251.6	56596.7	66912.3	44992.2	
2002	44462.9	37875.7	10307.3	75112.4	60534.9	31358.1	
2003	44279.2	39011.6	9094.5	82159.5	54209.1	30897.4	
2004	45116.4	38225.3	9753.9	93041.7	41359.5	32154.5	
2005	45034.4	38594.2	7289.7	58186.5	82096.6	28449.9	
2007	47246.1	39359.5	8172.4	74498.2	59178.5	31196.6	
2008	47822.7	38162.9	7835.8	81848.4	51944.2	32037.3	
2009	49541.6	40302.7	8003.1	69305.4	67745.8	24752.7	
2010	51173.4	40933.1	9641.5	65712.6	71601.5	20589.2	
2011	51693.1	41257.3	11529.4	76944.2	33919.7	44307.6	
2013	51339.8	41591.1	8482.9	78025.2	52872.2	27340.1	
2014	51297.1	42108.8	10967.7	84281.0	34361.9	36634.8	
2015	51431.3	42638.2	8191.2	59549.9	38149.1	59691.6	
2016	52312.7	43814.6	11648.6	51912.2	54860.3	45102.9	
2017	51824.4	44429.3	18167.4	61810.1	31592.6	51827.5	
2018	51997.2	44681.5	7923.4	75228.4	61445.6	18375.2	

Many numbers were derived for the 24 years as a result of the "reclassify" operation. Admittedly, it is difficult to read the table above without visual illustration by a proper bar chart. The bar chart (Figure 8) delineates specifically in which soil classes either an increase or a decrease occurred.

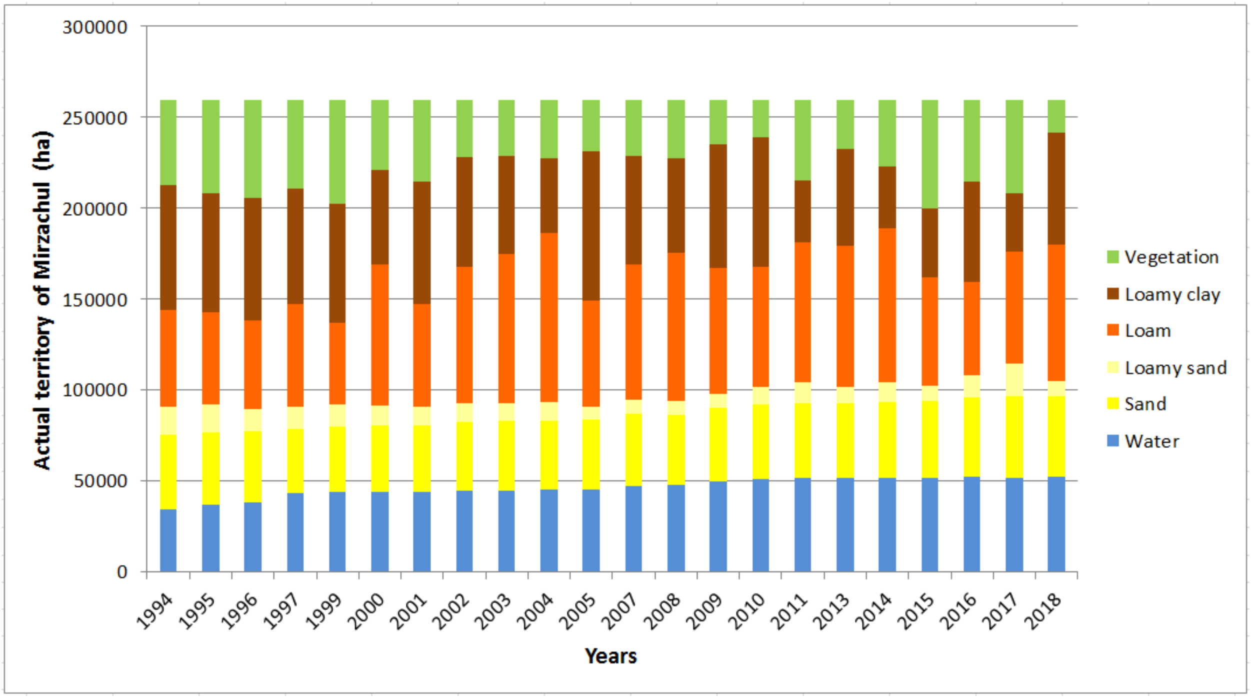

Figure 8. Soil and water dynamics over 24 years in Mirzachul

In general, as can be seen in Figure 8, there were upward trends of the extension of the actual water and sand territories, which started at around 35,000 hectares and 40,000 hectares in 1994, accounting for above 50,000 hectares and just less than 45,000 hectares, respectively, in 2018. Regarding the loamy sand, it almost remained stable during the entire period and a sharp decrease occurred at the end of 2017. However, the other two soil classes, loam and loamy clay, were completely uncertain in the entire period of the analysis, since the canopy cover took place over these soils at that time.

In line with the RQ1, the interest was in the annual average rate of DE in Mirzachul. Referring to Figure 8 above, it is now possible to calculate the loss of area due to the sand presence. The Table 4 indicates the changes to the actual sand area in 1994 with reference to time.

Some decreases, occurring throughout the whole period, were due to the extension of the lake (Tuzkan) located in the north-east of the study area. Interestingly, the extension of water was perceived to occur due to the massive unsustainable irrigation in the region. During the period, sand trespassed in arable land which led to a moderate increase on the actual territory of sandy area. Considering all of the above, compiling all of the enlarged and decreased areas together, the annual average DE rate of **143.15** hectares per year was determined.

Table 4. Change to the sand area in Mirzachul in hectares

Years	Area (ha)
1994-1995	*-1483.6*
1995-1996	*-1088.1*
1996-1997	*-3563.5*
1997-1999	*+401.7*
1999-2000	*+506.8*
2000-2001	*+635.3*
2001-2002	*+1162.3*
2002-2003	*+1135.3*
2003-2004	*-786.3*
2004-2005	*+368.9*
2005-2007	*+765.3*
2007-2008	*-1196.9*
2008-2009	*+2139.8*
2009-2010	*+630.4*
2010-2011	*+324.2*
2011-2013	*+333.8*
2013-2014	*+517.7*
2014-2015	*+529.4*
2015-2016	*+1176.4*
2016-2017	*+614.7*
2017-2018	*+252.5*

One question raised afterwards: how correct is this value so far? So as to find an answer for this question, firstly, an accuracy assessment was performed. This assessment was executed through partitioning the study area into districts and reclassifying the continuous satellite images into five discrete categories which are shown in the legend of GIS-based soil maps (Figures 6 and 7). Then the area of each soil type per district was calculated and transferred into percentages in order to compare with the data on the mechanic content of soils provided in the national reports (SCLRGCSCRU, 2008-2017). The assessment of soil mechanic contents is not carried out annually by the GIUs and the schedule of conducting the assessment is irregular and consists of huge time gaps. All data on the soil mechanic contents per district and the percentages of classified soil types in GIS were converted to the table to estimate the potential accuracy of the GIS maps (Tables 5 and 6, SCLRGCSCRU, 2008-2017).

Table 5. Accuracy assessment of the GIS maps in contrast to the data on soil mechanic contents per district in Jizakh province

Name of the district/ Year	Mirzachul		Arnasay		Zafarabad		Dustlik		Pakhtakor		GIS average acc. (%)
	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	
1997	Loamy sand	77	Loamy sand	73	Loamy sand	62	Loamy sand	74	Loamy sand	63	
1999	Loamy sand	71	Loamy sand	76	Loamy sand	77	Loamy sand	79	Loamy clay	75	
2005	Sandy	64	Loamy	69	Sandy	46	Loamy clay	87	Loamy	52	
2008	Sandy	48	Loamy	55	Loamy	51	Loamy	64	Loamy	80	70
2013	Sandy	53	Loamy clay	71	Sandy	69	Loamy clay	77	Loamy	66	
2017	Sandy	81	Loamy clay	84	Sandy	88	Loamy	86	Loamy	73	
Average		66		71		65		78		68	

Table 6. Accuracy assessment of the GIS maps in contrast to the data on soil mechanic contents per district in Sirdarya province

Name of the district/ Year	Ak-altin		Sardoba		Mirzaabad		Gulistan		Sayhunabad		Sirdarya		GIS average acc. (%)
	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	Soil type	GIS acc. (%)	
1997	Loamy clay	81	Loam	70	Loamy sand	66	Loamy sand	77	Loamy sand	58	Loamy sand	74	
1999	Loamy clay	79	Loamy clay	57	Loamy sand	74	Loamy sand	65	Loamy sand	60	Loamy sand	71	
2005	Loamy clay	88	Loamy clay	86	Loamy clay	80	Loamy clay	81	Loam	66	Loam	80	
2008	Loamy clay	64	Loam	77	Loam	63	Loam	70	Loam	61	Loam	58	69
2013	Loam	59	Loam	76	Loam	72	Loamy clay	53	Loamy clay	69	Loamy clay	75	
2017	Sandy	71	Loam	62	Loamy sand	81	Loam	49	Loamy clay	38	Loamy clay	71	
Average		74		71		73		66		59		72	

The average accuracy of the GIS maps is **70%**

Not all districts were mentioned in the tables above because the GIS-based results on tiny territories of these districts covered by the study area were not enough to generalize for entire districts. Therefore, they were neglected.
Once the overall average accuracy of the GIS maps was determined, the graph containing 30% of error bars was created only for water and sand (Figure 9). This was performed because, firstly, only these classes were perfectly and clearly demonstrated in the GIS maps while others remained uncertain. Secondly, it avoided too many details maintaining an improved visual context of the graph.

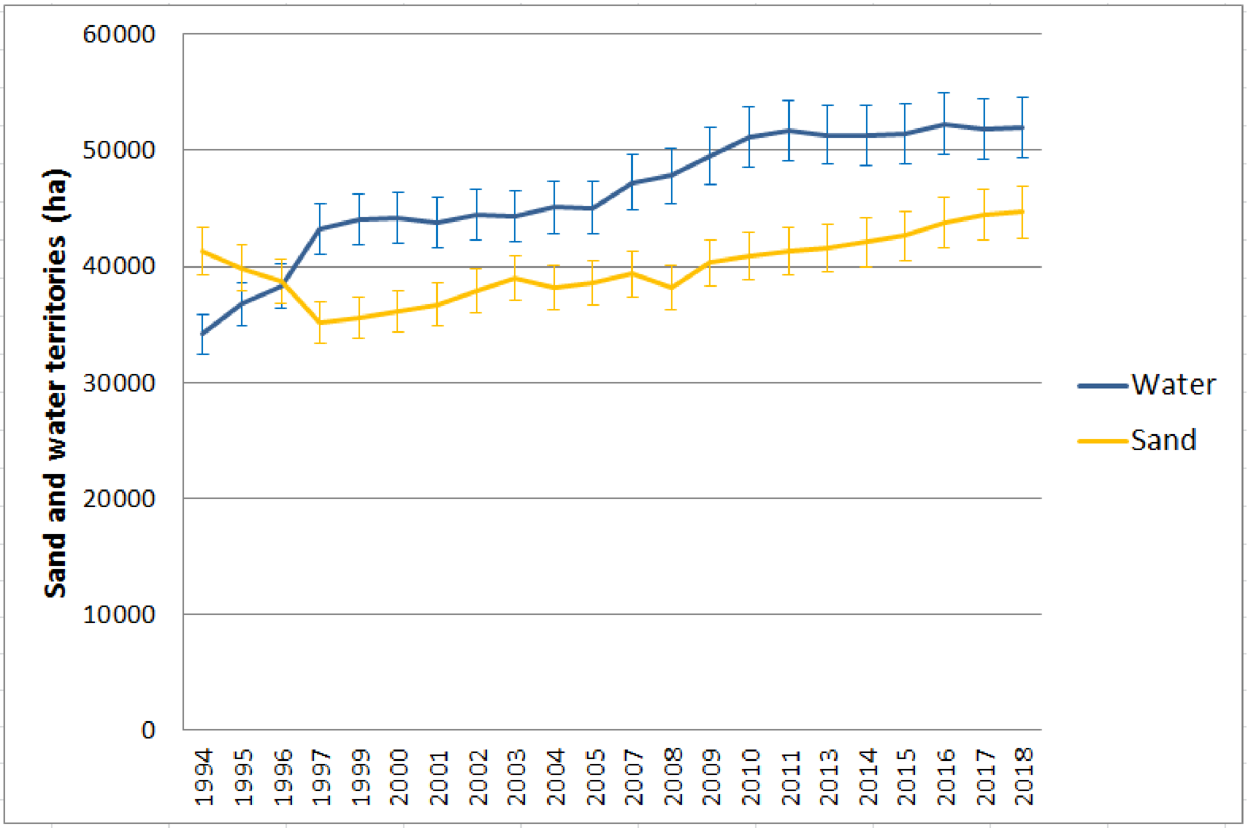

Figure 9. Sand and water dynamics in Mirzachul with 30% of error bars in whole period

Next, in order to validate the findings as the annual average DE rate and the accuracy, a statistical analysis was performed in the next sub-section.

2.4.2. Statistical analysis

First, a simple correlation analysis was carried out for water and all soil classes to see how the changes in each category interconnected each other (Table 7).

Table 7. Correlation between soil types, water and vegetation cover

	Water	Sand	Loamy sand	Loam	Loamy clay	Vegetation
Water	1	0.537	-0.401	0.408	-0.502	-0.349
Sand	0.537	1	0.119	0.066	-0.382	-0.131
Loamy sand	-0.401	0.119	1	-0.470	-0.176	0.632
Loam	0.408	0.066	-0.470	1	-0.496	-0.639
Loamy clay	-0.502	-0.382	-0.176	-0.496	1	-0.226
Vegetation	-0.349	-0.131	0.632	-0.639	-0.226	1

According to the interesting aspect of the correlation table above, sand was positively correlated with water and loam. More specifically, this means when sandy area increases, water and loam will stay proportional as a response to the increase of sandy area. However, loamy clay and loamy sand were negatively correlated with sand causing a decrease on the territory when sandy area extends. This non-proportional correlation between sand, loamy sand and loamy clay led to a reduction of the vegetated area.

After having seen the correlation between classes, the correlation between sand and wind speed was found to determine if wind speed is an important factor in the DE. The data on wind speed were taken out of the Hydro-meteorological Service of Uzbekistan (Uzhydromet, 2019) recorded in two meteo-stations, namely Dustlik and Jizakh, in Jizakh province, and was digitized (Annex 2). As a consequence, the statistical correlation between the sand presence and wind speed was approximately 68.6% (Dustlik meteo-station) and -1.7% (Jizakh meteo-station). The reason behind these different correlations was the location of the meteo-stations (Annex 3). Dustlik meteo-station is located much closer to the desert than Jizakh meteo-station which is situated at the Jizakh city center. The correlation between sand and wind speed (taken from Dustlik meteo-station) is more valid and reliable, so, wind speed is considered as a driver to cause the DE in Mirzachul.

Third of all, the regression statistics and *ANOVA* were applied for sand to check its dynamics and the growth whether it was significant or not. As a result, R^2 was equal to approximately 0.9987 in 22 observations, whereas *F* and *Significance F* were 2,375.4 and 2.27E-22, respectively, according to the results of *ANOVA*.

Last but not least, the regression analysis was executed to see the statistical significance (*p-value*) of sand in relation with other soil types, water and wind speed (Table 8). The *p-value* here is the main character of the table, indicating if the relation between variables is statistically significant ($p > 0.05$ – insignificant; $p < 0.05$ – significant).

Table 8. Output of the regression analysis for sand

Classes	Standard error	t-Stat	p-value	Lower 95%	Upper 95%
Water	*0.0178*	*-54.360*	*1.39E-19*	*-1.007*	*-0.932*
Loamy sand	*0.0223*	*-44.063*	*3.92E-18*	*-1.030*	*-0.935*
Loam	*0.0122*	*-80.447*	*2.69E-22*	*-1.010*	*-0.956*
Loamy clay	*0.0124*	*-78.899*	*3.66E-22*	*-1.012*	*-0.956*
Vegetation	*0.0119*	*-82.688*	*1.73E-22*	*-1.010*	*-0.960*
Wind speed	*0.0102*	*-33.477*	*3.50E-05*	*-1.009*	*-0.877*

Based on the statistical analysis above, either no weak correlation or no statistically insignificant decrease or growth on the sand dynamics in Mirzachul was identified. As such, the results of the GIS maps are now statistically proven and validated. The next step in the following sub-section was to decide on the type of scenario to foretell the future state of the DE in Mirzachul hinged on the interpreted GIS results above.

2.4.3. Application of scenarios to describe the future situation and expected changes on desert extension in Mirzachul from 2019 to 2050

The scenario analysis was chosen since it communicates a message to relevant stakeholders and decision makers and it consists of stories concerning the future state of a particular environmental problem. These stories are clear and comprehensible for almost everyone.
As the exact rate of the annual average DE was statistically consistent and the amount of area under desertification was determined in Mirzachul, forecasting the future context of the actual DE and measures to describe the potential changes was based on quantitative scenarios using the extrapolative method. Quantitative scenarios are effective in numeric data which are more important to note in the context of DE in Mirzachul than qualitative scenarios in this analysis. According to Leemans (2018), there are some pros and cons of quantitative scenarios. Referring to the advantages, quantitative scenarios are based on models, give numerical information and can identify underlying assumptions. According to the drawbacks, models used in the quantitative scenario analysis render a limited view of the world and they are not transparent. In these quantitative scenarios, models were therefore not used to describe the future changes to the DE. The future changes in this circumstance were then explained by using different narratives in this sub-section. Moreover, the scenarios were built at the regional extent and they are exploratory because they describe the future state: they start from the present time and explore trends towards the future.
The scenario analysis in this report was accomplished based on the step-by-step approach according to Leemans (2018) and, Kok and Van Delden (2004).

STEP 1: Objectives and boundary conditions
The objective of this scenario analysis is to build up quantitative scenarios that examine the future state of the DE in Mirzachul and narrate the potential impact of mitigation measures to make a change in the dynamics of the DE.
Boundary conditions:

- Base year: 2019
- Time horizon: 2050
- Time steps: 2030 (short term), 2040 (mid-term) and 2050 (long term)
- Spatial resolution: Region in Uzbekistan

STEP 2: Select themes of scenarios
The ideal number of scenarios was determined as mentioned in the Section 2.3.5 and themes were assigned for each scenario which hinged on the possible uncertain questions about the future state and changes on the DE in Mirzachul.

1. Will agroforestry be well-implemented and endorsed by locals and the central government?
2. Will the central government finance the activities towards the implementation of agroforestry or other mitigation measures?

In this case, the new term “agroforestry” appeared and it is considered as one of mitigation measures. Agroforestry stands for the management and integration of permanent trees, agricultural crops and livestock on the same plot of arable land and can be a fundamental component of agricultural production and a cautionary measure against the DE (Buck et al., 1998). In fact, agroforestry is applicable when the annual rainfall belt is between 250 and 400 mm which delineate the highest density in permanent trees (Saxena, 1984; Buck et al., 1998). As such, the climate of Uzbekistan supports the implementation of agroforestry. The main permanent tree for agroforestry considered in this analysis was a poplar (*Populus L.*) which is very common in the agriculture of Uzbekistan and does not require any additional care once planted. The poplar is also recognized as a slow-growing tree and takes approximately 10 years for maturity. The height of a 15-20 year old poplar varies from 10 to 40 m, the canopy diameter ranges from 2.5 to 4 m and the estimated volume is 8,700 cm^3 (Eckenwalder, 1996). So this tree is a favorable environmental and sustainable resource to protect arable land from sand presence by planting close to the border of the agricultural land with the desert.
After becoming acquainted with agroforestry and the main tree used in this analysis, the next step is to create themes for each scenario (Figure 10).

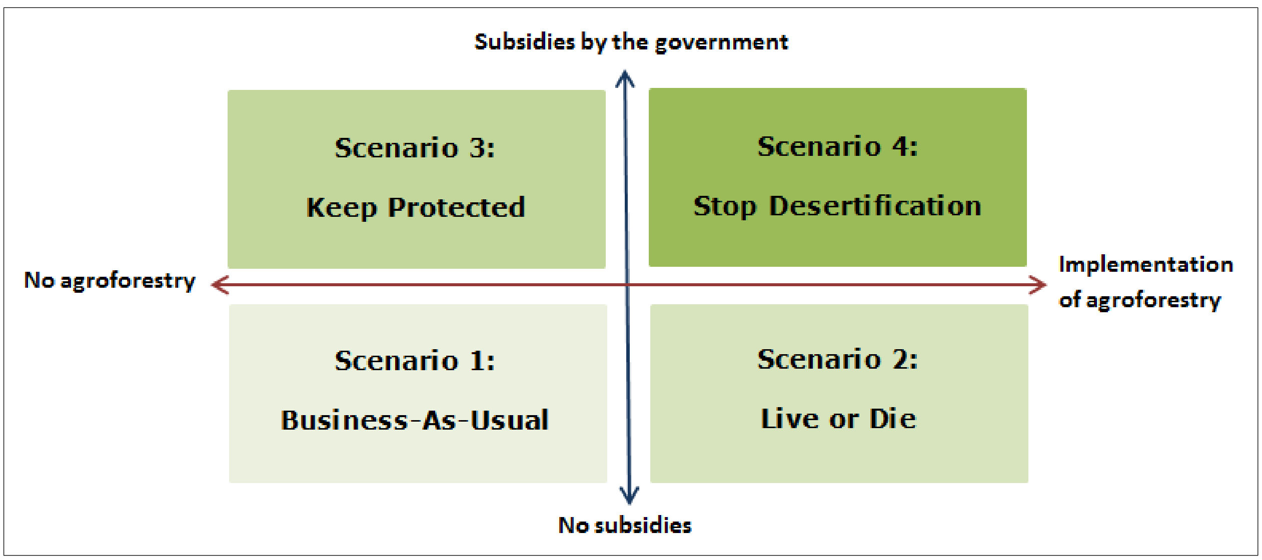

Figure 10. Four different themes created based on the future uncertain questions

Once themes on each scenario have been assigned, the following step was to identify actors and factors.

STEP 3: Selection of actors and factors

The main stakeholders and decision makers in the context of the actual DE in Mirzachul who have a key role in the promotion of agroforestry were identified in this analysis. In the beginning of the list, the central government is situated since it is the main decision maker in Uzbekistan, followed by Uzgeocadaster, MAWR and farmers.
The main factors which are important variables steering the scenario are possibly the implementation rate of agroforestry, the rate of the DE, the rate of unemployment and health issues.

STEP 4: Developing scenarios

In the scenario analysis of the DE, there are four different scenarios that consist of a description of step-wise changes in the future period and driving forces of the scenarios. Meanwhile, it was not feasible and unrealistic to take a certain measure against the DE in 2019 since the year had almost finished its third quarter. Thus, the scenarios were started from 2020.

Scenario 1: *Business-As-Usual (BAU)*

In the first scenario, how current low environmental awareness would look like in the future, and its negative consequences on the environment, were described. This scenario had an 18.5˚ angle, representing the increase of the rate of the problem.

2030 – Short term: The current territory of the desert was expected to reach around 45,000 hectares in Mirzachul in 2020 if no initiatives would be taken into consideration. According to the rate of the DE, 143.15 hectares per year, it means every year roughly 8 farmers would abandon his/her farm, because the average size of farmland is around 20 hectares in Mirzachul. The number of abandonment would rise year by year reaching 80 farmers within 10 years and thus sand would occupy an extra 1,500 hectares in arable land. Mirzachul would lose its reputation as the main cotton producer in Uzbekistan.

2040 – Mid-term: In the last decade, 80 farmers would abandon their farmyards and this number would double within this term. On average, one farm creates around 25-30 jobs in Mirzachul and this abandonment would significantly impact the regional rate of unemployment. At that time, the role of the agricultural sector would step by step be taken out of the GDP because the central government would be centralizing the development of services and industry by giving them priority. Agricultural investments would mainly be spent for developing and genetically modifying crops, especially cotton, which would require less water and area than usual and would give a better yield. Uzgeocadaster and MAWR would mainly focus on the joint programs on land owning in other provinces as a compensation which would require less money than implementing any mitigation or adaptation measures in Mirzachul towards the reduction of the DE rate.

2050 – Long term: In this term, the desert area would continue increasing by invading 5,000 hectares of arable land which would account for just less than 50,000 hectares in total in Mirzachul. Since the desert would be encroaching and approaching the central urban areas, there would be health issues because of the sandy air. Asthma would take first place in the list of health problems among local inhabitants. This would be an additional costly problem for locals who would be unemployed and would leave their yards due to the DE. At the end of this term, as there would not be permanent trees used in agroforestry nor other measures taken by the government, the rate of the DE would jeopardize other pristine environments in neighboring provinces. This would lead to the loss of regional biodiversity which might be very difficult to rehabilitate even with spending of millions of such monetary unit. Lastly, the polluted toxic sandy air, the high unemployment rate, health issues, the loss of agricultural yards and the low quality of life would ensnare the local residents in Mirzachul.

Scenario 2: *Live or Die (LoD)*

In the second scenario, there were no allocated subsidies by the government, but local farmers who were keen on updating would make some initiative to protect their fields and yards. The increasing rate for this scenario was lower than the BAU, accounting for 16˚ of an angle.

2030 – Short term: Firstly, the actuality of this environmental issue would be communicated to the public in Mirzachul. As far as subsidies to support mitigation measures were concerned, they would not be allotted by the central government. Some hubs would be organized by

Uzgeocadaster and MAWR aimed at capacity building of local farmers in this circumstance. In these hubs, all information and practical works concerning agroforestry would be sufficiently explained to the farmers. Of course, not all farmers could afford to upgrade their farms without financial support. These low and middle income farmers, whose farms were located close to the border with the Kizilkum desert, would take long-term loans from Uzgeocadaster and MAWR to purchase trees and cover operational costs. Across the border, taking a 100 meter buffer zone, 30 young trees, considering their mature canopy diameter, would be planted in three rows spacing of three meters per 100-meter distance at the end of this term. This would reduce the rate of the DE up to 30% (Buck et al., 1998)

2040 – Mid-term: This period would mainly be spent to breed the trees by making initial conditions for the trees. For example, irrigation would be used when there would not be enough precipitation to speed up the growing time. Admittedly, some trees would die owing to the rate of the DE. Therefore, the rows of trees would be added year-by-year until the trees would mature. It was predicted for poplars to be fully grown in the last years of this term. In 2040, farmers would pay the half-loans back to the GIUs and mature trees would partially protect their field from the DE, but still trees on their own would not be sufficient.

2050 – Long-term: The rate of DE would slightly be growing despite having an improved implementation rate of agroforestry by locals since not everyone among farmers would succeed in agroforestry and some of them would own a “dying” farm business. Well grown mature trees would preserve arable land from the threats of the sand presence and these trees would moderately reduce the severity of wind speed. At that time, almost 1,500 hectares of arable land would be saved from the DE. Succeeded (“living”) farmers in agroforestry would fully reimburse back the taken loan to the GIUs and “dying” farmers would spend the rest of their life to earn some money to pay back the unsuccessful loan.

Scenario 3: *Keep Protected (KP)*

In the third scenario, the central government prioritized this environmental issue and gave subsidies to implement one of mitigation measures, for instance, building sand dunes in the borders with Kizilkum desert, but not promoting agroforestry in Mirzachul. The angle of the increasing rate of this scenario constituted at around 4˚, far lower than the above-narrated scenarios.

2030 – Short term: At the beginning of 2020, the government would start building sand dunes close to the borders taking 100 meters as a buffer zone. The height of the sand dunes would be 10 to 20 meters depending on the rate of DE in the west and in the north, respectively. Sand dunes have a great potential to stop the DE by cutting wind speed which is the main driver to migrate sandy soil. Sand dunes would take place on the fields belonging to some farmers. These farmers would then be compensated through the transfer of another agricultural land in other provinces. The life span of sand dunes ranges from 9 to 12 years based on how severe the rate of the DE is and sand dunes help drop this rate up to 80%, according to Breckle et al. (2008). In this scenario, the life period for sand dunes was taken as 10 years and the condition of Mirzachul in terms of the DE would be uncertain after 10 years.

2040 – Mid-term: 10 years passed, the capacity of sand dunes would almost be full and wind would move sands from the top of the sand dunes into arable land. Of course, the rate of the DE would not be as indicated in the BAU or LoD, but wind would contribute to increase the chance of the sand presence in fields. This situation would thereafter be perceived by locals as short-term planning by the central government. The central government would not have a stake anymore in this issue since the DE was a complex issue and everyone inhabiting this region should be responsible and should make some efforts against the DE. At the end of this term, the area under desertification in Mirzachul would exceed approximately 45,500 hectares and the sand presence would have increased due to the high speed of wind.

2050 – Long term: The process of the DE would continue to increase and it would lead 75 farmers to abandon their farmlands. It might again cause around 2,000 people to be unemployed in this region and might oppress the agricultural sector, since the provinces located in Mirzachul are the main producers of agricultural products in Uzbekistan. As 17.6% of the total GDP of Uzbekistan consists of agricultural production, with specifically 10% denoted for cotton production, the cotton fields in Mirzachul would then be taken out of the use, slightly decreasing the total GDP. This will make the central government think of alternatives to requite the lost amount of GDP, causing other economic problems. At the end of this term, the total land loss would account for around 1,500 hectares, occupying over 46,000 hectares.

Scenario 4: *Stop Desertification (SD)*

In the last scenario, the central government had an interest in agroforestry and subsidizing other mitigation measures simultaneously. This would lead to the promotion of sustainable agriculture in Mirzachul by taking care of all aspects of the DE issue. Amongst other scenarios, this scenario was ideal to propose mitigation measures against the negative consequences of the DE. As such, interestingly, it had an angle of less than 1˚. Meaning that, there was no effect of the increase of the DE rate, stabilizing the severity of the DE.

2030 – Short term: At the beginning years, the sand dunes would be built simultaneously with the planting of trees behind the dunes. The same procedures would be repeated here as in the short-term section of the third scenario. Sand dunes, 10 to 20 meters high, would be constructed by the government and their life time would be 10 years. Planting poplars as much as possible behind the sand dunes would also be carried out by the government and the responsible GIUs and would reduce the rate of DE up to 95-99% (Buck et al., 1998; Breckle et al., 2008). Poplars would also be sowed at the edges of each farm in Mirzachul close to the desert as a precautionary measure against the probability of the DE. Potential sustainable fertilizers provided by the government would be used to grow the poplars as quickly as possible.

2040 – Mid-term: As the poplars would have grown well in the edges of the farmyards, they would completely protect arable land from the perilous impact of the DE. Once the capacity of the sand dunes would have been full enough at the beginning of this term, poplars would reach their almost peak biomass level with the height of 25-30 meters, which would be able to cut all impacts that wind speed might cause. However, there would cause some loss to arable land because of the occupancy of buffer zones, but it would be negligible. The compensation to the farmers who would lose their land would be fully covered by the government. At the end of the period, farmers would then start to understand the core of agroforestry and would comprehend what sustainable agriculture was. When the outcomes of agroforestry would be easily seen by farmers, afterwards they would initiate to also plant poplars at their own expense in order to make some contribution in line with the government. Older farmers would thereafter leave the habit of planting poplar trees as a heritage to younger generation.

2050 – Long term: Massively planting poplar trees in Mirzachul would lead to the reduction of regional severe climatic conditions in the past 10 years and stop “desertification”. At the beginning of 2050, planting poplar trees would be in the genes and culture of locals. Mirzachul would be famous for its amount of poplar trees that would have been planted over years. Referring to the definition of agroforestry, the integration of livestock husbandry is also important, which will provide continuous grazing under the trees. This might improve the soil

quality and fertility by neutralizing soil reactions, which would enable an increased amount of yield per hectare. This would bring extra earnings for farmers to continuously upgrade their farmyards. In the last years, the government would fully recover the budget that was spent to enact mitigation measures against the DE in Mirzachul by taxation and exports of the agricultural products. The main benefit of the government would be to have "green" farmers who would be aware of sustainable agriculture and the environment, and "green" Mirzachul.
All scenarios above summarized in one graph (Figure 11) to visualize the numbers denote the loss of agricultural land.

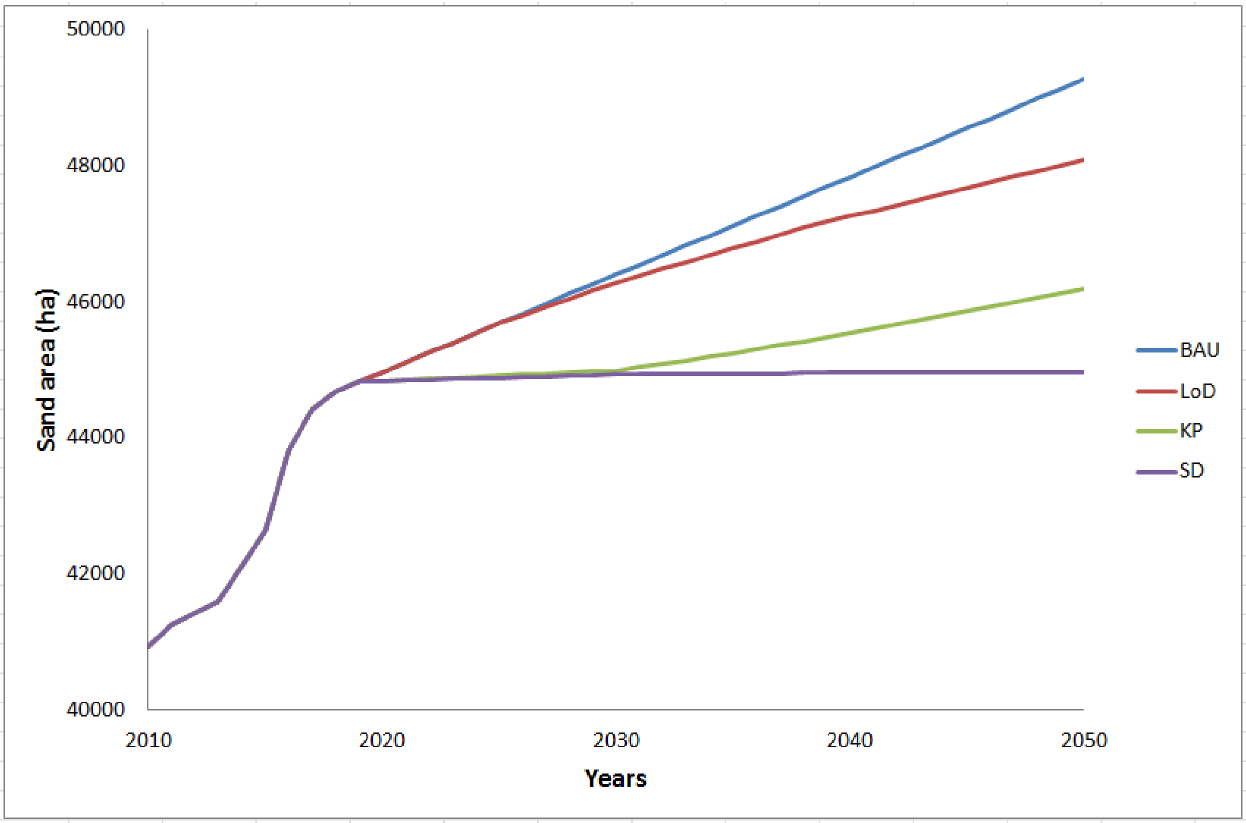

Figure 11. Visual description of the four scenarios

STEP 5: Reduce the number of narratives

This step was undertaken to reduce the number of scenarios to a manageable number and the elimination of implausible scenarios.
The created four narratives above give an efficient comparison between the scenarios. Additionally, it is recommended to have at least two, but no more than four, scenarios in the analysis to maintain the feasibility of the scenario analysis. Therefore, the reduction of the number of scenarios was not required.
To finalize the quantitative scenarios, these results were an input to the decision on the potential storylines on climate change and soil reactions in the future.

2.4.4. Storylines on climate change and soil reactions

In this sub-section, the results of the quantitative scenarios described above served to formulate additional narrative storylines for quantitative scenarios on the regional contribution of Mirzachul to the reduction of negative effects of climate change and stabilization of soil reactions.
Firstly, with respect to climate change and soil reactions, various influences of the four quantitative scenarios on common climate factors were subjectively ascertained and assumed in Table 9.

Table 9. Assumptions on the dynamics of variables of climate change and soil reactions given in additional narrative storylines in the context of Mirzachul

	Business-As-Usual	Live or Die	Keep Protected	Stop Desertification
Air temperature	↗	→	→	↘
Wind speed	→	→	→	↘
Microclimate	↘	↗	↘	↗
Vegetation cover	↘	↗	→	↗
Carbon sequestration	↘	↗	↘	↗
Soil erosion	↗	→	→	↘
Bio-drainage	↘	↗	↘	↗
Soil fertility	↘	→	→	↗
Evaporation	↗	→	↗	↘

In total, nine variables, which were strongly related each other, for climate change and soil reactions were identified aligning with the four quantitative scenarios above. Starting with air temperature, it seemed to be influential climate factor for desertification since higher air temperature leads to drought. Wind speed is crucial in Mirzachul as the main driver causing the actual DE and it has an indirect effect on climate change. As an example in the case of Mirzachul, higher wind speeds create a higher risk of sand presence, which reflects more heat, increasing actual air temperature, more than other types of soil, in arable land. Improved microclimates, which can be regulated by the amount of vegetation cover, are important for the well-being of the local residents. Regulated vegetation cover perfectly sequesters the carbon dioxide in the carbon pool beneath the ground and prevents soil erosion which might considerably affect the soil fertility. Bio-drainage helps to control over soil reactions and ensures the balance between alkalization and acidification. Besides that, the balanced soil reactions improve the soil fertility. To end with, evaporation responds to both climate change and soil reactions at the same time. This is because the high evaporation rate in open areas also results in the risk of drought and soil alkalization/acidification.

After providing justification for the chosen variables above, the narrative storylines were additionally given for each scenario considering how these scenarios would be likely to qualitatively assume dynamics of all of the above-mentioned variables of climate change and soil reactions.

BAU: In this scenario, as long as no more efforts by the government and locals would have been enacted, the trends for all variables would be aggravated. The positive changes were not expected in this scenario. Therefore, the current position and state of all variables would become even more substandard year-by-year. By the end of the time horizon, Mirzachul would be part of the desert in which it would be difficult to find any biotic components according to BAU.

LoD: Even though some initiative from farmers would be observed on the promotion of agroforestry, the environmental condition in Mirzachul would not be positively affected immediately. In the short term, there might be a slight positive change to the only vegetation cover and the carbon sequestration processes because of the loose density of young trees. Admittedly, some young trees would die due to the DE in this term, but the rest of them would survive and would mature in the mid-term, reaching the maximum biomass level in the long term. This would help remarkably improve the microclimate and the vegetation cover and speed up the process of carbon sequestration. Bio-drainage due to mature trees would be improved, which would ensure adequate soil fertility, reducing alkalinity and acidity of the soil. Soils in Mirzachul would be protected slightly by mature trees from wind and the probability of soil erosion would be lower due to wind speed. The air temperature and the evaporation rate would stabilize since the canopy cover would not be able to decrease enough owing to its loose distribution across Mirzachul.

KP: In this scenario, the central government would allocate some budget to build up the sand dunes without paying attention to agroforestry. For that reason, all variables such as microclimate, air temperature, etc., which could be improved by direct effects of the vegetation, would follow their business-as-usual pathway. The sand dunes would only help protect soils from the dangerous consequences of wind, causing soil erosion by stabilizing wind speed.

SD: As it was considered as the best scenario among the other scenarios, it could significantly change all variables of climate change and soil reactions at different levels over the 30-year period. Air temperature in Mirzachul would decrease, lower than the observed average, due to the high amount of biomass, which would also minimize the average rate of evaporation from the top-soil in the shade. With respect to the mature poplars, which were expected to grow up to 40 meters, they would be a biotic barrier to wind speed, reducing the chance of soil erosion. The massive implementation of agroforestry would also cause an improvement of the microclimate inside rural and urban areas, due to the vegetation cover of Mirzachul and the processes of carbon sequestration. Moreover, dense mature trees would establish a proper bio-drainage as a supplement to the main drainage systems, contributing to the improvement of soil fertility. This would also possibly be performed through the livestock husbandry taking place underneath the trees as part of agroforestry.

Summarizing all of the above, the current average rate of the DE accounts for 143.15 hectares per year based on the GIS results and the statistical analysis. Of course, it is a huge number in the agricultural sector of Uzbekistan. Therefore, it is essential to take some effective measures towards this environmental issue by applying different scenarios with various options to tackle the DE to foresee the future state and the future changes of this issue. Referring to the RQs of the scenario analysis, quantitative scenarios were preferred to see the future state of and expected changes on the DE in numeric data by creating four various scenarios hinged on different mitigation measures. Afterwards, additional narrative (qualitative) storylines for these scenarios gave more desirable results as to the future context of climate change and soil reactions in Mirzachul. Among the scenarios, the fourth scenario "Stop Desertification" was deemed affirmative than the others, being predominant in all circumstances. The feasibility of this scenario in the economic cases is still unknown, which requires further research.

2.5. Discussion

The objective of this experiment was to monitor the sand dynamics in Mirzachul, Uzbekistan by using GIS and RS tools to apply proper scenarios against the DE for the first experiment. In this chapter, first of all, before drawing conclusions on whether the interpretations followed valid and reliable methodology or not, the possible systematic and non-systematic limitations influencing the results were reviewed. Next, in the second sub-chapter, the results of this experiment were interpreted as compared to the results of other studies and presenting possible explanations for the results of this experiment.

2.5.1. Validity and reliability of methods

Satellite images

Including the satellite data from Landsat TM 5, Landsat ETM+ 7 and Landsat 8 OLI sensors in the experiments probably contain an error source. Especially the two Landsat sensors although claimed to provide continuity (Irons, 2015), do not have the exact identical 9 and 11 bands on board. This implies that the reflectance values of objects might not be comparable. For instance, Xu and Guo (2014) found that the NDVI calculated with Landsat 8 images is slightly larger than the calculation with Landsat 7. The satellite datasets which were downloaded for the experiments in this report could also consist of such an effect. This would possibly affect the trends of DE. However, eventually it did not because of the precise results ($p > 0.0000035$) of the GIS mapping for this experiment.

Mosaicking and image pre-processing

Mosaicking is performed to combine two or more satellite images and is used when the study area does not fit in one satellite image. In this research, two satellite images covered Mirzachul. After performing this operation, a noise between two satellite images appears due to the divergence of capturing date, leading to change of the Digital Number (DN) values of images, probably affecting the NDVI and SAVI values.
Image pre-processing steps do not remove all outliers completely, but reduce the severity of potential impacts of outliers. For example, most of images taken by Landsat 7 have significant stripe noises because of a broken sensor lens (Wulder et al., 2008). Such noise could not be fully removed by image pre-processing steps. Of course, some DN values could be restored, but not completely. These images could not be replaced by others since it would directly impact the consistency of the results. Finally, the negative consequences of such noise cannot be

observed in the maps, since these maps reproduced statistically significant results (i.e. precise results of the correlation analysis and ANOVA).
I changed the actual pixel size of the satellite images, from 30 x 30 meters, to 150 x 150 meters. This did not seriously impact the outcome of the research, since the DE rate was still precisely quantifiable. I did this to store the data properly.

SAVI

SAVI is also considered to have the ability to classify the soil types based on the reflection of soils (Huete, 1988; Bannari et al., 1995). The most important operation that should be completed before applying SAVI is to remove all pixels with a NDVI above the threshold (NDVI > 0.3) from the study area. Removal of the canopy cover improves the accuracy of SAVI values since they are sensitive to the reflection from vegetation. The SAVI range is also proposed by distinguished scientists only for the arid zone to determine the soil relations. Mirzachul is located mainly in the semi-arid zone, sharing borders with the arid zone from the west. The SAVI range for the arid zone was used to assess the DE based on the soil relations in Mirzachul and gave satisfactory outcomes, compared to the base map created in 1994. As such, the proposed SAVI range can be used for the assessment of the DE in the semi-arid regions.

Primary data

The accuracy of the DE rate was difficult to determine when compared to the ground truth data, since the soil sampling method of the GIUs to assess soil textures was incomplete. The GIUs mainly take around 500 soil samples per district at different points and interpolate the results in order to determine the most common soil type per district (SCLRGCSCRU, 2008). Therefore, the exact results of the GIUs on the soil texture were unknown. These results were significantly correlated with the results of the DE. Another reason at to the difficult determination of the DE rate could be a lack of the sand maps which would allow the visualization of the dynamics of sandy soil over time in the study area. No information about the DE rate was given neither in the scientific papers nor national reports of the GIUs. Hence, the experiment of the DE was based on only the atlas map of Uzbekistan, which was created by the scientists from the former Soviet Union countries. Moreover, this experiment provided only the exact value of the rate of the DE in Mirzachul.

Statistical analysis

Several statistical analyses, such as simple correlation, *ANOVA* and regression analysis were carried out in this research. In the first experiment, the point of interest was to correlate sandy soil with wind speed because wind speed, was taken as the main driver of the DE in Mirzachul. Consequently, the correlation was 68.6% and this correlation was statistically significant, as determined by *p-test* in the regression analysis ($p = 0.0000035 < 0.05$).
The only and previous study on the DE in Uzbekistan was not statistically tested (Liu et al., 2005). Therefore, now we have a statistically tested exact DE rate.

Scenario analysis

Scenario analysis was performed in this research to visualize the future condition of the DE and the expected changes towards reducing the rate of the DE. In this part, quantitative scenarios were used which require models to generate exact numeric information. However, models use many assumptions and are not always realistic (Müller et al., 2011). For that reason, models were not included in the scenario analysis. Narratives, instead of models, for different scenarios based on the mitigation measures against the DE were written according to the real data, which were used to quantify the dynamics of the DE rate, derived from the literature.

Recommendations for further research

The recommendations formulated here go beyond the scope of this research since the aim of the first experiment was fully fulfilled.
As the first recommendation for further research, accurate and reliable models should be created and validated to gain enhanced quantitative results in the scenario analysis on the DE at the regional area. Secondly, it is highly recommended to perform a brief cost and benefit analysis of the implementation of agroforestry. This might improve the feasibility of this mitigation measure in Mirzachul.

2.5.2. Interpretation of results

The aim of this experiment was to monitor the sand dynamics in Uzbekistan by using GIS and RS tools and then apply proper scenarios against the DE. After the appearance of the Aralkum Desert, scientists specialized in desertification have begun to learn the consequences and the future context of this young desert (Breckle and Wucherer, 2012; Opp et al., 2019; Nachtnebel et al., 2006). However, scientists tended not to be interested in the state or negative consequences of other deserts located in Uzbekistan. As mentioned in the introduction chapter, the actual area of all deserts in Uzbekistan was expected to increase. This study confirmed this expectation by applying various analyses and showing multiple significant correlations between the main driver and sandy soil. Moreover, since the study-area is known to be vulnerable to desertification, it is surprising that not more precautionary measures have been taken into consideration by Uzgeocadaster and other GIUs. Groups of expeditors and scientists were distributed across Uzbekistan by Uzgeocadaster to learn the current circumstances of all deserts, after having received too many complaints from local farmers (SCLRGCSCRU, 2016). However, these groups of scientists did not quantify the severity of the DE in the republic. This research contributed to obtaining an exact annual value of the DE rate, to develop a method to monitor the sand dynamics, to foreseeing its future state and to proposing potential mitigation measures against the DE in Uzbekistan by applying scenarios in a particular region of the country. Despite having an exact value for the average annual DE rate, it is 70% accurate. To enhance this accuracy, an in-field exploration is required. Searching more recent local studies conducted by local scientists on the DE, to compare the results of this research, was challenging and very limited.
Another point is that, this case study has been done at the regional area by few (inter-)national scientists. Liu et al. (2005) conducted research in Central Asia on the GIS and RS mapping of the DE using National Oceanic and Atmospheric Administration (NOAA) – Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS) data over the time-period, from 1995 to 2001. They chose five desertification indices to create the maps revealing the distribution of the DE. Interestingly, they found that there was no desertification footprint in the study area selected in this report since they converted the actual

pixel size to 5km x 5km to cover whole Central Asia, in which Mirzachul is of negligible size and lost all detail because of the coarse resolution. They did not support their results through statistical analysis, only restricting the analysis by quantifying the rate of the DE in percentages. As their results were not supported by statistical analysis, the statistically significant results of my research contradict the DE rate found in Liu et al's research.

2.6. Conclusion

In the last decade, municipalities received too many complaints from farmers because of the DE, and almost 23% of total complaints were given by farmers who live in Mirzachul. Local scientists and expeditors did not render an exact value of the DE rate and just concluded as it was due to the DE. Since Mirzachul is considered as a main region which plays a key role in the agricultural sector of Uzbekistan, the research was conducted in Mirzachul. The main objective of the first part of the research was to monitor sand dynamics in Uzbekistan by using GIS and RS tools and applying proper scenarios against the DE. This objective was fully achieved based on the following findings which contributed to improving the chance of solving the current problem.

First of all, the DE rate, 143.15 hectares per year, was determined by using GIS and RS techniques. Interestingly, DE was expected from the east, but in the recent years, the severity of DE from the north has increased. Additionally, according to the GIS results, the actual territory of water has increased over the period, which was also not expected. I can conclude that the first finding is sufficient and provides a specific quantity for use to formulate potential mitigation and adaptation measures.

Second of all, this rate was then validated by the statistical analysis, which shows a high correlation between the variables. Besides that, the statistical value of this correlation was found to be very significant. It is assumed by these results that they enable to formulate a proper methodology to monitor the sand dynamics in this study area. The consistent results of this methodology serve as a strong basis to build up potential scenarios to describe the future state and the expected changes on the DE rate.

Lastly, four different quantitative scenarios are created from 2019 to 2050 against the DE, considering all available options in this context. The option called agroforestry, as one of mitigation measures against the DE, seems ideally suitable and feasible in the environment of Mirzachul. This is because the required amount of precipitation can be found in this region to breed and speed up the growing period of trees, specifically poplars. Summarizing all findings in this part, the implementation of agroforestry with poplars can stop the DE by the end of the mid-term, based on the estimation provided in this experiment. The policy gap between the best and the worst scenarios would cost additional loss of arable land. It is assumed that four scenarios are sufficient to take an action against the DE. Otherwise, the possible foreseen negative damages of the DE would be significant. Moreover, the qualitative storylines are created for these scenarios to visualize their impact on climate change and soil reactions. Of course, the scenario standing for agroforestry is dominant among others due to its direct and indirect positive effect on climate change and soil reactions.

All of the findings can facilitate the current condition in Mirzachul if they are used properly by the responsible actors who have a high stake in the outcome.

3. EXPERIMENT 2. THE SOIL SALINITY ASSESSMENT

3.1. Introduction

The State Scientific Research Institute of Soil Science and Agro Chemistry (SSRISSAC, 2014) has published the latest data available, which states that more than 46.7% of Uzbekistan's arable land is salt-affected at different levels. The breakdown of these levels across the republic was then defined by the State Committee for Land Resources, Geodesy, Cartography and State Cadasters of the Republic of Uzbekistan (SCLRGCSCRU or Uzgeocadaster) with 2.5% severe salinity (EC_e = 8-16 dS/m), 13.3% moderate salinity (EC_e = 4-8 dS/m) and 30.9% low salinity (EC_e = 2-4 dS/m) (SCLRGCSCRU, 2015). Sirdarya province in the republic is nowadays considered as one of the most salt-affected areas due to the massive usage of salty irrigation water. This is due to the main crop type in the area, cotton, which has a high water demand (SCLRGCSCRU, 2015). Statistics have shown that the percentage of salt-affected land increased from 87% to 95% as a result of human-induced factors in Sirdarya province between 2003 and 2008 (Toderich et al., 2008). Amongst this area in Sirdarya province, more than 80% of arable land is severely affected by salinization. Arable land under severe salinity was still used until 2007 despite having low productivity and it has gradually been taken out of use for agricultural purposes. The actual area of irrigated land has been reduced from 805,000 ha in 1991 to 531,000 ha in 2006 and is still being reduced in Mirzachul steppe which partially covers Sirdarya province (Toderich et al., 2008; Ivushkin, 2014). The root causes of the salt accumulation in the soil are out-of-date drainage systems, a lack of innovative agricultural practices, the absence of integrated water resources management and a lack of activities to raise awareness of farmers on sustainable agriculture.

The work load for this soil salinization issue was heavy for one governmental actor (Uzgeocadaster), and it is an issue which is highly dependent on subsidies to manage. Therefore, according to the Decree of the First President on 29 October, 2007, another GI was established, namely "the Fund for Land Reclamation in Arable Lands" as a subsidiary of the Ministry for Agriculture and Water Resources (MAWR) to facilitate soil salinity issues (MFRU, 2019). Together they track the main technical land reclamation indicators of arable land such as the level of soil salinity, depth and mineralization of groundwater, drainage discharge and mineralization of irrigation water (ADB, 2008). In addition to this, scientists from Uzsoilscience are nowadays working on in-situ researches on the enrichment of soil organic compartments, monitoring and improvement of soil fertility, soil-water quality and economic evaluation of agricultural and rain-fed irrigation (Eltazarov, 2016).

3.2. Problem definition and research questions

The identified GIUs, which take responsibility for soil salinity issues in Uzbekistan, have been publishing field data on soil salinity in their national reports for every four and five years. Before leaching salts, soil samples are usually taken in late October or at the beginning of November (SCLRGCSCRU, 2008). Over 200 soil samples are taken per district and sampling is carried out by soil specialists with an automatic sampler and a hand drill (SCLRGCSCRU, 2008). Despite the method of sampling, each of 30 injections is determined with a GPS receiver to locate one sampling point in the sampling area (area and border of selection). The drilling depth of the soil samples is equal to the depth of the root zone (0-90 cm) and before withdrawing the soil, soil Electro-Conductivity (EC) is determined. Once the soil samples have been taken out, the soil salt-content analysis is performed in soil laboratories to determine total dissolved solids, water-soluble salt concentration and soil organic contents (Tuproq bonitirovkasi, 2019). Results of this analysis are interpreted with Soil Quality Index (SQI) values, ranging from 0 to 100 points and these points serve to assess only the current quality of arable land. SQI values, ranging from 30 (severe salinity) to 70 (no salinity), are commonly used in the agricultural field of Uzbekistan to describe the soil quality due to the salinity level and soil organic content. When SQI values are identified at less than 30, these lands are taken out of the agricultural use. Whereas, SQI values over 70 represent the soil quality beneath the permanent trees in the forests (SCLRGCSCRU, 2008).

According to the description of processes of the in-situ governmental soil salinity assessment above, the GIUs are still using this in-situ assessment as a primary method. It is considered inefficient prioritizing this in-situ method of the data collection since there is a tendency for time and resources to be wasted while using the in-situ method. Also, there would be unexpected changes within the five-year interval which are likely to be dismissed until the next in-situ assessment. Additionally, any control over the soil salinization processes would be lost over the five-year gap owing to the limited usage of GIS techniques (Allbed and Kumar, 2013; Martius et al., 2011; Platonov et al., 2015).

Many studies have been carried to assess soil salinity using GIS techniques in Uzbekistan (Ivushkin, 2014; Ivushkin et al., 2017; Eltazarov, 2016; Akramova, 2008; Akramova Akramkhanov et al., 2011; Platonov et al., 2015). They found a relatively high correlation between in-situ data and GIS-based data, and determined the potential accuracy of GIS maps at the Water Consumers Association extent (at low spatial scale) by analyzing one-year data. However, the regional GIS-based soil salinity maps, created for the same years that the in-situ governmental soil salinity assessments were conducted, are still missing. Comparisons of both approaches are thus impossible.

The GIS results are perceived to give non-validated information on soil salinity by Uzgeocadaster when the validity of the in-situ assessment is acceptable. Insufficient information is available from the national reports as to the reason why the primary choice of the GIUs is the in-situ method to assess soil salinity. This insufficient information and the use of misbalanced GIS-based and in-situ approaches resulted in weak methodology development for soil salinity assessment.

To contribute to solutions to the above-mentioned soil salinization problems and to the methodology development, the second experiment aims to compare both methods of soil salinity assessment, in-situ and GIS-based, by applying MCDA, serving to learn the current perception of the GIUs. This aim will be reached through finding possible reflections for the following RQs:

RQ5. How valid is the GIS-based method to assess soil salinization than the in-situ method in Uzbekistan?

RQ6. What kind of criteria which appertain to both methods are important and should be considered in the multi-criteria decision analysis?

RQ7. If advantages of the GIS-based method outweigh those of the in-situ, why do the governmental institutions still keep following the in-situ method?

RQ5 will help to facilitate heavy discussions on the validity of GIS results for the soil salinity assessment at the regional extent. Afterwards, provided it will be as accurate as expected, a MCDA will be performed to weight and compare the two soil salinity assessment methods, which will describe the possible and compatible choices for the GIUs. Lastly, an expert interview will be employed with specialists working at Uzgeocadaster to learn why the GIUs are using the in-situ method as a primary approach in response to RQ7.

3.3. Methodology

3.3.1. Study area

Mirzachul, which was previously introduced in the first experiment, was also taken as the study area in this experiment. As Mirzachul mainly and partially covers Sirdarya and Jizakh provinces, which are leading provinces on the agricultural sector, this area is more vulnerable to soil salinization (International Commission on Irrigation and Drainage, 1976, Platonov et al., 2015). Mirzachul includes 18 districts (Figure 12), which have the lowest SQI values across the country (SCLRGCSCRU, 2017).

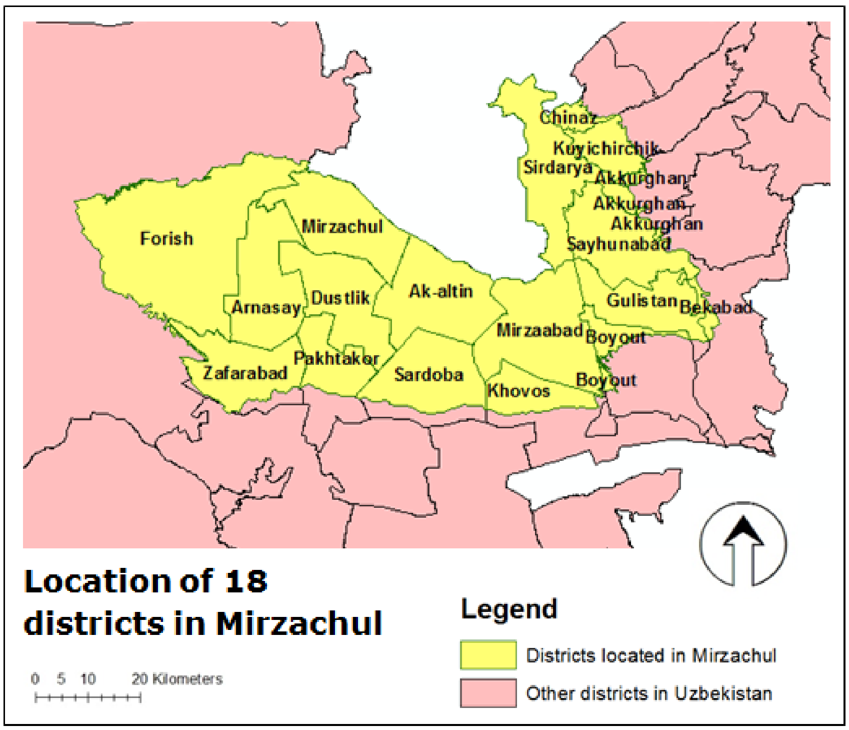

Figure 12. Location and name of the districts in Mirzachul

Regarding the annual report of Uzgeocadaster (SCLRGCSCRU, 2014), approximately 74% of arable land in Mirzachul is at different levels of soil salinization. Specifically, soils are commonly affected by the moderate level of soil salinity accounting for 59.1% of the total arable land, whilst the weak and the severe salinity levels occupied 10.65% and 30.25% of salt-affected arable land, respectively.

3.3.2. Role of geo-information systems and remote sensing in soil salinity assessment

RS data created an important revolution in research within the field of soil, land use and management, water and geomorphology. RS techniques allow researchers to easily investigate and evaluate these phenomena and lead to more awareness of sustainable development. RS data are capable and multifunctional for monitoring soil dynamic processes, including soil salinization processes. Therefore, working with RS techniques saves labor, time, energy and physical effort in contrast to the in-situ assessment of soil salinity level (Robbins and Wiegand, 1990). The ability to delineate and map soil salinity has considerably improved after the successful integration of RS, in terms of satellite imagery, with GIS (Al-Mulla, 2010). RS demonstrated its reliable facets and functions in detecting the salinity trend using satellite images, aligning with other in-situ data and topographical maps. In fact, the soil salinity map created with the use of RS tools such as NDVI showed a significant correlation, 67%, with in-situ electrical conductivity values (Ochieng et al., 2013). The role of GIS and RS is important for the soil salinity assessment, however, an adequate background on cropping patterns and climate conditions at recording time of the satellite image and, an understanding of agricultural practices, are additionally required to conduct the assessment reliably and correctly (Singh and Somvanshi, 2012).

Nowadays, well-developed countries (e.g. the USA and Australia) and some of the developing countries (e.g. Algeria) have already started to assess soil salinization using GIS and RS tools (Metternicht and Zinck, 2003; Dehni and Lounis, 2012; Ivushkin et al., 2018). Scientists in these countries claim that using GIS and RS tools is more time efficient and has potential to cover a wider area at a lower cost. Considering all of the above, local scientists and researchers have also begun to follow the GIS methodology to approach soil-salt-related issues in Uzbekistan, using GIS and RS techniques.

3.3.3. Introducing the multi-criteria decision analysis for the methods of the soil salinity assessment

In this case, Multi-Criteria Decision Analysis (MCDA) allows for the identification of the most preferred option among both GIS-based and in-situ based soil salinity assessment methods. MCDA, which is widely applied in the ESA, provides the preferred option by comparing and ranking qualitative and quantitative criteria, taking into account and evaluating their respective consequences (Macoun and Prabhu, 1999; Lahdelma et al., 2000; Huang et al., 2011). MCDA mainly emphasizes the judgment of the decision-making, estimating the relative weights of criteria, as well as the judgment of the contribution of each option to each performance criterion (Dodgson et al., 2009). The criteria can have different measurement units, in that there is no demand to use only one measurement unit, like monetary values (Grima et al., 2017).

The key point of the MCDA method is to create a decision model which is served as a framework depicting a formal specification of how different criteria are combined together to find a potential and wise way to make a decision. The decision model is then used to identify proper alternatives towards solutions for environmental problems and to facilitate decision-making processes as to define the planning process clearly and to circumvent various distortions. Distortions are the outcomes of inappropriate choices to manage all information related to criteria, uncertainties, and importance of the criteria (Lahdelma et al., 2000; Nguyen et al., 2015).

For this reason, it is now difficult to make a compatible choice about the existing assessment methods of soil salinity and to recommend the appropriate choice to the GIUs without using MCDA functionalities.

3.3.4. Data collection

Using the primary data of this experiment, the SQI values per district (Table 10) belonging to this study area were taken out of the national reports of Uzgeocadaster (SCLRGCSCRU, 2008-2015) to compare with the GIS-based results. Interestingly, the in-situ assessment of soil salinity was also conducted before 1994. The base year for starting analysis was set at 1994 because it was the first in-situ assessment performed after the independence of the country.

Table 10. SQI values per district in Mirzachul (SCLRGCSCRU, 2008-2015)

Districts	Years of the SQI assessment				
	1994	1999	2005	2010	2014
			Jizakh province		
Forish	39.7	42.0	41.1	42.0	42.2
Arnasay	42.0	44.0	43.5	45.2	45.0
Zafarabad	48.0	50.0	50.4	52.0	53.1
Mirzachul	42.8	45.0	45.5	46.5	47.0
Dustlik	49.3	51.0	52.0	53.6	54.2
Pakhtakor	50.1	52.7	52.0	55.3	57.6
			Sirdarya province		
Sardoba	44.0	45.0	48.0	49.0	49.0
Ak-altin	51.0	53.0	55.5	54.0	56.0
Mirzaabad	42.0	43.0	46.0	46.0	47.0
Khovos	42.0	43.0	46.0	46.0	47.0
Boyout	48.0	51.0	53.5	53.0	55.0
Gulistan	51.0	50.0	53.0	51.0	54.0
Sayhunabad	47.0	51.0	54.0	57.0	56.0
Sirdarya	51.0	52.0	59.0	58.0	61.0
			Tashkent province		
Chinaz	56.6	57.0	57.2	59.0	60.0
Kuyichirchik	57.2	58.0	59.0	61.1	63.0
Akkurghan	54.3	57.0	59.0	60.6	61.0
Bekabad	50.9	54.0	52.4	54.0	53.0

Another table categorizing these values into the actual soil salinity levels was derived (Table 11) to digitize and convert to the SQI-based ordinal GIS maps.

Table 11. Classification of the SQI values with reference to soil salinity levels

SQI	ECe (dS/m)	Soil salinity levels
61-70	<2	No salinity
51-60	2-4	Low
41-50	4-8	Moderate
30-40	>8	Severe

Once the SQI maps were created, Landsat images taken on the mid-days of August were downloaded from the open sources (www.earthexplorer.usgs.gov; www.glovis.usgs.gov) for each year in which the in-situ soil salinity assessments were carried out by the GIUs. For detailed information on satellite images, see Annex 1.

3.3.5. Data analysis

During the analysis in the second experiment, districts (e.g. Forish and Khovos) with an area not covered fully or at least majorly by Mirzachul, were discarded so as to avoid the dissemination of the incomplete results for each entire district.

Then, the same pre-processing steps and operations on Landsat images described at the beginning of the Section 2.3.5 were performed before starting the experiment. This experiment was also undertaken by using ArcGIS and Erdas Imagine software.

Some scientists claimed that the vegetation cover is a good proxy for soil salinity assessment (Allbed and Kumar, 2013; Mashimbye, 2013; Ochieng et al., 2013). Therefore, they used the NDVI tool which is sensitive to target the green vegetation cover to map the soil salinity. Using NDVI to assess soil salinity requires awareness of the crop type in the study area. Otherwise, the results on soil salinity would be likely to be interpreted incorrectly because of the difference between spectral signatures of crops (Allbed and Kumar, 2013; Elhag and Bahrawi, 2017). Considering this, the NDVI tool (Section 2.3.5) was also used here to analyze the soil salinization processes in Mirzachul. The most common crop type, cotton, was identified (SCLRGCSCRU, 2015) as an annex to decide on the date of Landsat images to be downloaded for analysis according to the cotton schedule (Table 12).

Table 12. Crop schedule indicating different stages for cotton in Uzbekistan (Khamidov et al., 2009)

	Initial stage	Vegetative stage	Middle season	Late season (defoliation)	Harvesting
Date	01/May-01/Jun	01/Jun-01/Aug	01/Aug-01/Sep	01/Sep-15/Sep	15/Sep-01/Nov

In the middle of August, the canopy cover for cotton reaches its peak (Khamidov et al., 2009; Conrad et al., 2010). For that reason, Landsat images taken at mid-August were downloaded to ensure the accuracy of NDVI soil salinity maps.

As cotton is the main crop type in Mirzachul, the proposed NDVI ranges for the maximum growing season of cotton and wheat (Table 13), in response to soil salinity levels, were given by local and other scientists for Uzbekistan. The NDVI maps were then classified based on these proposed ranges (Platonov et al., 2015; Wu et al., 2008; Yengoh et al., 2014).

Table 13. Proposed NDVI ranges for soil salinity levels in Uzbekistan

NDVI range	Soil salinity levels
<0.30	Bare soil
0.31 – 0.40	Severe
0.41 – 0.55	Moderate
0.55 – 0.70	Low
0.71 – 1.00	No salinity

Following, the bare soil classified below 0.3 NDVI according to Ivushkin et al. (2017) was disposed of during the analysis and the average NDVI values were taken, considering the values higher than 0.3 NDVI per district by operating “Zonal statistics” in ArcGIS software.

Afterwards, basic statistics including correlation analysis, linear regression analysis and *ANOVA* were implemented by using R and MS Excel software to validate the similarity and relationships of the average NDVI values to the SQI values per district. This helped to determine how valid the NDVI maps were at the regional area (RQ5). Furthermore, climate data, taken out of three meteo-stations, Dustlik, Jizakh and Sirdarya, on air temperature and precipitation (Annex 2) were also used in the correlation analysis to gain greater insight into the role of these climate factors in soil salinization.
Once the NDVI-based soil salinity maps had been validated through statistical analysis, the next step was to identify the most important criteria, as aspects of the assessment of soil salinity appertain to both the GIS-based and in-situ methods, so as to apply MCDA. Important criteria were pinpointed by the literature review. The literature-based identified criteria were next divided into indicators in order to facilitate the process of scoring. Weighting was then executed using Rank Order Centroid method (Edwards and Barron, 1994; Goyette, 2013) (Equation 3).

$$W_i = \left(\frac{1}{M}\right) \sum_{n=1}^{M} \frac{1}{n} \quad \text{(Equation 3)}$$

Where:
M is the number of criteria; W_i = the weight for i^{th} criterion

The overall preference scores (S_i) were calculated by using Equation 4 (Mendoza et al., 2000) before executing the sensitivity analysis (RQ6).

$$S_i = w_1 \bullet s_{i1} + w_2 \bullet s_{i2} + \cdots + w_n \bullet s_{in} = \sum_{a=1}^{n} w_a \bullet s_{ia} \quad \text{(Equation 4)}$$

Where:
W_a = weight for the criterion *a;* S_{ia} = score for alternative *i* on criterion *a; and* n = amount of criteria taken for the analysis

The overall results on the preference scores in MCDA were perceived to determine the potential option among the two soil salinity assessment methods. The MCDA results served to compare with the specialists' perception who work at Uzgeocadaster on why the GIUs have still been using the in-situ method as the primary choice through an expert interview (item list was given in Annex 5) (RQ7).

3.4. Results

In this sub-chapter, two soil salinity assessment methods, namely GIS-based and in-situ performed by the GIUs, are briefly discussed. With respect to the RQs, initially, the GIS-based results were visually compared to the actual in-situ assessment results and statistically validated. Next, MCDA was applied to determine the preferable option among the two methods to assess soil salinity, after the GIS-based results were successfully validated. Finally, the main reasons as to the current GIUs' choice on the soil salinity assessment were discovered through the expert interview with specialists from the GIUs.

3.4.1. Results of GIS-based soil salinity assessment method

As Tashkent province was dismissed in this analysis because of the unsatisfactory inclusion of districts, the in-situ soil salinity assessment was carried out by the responsible GIUs in 1994, 1999, 2005, 2010 and 2014 in Sirdarya and Jizakh provinces, partially extended over by Mirzachul. In general, the results of the assessment were indicated by the SQI values per district located in these provinces. These values were then transferred to ArcGIS software in order to create SQI-based maps to visualize the breakdown of SQI values on the entire study area.

Regarding the years in which in-situ research on soil salinity was carried out, Landsat images captured in the middle of August were downloaded to fulfill the comparison. After several pre-processing steps were undertaken and the actual cell size was changed, the NDVI tool was applied to map soil salinity hinged on the canopy cover which is exceptional indicator evincing soil salinity. All maps were compiled together and are presented in Figures 13 and 14.

Referring to the Figures 13 and 14, it could be seen that there was a substantial improvement on the soil quality over the period and quite a few areas are classified as bare soil. Patterns in the NDVI maps were almost identical to the SQI maps, and when the salinity trends increase or decrease in the SQI maps, the same could also be observed in the NDVI maps. Of course, some inaccuracies could be found in the NDVI maps because there was no cotton field in the desert located to the north-west of the study area. This means that the applied proposed NDVI range for the maximum growing season of cotton was also sensitive to other vegetation. Consequently, the outcomes of the NDVI mapping were considered as valid and accurate as the SQI maps. At the time, very strong similarities were spotted by comparing the maps visually.

The salt-affected areas in Mirzachul were thereafter quantified per district located in two provinces (Annex 6) to observe the spread and changes to the soil salinity levels over time according to the NDVI maps. These maps rendered the precise amount of saline areas, determined by calculating the number of pixels in each salinity class. These areas were then plotted in the graphs below (Figures 15 and 16).

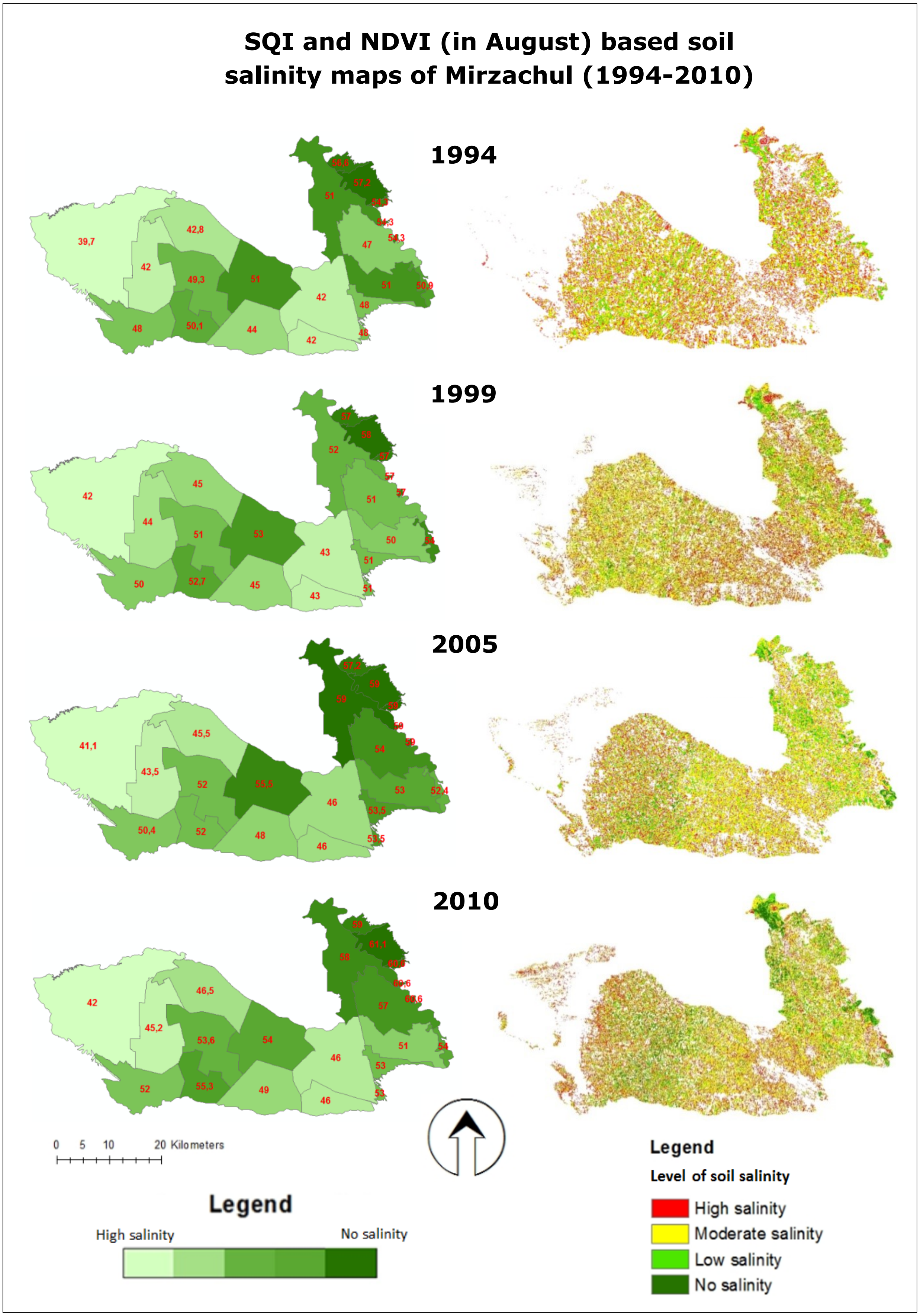

Figure 13. SQI and NDVI-based soil salinity maps

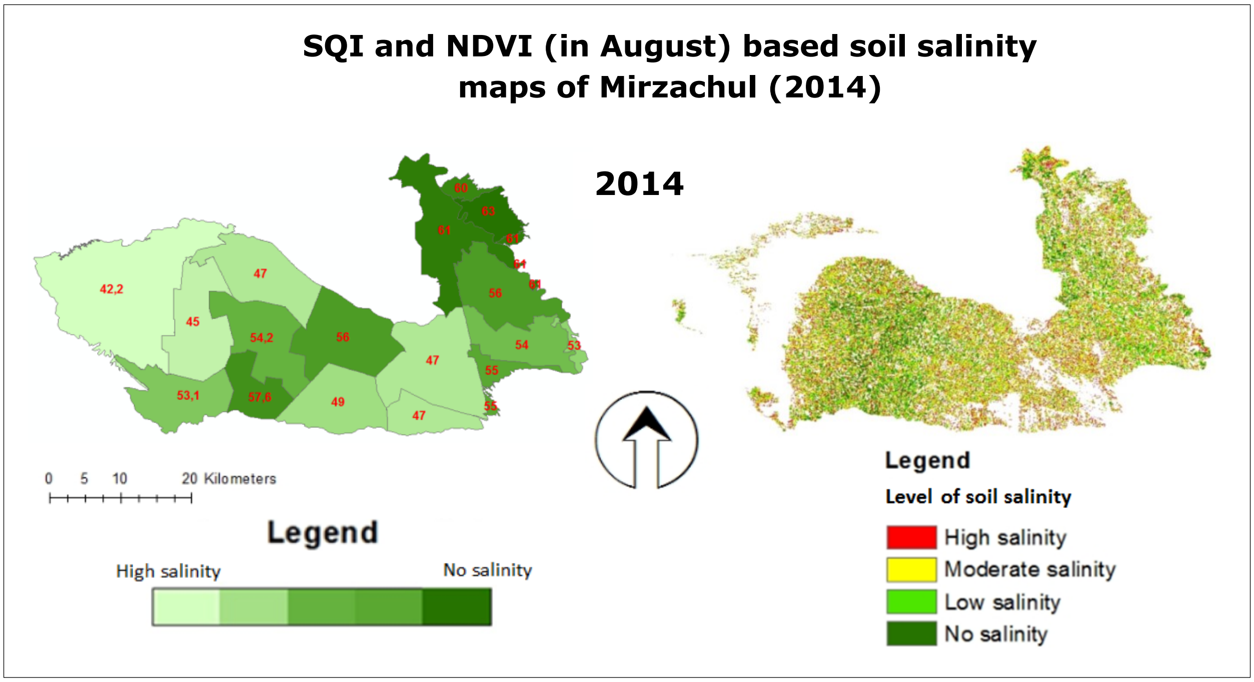

Figure 14. Continuation of the SQI and NDVI-based soil salinity maps

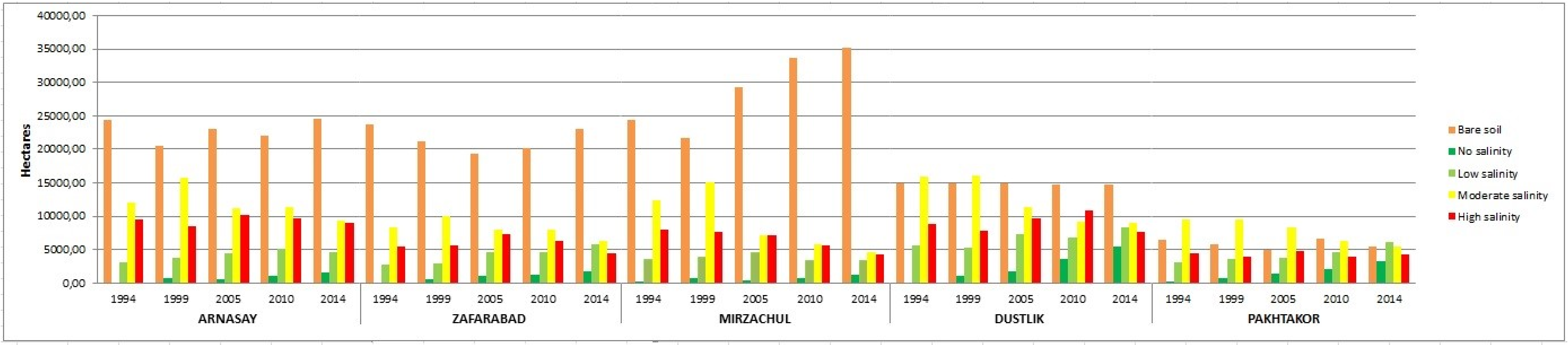

Figure 15. Distribution and dynamics of soil salinity levels and bare soil over the period in Jizakh province

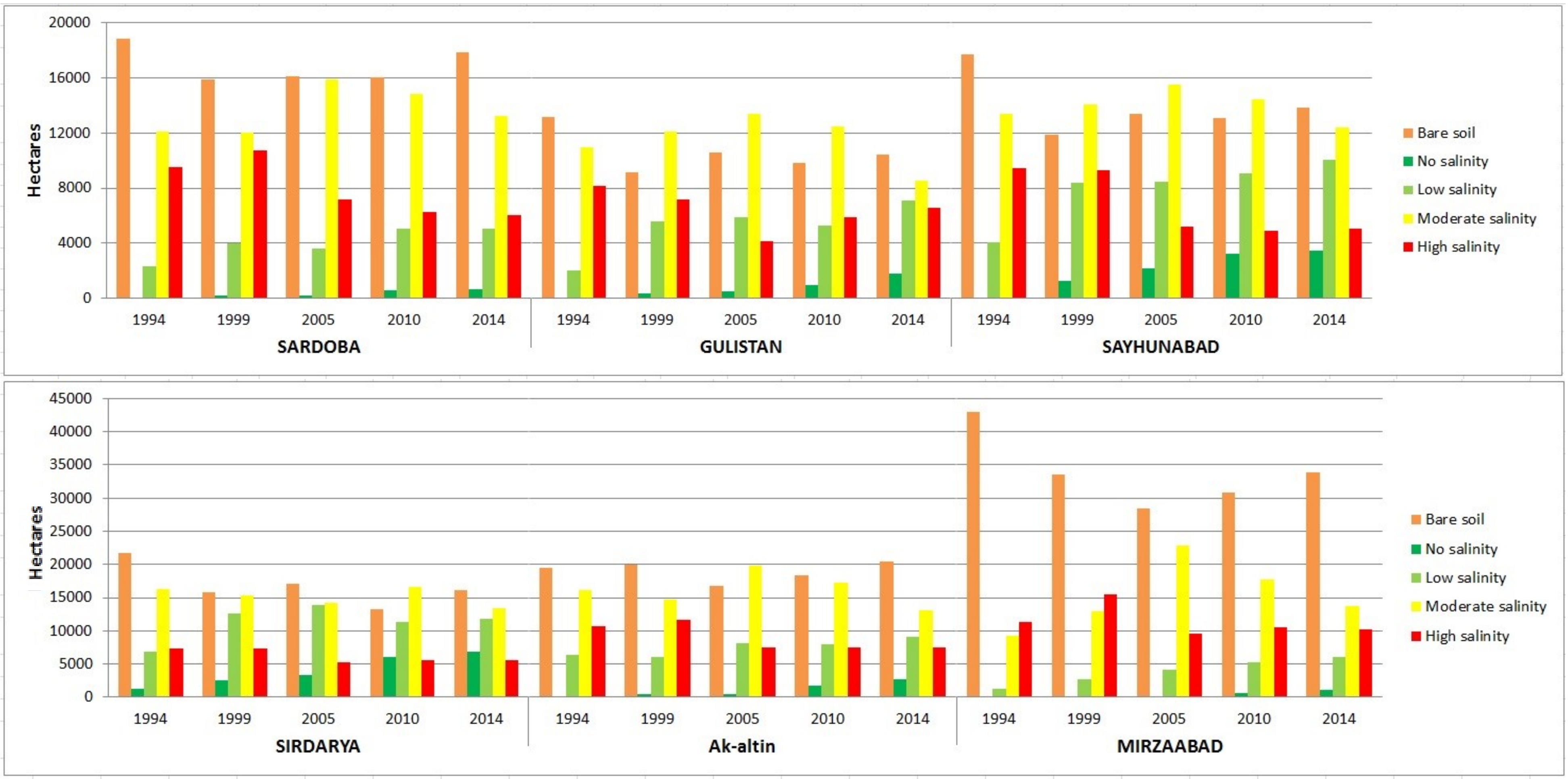

Figure 16. Distribution and dynamics of soil salinity levels and bare soil over the period in Sirdarya province

According to Figures 15 and 16, it is interesting to note that an increase to the areas classified as no salinity and low salinity was observed in the entire period in both provinces. On the one hand, there was a slight decrease to the moderate and severe salt-affected areas in almost all districts until 2014, despite having some oscillations in the middle of the period. This decrease could be seen after 2005 because there was a President Decree (PD-718 on October 31, 2007) on the improvement of the soils in arable land and 400 million soums (the local currency of Uzbekistan) was spent from the budget to massively implement agricultural practices such as salt leaching. On the other hand, the amount of bare soil in the study area remarkably decreased in some districts in the two provinces due to the urbanization and land owning for agricultural purposes. However, the area of bare soil in Ak-altin and Mirzachul districts rose slowly and dramatically, respectively, because of the DE from the northern direction.
Once the breakdown of the total area of Mirzachul into saline areas and the bare soil was accomplished using the NDVI tool, the next step was to check whether these results were true by statistical validation.

3.4.2. Statistical validation

Before diving into the statistics, an average NDVI was taken out of the NDVI values which were above 0.3 per district in order to ensure the quality of the analysis since the NDVI values below 0.3 were considered as an area where there is no biomass that indicates the actual soil salinity.
Basically statistical analysis was started with checking the correlation between variables. Therefore, before performing the regression analysis and *ANOVA*, the correlation between the average NDVI and SQI values of the districts was separately determined for each province (Annex 7). As emphasized in the methodology, climate data like precipitation and air temperature were additionally included in the correlation analysis for each province. For that reason, the previous detailed correlation between the average NDVI and SQI values were generalized per province and can be found in Tables 14 and 15.

Table 14. Correlation between climate data, the average NDVI in August and the SQI values in Jizakh province (P is precipitation (mm), T is air temperature (˚Celsius) in August)

	Average NDVI	**SQI values**	**P *(st. Jizakh)***	**T *(st. Jizakh)***	**P *(st. Dustlik)***	**T *(st. Dustlik)***
Average NDVI	1	0.958	0.772	0.259	0.904	0.219
SQI values	0.958	1	0.737	0.233	0.854	0.268
P *(st. Jizakh)*	0.772	0.737	1	0.039	0.964	-0.094
T *(st. Jizakh)*	0.259	0.233	0.039	1	0.093	0.941
P *(st. Dustlik)*	0.904	0.854	0.964	0.093	1	-0.027
T *(st. Dustlik)*	0.219	0.268	-0.094	0.941	-0.027	1

Table 15. Correlation between climate data, the average NDVI and the SQI values in Sirdarya province (P is precipitation (mm) and T is air temperature (˚Celsius) in August)

	Average NDVI	SQI values	P	T
Average NDVI	1	0.967	0.745	0.223
SQI values	0.967	1	0.734	0.169
P	0.745	0.734	1	0.178
T	0.223	0.169	0.178	1

Tables 14 and 15 above revealed that there was a very strong correlation between the average NDVI and SQI values in the two provinces. This was statistical proof that the NDVI soil salinity maps were as accurate and valid as the in-situ soil salinity maps and the NDVI soil salinity assessment could also be applied at the regional extent. On the subject of precipitation, there was a considerable correlation with SQI and the average NDVI values in both provinces. When the amount of precipitation increases, it helps peripherally leach salts from arable land and indirectly improves the soil quality. Precipitation also contributes to the growth of the vegetation which directly and proportionally influences the NDVI values. The role of air temperature was negligible in this analysis and nothing was found by this correlation.
Linear regression analysis and *ANOVA* were used to gain detailed insight into the relationship between SQI and the average NDVI values. In total, 24 and 29 observations were detected to form the regression graphs for Jizakh and Sirdarya province respectively (Figure 17).

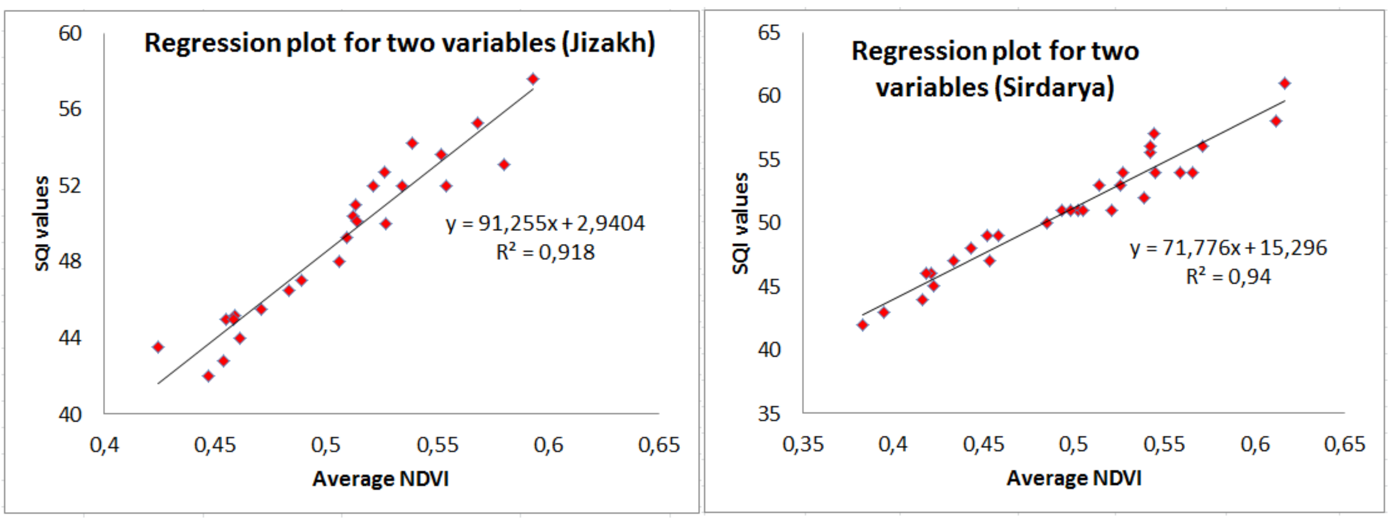

Figure 17. Regression plot for the SQI and average NDVI values observed in the two provinces

It can be seen that results of the linear regression that these two variables have shown a strong relationship between them as well. This could also be perceived as a positive validation result and indeed the NDVI soil salinity maps were almost identical to the SQI-based in-situ soil salinity maps. To finalize the statistical validation, the last step, *ANOVA* was performed to examine the statistical significance of the relationship between SQI and the average NDVI values (Table 16). Note that *Significance F* is equal to the *p-value* and denotes the results whether are statistically insignificant (> 0.05) or vice versa (< 0.05).

Table 16. Analysis of variance test for the SQI and average NDVI values

	Df	SS	MS	F	Significance F
Jizakh province					
Regression	1	0.045	0.0450	257.556	5.51E-14
Residual	23	0.004	0.0002		
Total	24	0.048			
Sirdarya province					
Regression	1	0.108	0.1080	438.806	1.20E-18
Residual	28	0.007	0.0002		
Total	29	0.115			

Significance F for both provinces was lower than 0.05 and the relationship between the average NDVI and SQI was statistically significant. As such, the soil salinity mapping based on the proposed NDVI range is valid for further research on the soil salinity assessment at the regional extent in Uzbekistan.

After the results on detecting the strong relationship between the in-situ and the GIS-based soil salinity assessment methods were statistically proven and validated, the potential option amongst the two soil salinity assessment methods were determined using MCDA by comparing and weighting the criteria in the following sub-section.

3.4.3. Application of multi-criteria decision analysis to soil salinity assessment methods

As it was previously stated, the two soil salinity assessment methods were mainly taken into consideration in this sub-chapter. These two methods then served as options in MCDA and the main task was to find out the important criteria appertaining to these methods to perform the comparison. For that reason, MCDA was conducted using its step-by-step generic procedures in this sub-section. The procedure begins with formulating of the main objective and identifying criteria in order to score and weight and terminates with sensitivity analysis to test the most preferred option.

STEP 1: Establishment of the decision context

The overall goal of MCDA was to determine the most preferred soil salinity assessment method by scoring and weighting the important criteria belonging to the two soil salinity assessment methods. So as to achieve this goal, several important criteria and their indicators were identified by a desk study based on the scientists' perception.

Below, the short description on the importance of each criterion involved in the soil salinity assessment and MCDA was given.

Time. Some scientists claimed that the in-situ method of the soil salinity assessment is slow, time consuming and requires a lot of activities, however, the GIS method is time efficient and a rapid tool giving quick results as to the actual soil salinity (Allbed and Kumar, 2013; Ghabour and Daels, 1993).

Costs. Nowadays, some tools were created to minimize expenses on innovative technologies and the operational costs during the in-situ soil salinity assessment (Rhoades and Chanduvi, 1999; Doolittle and Brevik, 2014). However, some scientists have already proven the economic efficiency of the soil salinity assessment using GIS techniques (Allbed and Kumar, 2013; Ghabour and Daels, 1993).

Labor. Some stated that while the in-situ soil salinity assessment can be carried out based on past experiences and basic knowledge on soil sciences, using or integrating GIS requires additional knowledge and education. The type of labor is important to decide on the method of soil salinity assessment (Carter et al., 1993; Lobell et al., 2010)

Validity. Rhoades and Chanduvi (1999) claimed that the outcome map of the in-situ soil salinity assessment could be up to 99% accurate and highly reliable depending on the tools and methods of processing and analysis. According to the GIS soil salinity maps, the accuracy can be derived only by comparing to the ground truth data, when the level of reliability depends on the chosen tools and external factors (e.g. crop type) (Woodcock and Gopal, 2000).

Temporal and spatial resolution. This is one of the most important criteria which shows the ability of monitoring the soil salinization processes. The temporal resolution is crucial to see the temporal changes in salinity, while the spatial resolution depicts how large the area is where there the soil salinity assessment is being conducted (Metternicht and Zinck, 2003).

STEP 2: Scoring options and performances against criteria

Identification of the expected performance of the two soil salinity assessment methods against the criteria was performed according to the literature used in the Step 1 respectively for each criterion. In this step, the combination of qualitative and quantitative performances was used and the outcome was formulated in the performance matrix below (Table 17).

Table 17. Identification of performances for the two soil salinity assessment methods

	In-situ soil salinity assessment	GIS-based soil salinity assessment
TIME**		
Duration of fieldwork	2 months**	-
Time for conducting analysis	2-4 months**	Up to 10 days
COSTS		
Technologies	++	+
Operational	++	+
LABOR		
Well educated	-	+
Experience based	+	+
VALIDITY		
Accuracy	Up to 99%	N/A
Reliability	High	Low
TEMPORAL AND SPATIAL RESOLUTION**		
Temporal scale	Once per 5 years**	1 month
Spatial scale	District extent**	Regional extent

** - details of criteria under this sign were taken out from Uzgeocadaster in the context of Uzbekistan

The performances of the two options were comparable, with a higher performance denoted by 1, whereas the lower performance was found for 0. Next, the options were scored with respect to the quality of the performances (Table 18).

Table 18. Scoring options against the quality of performances

	In-situ soil salinity assessment	Score	GIS-based soil salinity assessment	Score
TIME				
Duration of fieldwork	2 months	0	-	1
Time for conducting analysis	2-4 months	0	Up to 10 days	1
COSTS				
Technologies	++	0	+	1
Operational	++	0	+	1
LABOR				
Well educated	-	0	+	1
Experience based	+	1	-	0
VALIDITY				
Accuracy	Up to 99%	1	N/A	0
Reliability	High	1	Low	0
TEMPORAL AND SPATIAL RESOLUTION				
Temporal scale	Once per 5 years	0	1 month	1
Spatial scale	District extent	0	Regional extent	1

STEP 3: Weighting criteria

After having determined the scores of each criterion by summarizing the scores of the indicators, the criteria weighting was performed to reflect their relative importance. There are plenty of methods on how to weight the criteria (Macoun and Pranhu, 1999). Amongst them, Rank Order Centroid was chosen since the rest of the methods were suitable only for a group of experts, stakeholders and actors. Before weighting, the criteria were ordered by the level of importance based on subjective preference. The validity of the soil salinity assessment seemed the most important criterion that scientists should pay attention to first, followed by costs, time, temporal and spatial resolution and lastly, demand on labor. Weights were then assigned based on Equation 3 and registered in Table 19.

Table 19. Assigning weights for the criteria of the soil salinity assessment

	In-situ soil salinity assessment		GIS-based soil salinity assessment	
	Score	**Weight**	**Score**	**Weight**
Time	0	16%	2	16%
Costs	0	26%	2	26%
Labor	1	3%	1	3%
Validity	2	46%	0	46%
Temporal and spatial resolution	0	9%	2	9%
		100%		100%

STEP 4: Calculation of overall preference scores

The overall preference scores of the two soil salinity assessment methods were calculated in this step by using Equation 4 and converted into tabular view (Table 20).

Table 20. Overall preference scores of the two options

	In-situ soil salinity assessment		GIS-based soil salinity assessment	
	Score	**Weight**	**Score**	**Weight**
Time	0	16%	2	16%
Costs	0	26%	2	26%
Labor	1	3%	1	3%
Validity	2	46%	0	46%
Temporal and spatial resolution	0	9%	2	9%
Overall scores		0.95		1.05

As can be seen from the table above, the option for the GIS-based soil salinity assessment slightly outweighed the alternative, the in-situ soil salinity assessment option, and was found to be the most preferred option. The sensitivity of the most preferred option was then examined in the following step.

STEP 5: Sensitivity analysis

Hereby, the only criterion standing for labor type was equally shared between two options while the GIS-based option was dominant in the rest of criteria, apart from the criterion for validity. Therefore, the order of this criterion was placed one level above afterwards to see first the low level sensitivity, exchanging places with the temporal and spatial resolution. Then the final overall preference scores table was as following (Table 21):

Table 21. Overall preference scores of the two options after the application of sensitivity analysis

	In-situ soil salinity assessment		GIS-based soil salinity assessment	
	Score	Weight	Score	Weight
Time	0	16%	2	16%
Costs	0	26%	2	26%
Labor	1	9%	1	9%
Validity	2	46%	0	46%
Temporal and spatial resolution	0	3%	2	3%
Overall scores		1.01		0.99

In regards to the most preferred option, it was so sensitive that one level change of the least important criterion was remarkably affected, which was sufficient to cause a switch to the most preferred status of the GIS-based method over the in-situ method.

Summarizing all of the above on the MCDA, the GIS-based soil salinity assessment was determined as the most preferred option which is sensitive depending on the order of importance of the identified criteria. Once the GIS-based soil salinity assessment outweighed the in-situ method, in the following sub-section, the perception of specialists working at Uzgeocadaster on the dependence of the GIUs on the in-situ soil salinity assessment was discovered through an expert interview via telephone.

3.4.4. Choice of the governmental institutions on soil salinity assessment methods

In total, two interviewees (latter, representatives) working at Uzgeocadaster barely agreed to have an interview on the topic of the soil salinity assessment methods. One is a specialist on land monitoring and soil fertility and another has a GIS and RS background. The name and working department of the interviewees were kept anonymous as per request, in order to prevent additional unnecessary internal pressure on them. Several items (Annex 5) based on the results of MCDA were prepared and some additional questions, related to the results of the first part of the soil salinity assessment in this report, were asked. The interview was conducted in Uzbek language, since the interviewees do not have sufficient knowledge on English, and lasted approximately 15 minutes due to their tight working schedules.
With respect to the perception of the first representative, who is an expert on land monitoring and soil fertility, the reasons for the current choice (the in-situ method) of the GIUs for the soil salinity assessment were sufficiently determined. First of all, the representative of Uzgeocadaster compared the in-situ method with the GIS-based method. It was admitted that GIS indeed has greater potential in terms of the effects of time and cost. According to the validity of the GIS soil salinity maps, only the distribution of soil salinity levels in a particular area can be determined by using GIS and RS tools, especially the NDVI tool that was used in the Section 3.4.1. However, the point of interest of the GIUs is to figure out the type of soil salinity, determined through laboratory analysis, which requires soil samples. In order to maintain the

consistency of the analysis, more time than usual is likely to be spent and lower spatial coverage is usually taken (e.g. farmyards). Therefore, the in-situ soil salinity assessment is always conducted in Uzbekistan to determine potential mitigation measures against the chemical types of soil salinity (e.g. chloric, sulphur, sodic, etc.) since each chemical type of soil salinity requires specific measures which are not applicable to other types of soil salinity (Representative of Uzgeocadaster, July 18, 2019).

Secondly, the representative mentioned another reason why the GIUs are relying on the in-situ soil salinity assessment by highlighting some issues which restrict the application and the integration of GIS with the in-situ assessment. A lack of technologies is one of the issues. Departments are not sufficiently provided with hardware packages containing special GIS and RS software and multi-spectral drones, which are prohibited to use in Uzbekistan. Another issue is a lack of specialists of the GIS and RS field of expertise. “Subsidies can be provided by the government to buy hardware, but we do not have enough experts who can understand and work with this hardware” said Representative of Uzgeocadaster (Translated from Uzbek language, July 18, 2019). Young experts in Uzbekistan, who are specialists on GIS and RS, tend to seek a prestigious job abroad since they do not agree to work for low salary given by the GIUs (Representative of Uzgeocadaster, July 18, 2019).

At the end of the interview, the representative pointed out some hubs organized by Uzgeocadaster to raise farmers’ awareness of the soil salinization processes as a precautionary measure. This helps to prevent salt accumulation in soils and the soil salinity assessment by building local laboratories, which economizes time of the fieldwork and minimizes operational costs. Through these hubs it is expected to receive data on the actual soil condition of a particular farmyard faster, enabling the monitoring of soil salinization at the shorter temporal scale (Representative of Uzgeocadaster, July 18, 2019).

Regarding the outcome of the second interview with the representative of Uzgeocadaster who is a specialist on GIS and RS, the answers partially overlapped those given by the first representative and some extra information was derived on the role of GIS and RS specialists and the current choice of the GIUs as to the soil salinity assessment. The role of GIS and RS specialists in Uzgeocadaster is to map annually-updated land uses, to create the Digital Elevation Model (DEM) of a particular area of interest and lastly, to control the existence of specific agricultural crops in a farmyard. As for controlling over the existence of agricultural crops, every farmer has an obligation to sow agricultural crops like cotton and wheat depending on the demand of the government since the agricultural land can be loaned from the government based on the rental agreement. So farmers pay back the rental contract fee with the required yield of a certain agricultural crop that the government has demanded, instead of paying by the monetary unit. The role of GIS and RS specialists here is to continuously observe the agricultural crops by their spectral signatures to ensure the avoidance of cheating by the farmers. For that reason, specialists could not find time to perform the analysis of soil salinization (Representative of Uzgeocadaster, July 31, 2019).

As a reason for the GIUs’ dependence on the in-situ soil salinity assessment, the representative also emphasized some issues related to the capacity of technologies and personnel. Additionally, the GIUs always hold a proactive position on false positives and true negatives which can occur in the GIS soil salinity maps (Representative of Uzgeocadaster, July 31, 2019).

Summarizing the findings of these interviews, plenty of reasons were identified to support the choice of the GIUs as to the in-situ soil salinity assessment rather than the GIS-based soil salinity assessment. As it was mentioned in the previous section where MCDA was performed, the validity of the soil salinity results is very important, which can fully be ensured by the in-situ method. The GIS results were also consistent with the in-situ results in the Section 3.4.1, but can only be used to determine the distribution of soil salinity levels, not the chemical types of soil salinity.

3.5. Discussion

The objective of the second experiment was to compare both methods of the soil salinity assessment, in-situ and GIS-based, by applying MCDA, serving to learn the current perception of the GIUs for the second experiment. This sub-chapter also has two sections, describing the used methods' validity and reliability, and the interpretation of results.

3.5.1. Validity and reliability of methods

To begin the discussion, all results were generated without fieldwork. Other specific discussion points are discussed in the following sub-topics.

NDVI

NDVI is an indicator that assesses whether the area contains photosynthetically active vegetation (Bannari et al., 1995). So this indicator does not measure the soil salinity level directly and instead, the amount of green vegetation is considered a proxy of the soil quality. However, another factor, water stress of the vegetation, also influences the soil salinity results, giving low NDVI values (Tilling et al., 2007). The NDVI range that is used in the experiment is highly dependent on the crop type. This range is an assumption of local scientists, but it gave valid NDVI mapping results. This NDVI range considers the spectral reflection of cotton. Actual cotton areas in Mirzachul had not been reduced until 2017. As NDVI does not directly measure the actual soil salinity, the application of thermography is essential to support the NDVI maps when there are uncertainties as to the NDVI values (Ivushkin, 2019). Thermography is not applied in this research since the results of the NDVI maps were valid (R^2 is 0.84 and *Significance F* > 5.51E-18) when compared to the ground truth data.

Statistical analysis

According to the second experiment, the correlation analysis set up for mainly SQI values and the average NDVI, additionally air temperature and precipitation were included. The correlation of air temperature and precipitation with the SQI values and the average NDVI is also interesting to observe because, on the one hand, by rising air temperature, the evaporation rate increases simultaneously, causing salt accumulation in soils. On the other hand, precipitation has no adverse effect on the soil quality, but rather improves it by the supplementary leaching of acidic/alkaline substances and salts from the top-soil. As a result, the SQI values and the average NDVI were strongly correlated each other, at around 97%. Unfortunately, the SQI values and the average NDVI were not correlated with air temperature (17-22%) and the correlation of the SQI values and the average NDVI with precipitation was around 72-90%. The *F-test* was executed to check the significance of the correlation between the SQI values and the average NDVI resulting in 5.51E-14 and 1.20E-18 respectively for the two provinces in

Mirzachul. Indeed, it was highly significant because of the observation points in the analysis. Lastly, the R^2 between the SQI values and the average NDVI was determined, ranging from 0.92 to 0.94 depending on the provinces in Mirzachul. As such, these results serve as a statistical proof of the GIS-based results to compare to the ground truth data.

Multi-Criteria Decision Analysis

The main criteria belonging to the two soil salinity assessment methods were mainly defined by desk study. In order to weight these criteria, Rank Order Centroid (ROC) method was used because it does not require an expert's opinion and the criteria can be ordered by their perceived importance by author (Edwards and Barron, 1994; Goyette, 2013). As a result, MCDA is completely performed based on the author's preference.

Expert interviews

In total, I had two expert interviews with experts who work at Uzgeocadaster, of different expertizes on the soil salinity assessment. Admittedly, two representatives cannot fully represent the perception of the GIUs and a lack of participation of the representatives possibly affects the outcome of the interview. On the other hand, they are able to express their opinion on the choice of the GIUs on the soil salinity assessment, which is sufficient to determine key reasons at to the choice. As well, they both gave their interviews in their local language since they do not have sufficient knowledge of English and they wanted to keep their names and their working departments anonymous. This reduces the quality of interviews and the trust in the results of the readers.

Recommendations for further research

Since the goal of the second experiment was positively achieved and RQs were fully answered, several recommendations, which are outside of the scope of the research, are created for further research.

One question might possibly be raised above the results of MCDA, what will happen if the relevant criteria are determined and are weighted by involved experts? This question is open for further research and it is recommended to delve into it, since it is also vital in determining the preferred option in the soil salinity assessment. Another recommendation for further research is that the first step for designing the methodology for the use of GIS techniques in determination of the chemical type of soil salinity should be taken into consideration. It is assumed that this might significantly lower the costs and improve the time efficiency of soil salinity assessment as well as improve the accuracy of the GIS soil salinity mapping.

3.5.2. Interpretation of results

The second experiment aimed to compare both methods of the soil salinity assessment, in-situ and GIS-based, by applying MCDA in order to learn the current perception of the GIUs. Up to now, many previous studies revealed the correlation between the vegetation indices and soil salinity at the local extent (Ivushkin, 2014; Ivushkin et al., 2017; Eltazarov, 2016; Akramova, 2008; Platonov et al., 2015), which drove the usage of the vegetation index, NDVI, to map soil salinity in this research. Additionally, Ivushkin (2019) has recently introduced a new innovative method of the soil salinity assessment using thermal images, which are lacking in this experiment. August is the most suitable month to accomplish soil salinity assessment using NDVI in the area where the main crop type is cotton, as confirmed by Ivushkin et al. (2017), who took satellite images in August to conduct the analysis. The results confirm that the created GIS-based soil salinity maps for each year as response to the years in which the official governmental in-situ soil salinity assessments were conducted, were valid to use in the soil salinity assessment. They gave very accurate patterns and providing approximately 97% of correlation with the official one. Beyond this, the R^2 value accounts for around 0.93 between the GIS-based results and the official governmental results in this experiment.

The previous studies were mainly conducted in Sirdarya province at the local area, within the area of the Water Consumers Association, which comprises of several farmyards (Ivushkin, 2014; Eltazarov, 2016; Akramova, 2008; Platonov et al., 2015). Researchers took soil samples during the fieldwork and analyzed these in the laboratories in order to compare the GIS results to the actual context of soil salinity. Amongst them, no one directly worked with the SQI values as a basis for the GIS soil salinity maps nor compared their results to the official assessment results over the period. The comparison results in this experiment were concise, which allowed for the application of MCDA to determine the most preferred option. MCDA was recently introduced in Uzbekistan by Umarova (2019) to study the implementation of payment for ecosystem services. To compare with the previous study, MCDA here was firstly applied for the soil salinity assessment methods in Uzbekistan. The straightforward method of MCDA, namely Rank Order Centroid, was used to highlight the preferred choice which was the GIS-based soil salinity assessment. Then, expert interviews, as recommended by Bogner et al. (2009), were organized to learn the perception of specialists in the GIUs. This preferred option was denied by the representatives of Uzgeocadaster, considering certain reasons limiting the integration of GIS and RS into the soil salinity assessment in Uzbekistan. This was because restricted capabilities of GIS do not determine the chemical type of soil salinity. Indeed, as long as the chemical type of soil salinity is in the interest of the specialists, GIS and RS are not proper tools to assess this. It is certainly required to perform field work to assess the chemical properties of soil salinity.

3.6. Conclusion

The GIUs use the SQI values per district in the country to interpret the level of soil salinity determined by the in-situ method of assessment, conducted once every five years. However, there is another method, using GIS and RS techniques, to assess soil salinity and some scientists have indeed already proven several methodologies to conduct the assessment. A few studies have been conducted on the soil salinity assessment using GIS and RS tools in Sirdarya province, which is considered as the most vulnerable area in terms of soil salinization and the main province for agricultural purposes. Since Sirdarya province is located in Mirzachul region, generally, this region was chosen to undertake the research. This study aimed to compare both methods of the soil salinity assessment, in-situ and GIS-based, by applying the MCDA, which served to understand the current perception of the GIUs. This goal was also completely fulfilled according to the following findings, presented as responses to the RQs.

To begin with, the GIS maps were created using the NDVI tool, which is sensitive to green vegetation, as a proxy of soil salinity. These maps are highly consistent and satisfactory when compared to the in-situ results. A very strong correlation was found between the GIS-based and the in-situ results. The R^2 for the SQI values and the average NDVI was substantially considerable and was positively tested by *ANOVA*. So it can be assumed that the integration of

GIS and RS provides results for the soil salinity assessment as accurate as those from the in-situ method and the potential of GIS and RS for soil salinization was once more proven by this experiment.

Once the expected results described above were derived, the MCDA was performed to determine the most preferred method of the soil salinity assessment. Criteria for this analysis are found by a desk study. To conclude, the GIS approach towards soil salinity is indeed much faster and much cheaper, which would minimize the expenses from the budget of the country need to perform the in-situ soil salinity assessment. However it is found that the validity of GIS results is highly dependent on the results of the in-situ assessment. Specifically, there is no exact accuracy of the GIS soil salinity mapping. As expected, the GIS method of soil salinity assessment outweighs the in-situ method when ranking without the participation of experts. Consequently, the MCDA gave expected outcomes by subjectively ordering the perceived importance of criteria.

The GIUs, those responsible for the soil salinity assessment, tend to ignore the most preferred method as defined in the MCDA. This is due to the main finding of the RQ7 in this experiment, that the GIUs use the in-situ method of the soil salinity assessment to determine not only the level of soil salinity, but also the chemical type of salts. Nowadays, the GIS techniques are not able to render accurate results of the chemical type of soil salinity. Specific measures are taken to combat with soil salinity based on chemical type, since the generic procedures of salt-leaching measures do not fit all chemical types of soil salinity, according to the representative of one of the GIUs. Summarizing this, the choice of the GIUs is reasonable and I assume that GIS and RS do not provide sufficient tools to evaluate the chemical content of soil salinity.

4. SYNTHESIS

The overall goal of this thesis research is to contribute to the methodology development for desertification and soil salinity assessments. To achieve this goal, two separate experiments are conducted based on seven RQs. Following are the main findings of this research.

4.1. First experiment

The majority of previous studies investigated desertification mainly in African arid zone. Most of the studies followed the UNNCD definition of desertification. Only few studies, following the same approach 'desertification is the desert encroachment' as I took during my research, can be identified and have been carried out in the world-wide and Uzbekistan. The aim of these studies in Uzbekistan was generally to assess the likelihood of desertification, occurred aftermath of the Aral Sea Crisis. However, I took another study area, Mirzachul, to explore since this study area includes one of the agro-economical significant provinces.

I regionally assessed DE using SAVI that is the more conventional indicator of soil texture mapping. To perform this, I firstly compared the preliminary SAVI-based soil texture map of Mirzachul to the actual soil map to visually examine the similar observable patterns. The patters were reasonable to enable to proceed creating the SAVI-based soil texture maps until 2018. Once I got the all soil texture maps, I calculated the annual average DE rate. From this obtained result, I conclude that the DE assessment can be carried out using the SAVI indicator in arid zones. Statistical analysis showed that the SAVI-based results significantly distinguished between sand and other types of soil as well as wind speed, producing significant *p-values*. Overall, the initial step in this experiment confirmed that the SAVI-based approach has substantial potential for the DE assessment.

Another finding of this experiment was that the severity of future DE is now projected. This projection was conducted to consider the appropriate mitigation measure against desertification. The potential mitigation measures were then plotted by scenarios to quantitatively foretell the expected changes in the area of Mirzachul. Amongst mitigation measures, agroforestry can be favorably applied in Mirzachul since its climate condition supports agroforestry. Consequently, agroforestry is reasonable to stop desertification. I assume that agroforestry is an appropriate mitigation measure which can stop desertification. Besides that, agroforestry has a potential for the improvement of regional climate conditions and soil reactions. This measure enhances regional microclimate, carbon sequestration, vegetation cover and soil fertility, and reduces regional air temperature, the evaporation rate, the risk of soil erosion and wind speed.

Summarizing all of above, I can say that this experiment contributed to the methodology development to assess DE. The factor of DE, sand dynamics, can be monitored using SAVI tool and agroforestry can be an effective mitigation measure to stop the severity of desertification.

4.2. Second experiment

Once the SAVI-based approach was successfully tested for the desertification assessment in the first experiment, the results of second experiment contributed to the methodology development to assess soil salinity. As a study area, Mirzachul was also selected which includes Sirdarya province itself. I considered this study area as a proper area to perform the experiment since Mirzachul has large agricultural fields and the majority part of its area is affected by some degree of soil salinity.

It was clear before this research that the in-situ soil salinity assessment gave concise results which have been tested through GIS-based approach at a local extent. These results, which were published in the national reports of the GIUs, were the main base in this experiment to create regional qualitative maps of soil salinity. After I mapped the in-situ data, I dared to use more traditional NDVI indicator to regionally assess soil salinity and compare with the in-situ data-based soil salinity maps. During the comparison, I investigated a substantial relationship between the NDVI-based and the in-situ based maps. Statistical analysis proved that the combination of NDVI values and in-situ data in a Simple Linear Regression analysis has enhanced R^2 values. Therefore, I conclude that regional NDVI-based maps are tremendously correlated to soil salinity and an NDVI indicator can be used to regionally assess soil salinity in Uzbekistan.

The addition of MCDA into the experiment can act as a potential ESA tool that allows comparing and weighting the two soil salinity assessment methods against identified criteria. This analysis was performed by using the Rank Order Centroid approach that is time effective and can be applied without an expert's participation. The approach applied, allowed us to estimate overall score for the two soil salinity assessment methods, in which the GIS-based method outweighed the advantages of in-situ method. Therefore, in general, I can conclude that applying MCDA to rank alternative options is reasonable in the assessment of LD effects.

Nevertheless, GIS-based approaches have their limitations and can hardly be applied without using the ground truth data of soil surveys. During the expert interview, one major drawback of the GIS-based approach was determined. In this, the GIS-based assessment cannot provide the chemical properties of soil salinity that serve a main base to organize salt-leaching measures. This drawback limits the integration of GIS-based approach in soil salinity assessment. To summarize, I conclude that the GIS-based soil salinity assessment indeed does not provide information about the chemistry of soil salinity, but it is a potential approach to instantly assess the soil salinity degree. As the chemical content of soil salinity is in the interest, the in-field soil salinity survey is required.

All in all, the overall goal of this research was fully achieved. Some recommendations, which are outside of the scope of this research, were created to enhance the both namely, the assessment of DE and the soil salinity assessment results.

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6. ANNEXES

Annex 1. Detailed information on satellite images

Satellite images used in the assessment of DE in Mirzachul

Year	Date		Sensor type
	Row/Path 154/32	*Row/Path* 155/32	
1994	23.11	08.11	Landsat TM5
1995	15.11	21.11	Landsat TM5
1996	28.10	01.11	Landsat TM5
1997	08.11	23.11	Landsat TM5
1999	12.11	15.11	Landsat TM5
2000	21.11	06.11	Landsat TM5
2001	29.10	22.10	Landsat TM5
2002	04.11	15.11	Landsat ETM+ 7
2003	18.11	17.11	Landsat ETM+ 7
2004	25.11	02.11	Landsat ETM+ 7
2005	10.11	18.11	Landsat ETM+ 7
2007	23.11	16.11	Landsat ETM+ 7
2008	30.10	04.11	Landsat TM5
2009	18.11	26.11	Landsat TM5
2010	28.11	11.11	Landsat TM5
2011	17.10	31.10	Landsat TM5
2013	13.11	20.11	Landsat 8 OLI
2014	16.11	25.11	Landsat 8 OLI
2015	25.10	13.11	Landsat 8 OLI
2016	05.11	27.10	Landsat 8 OLI
2017	08.11	10.11	Landsat 8 OLI
2018	28.11	14.11	Landsat 8 OLI

Satellite images used to soil salinity assessment

Year	Date		Sensor type
	Row/Path 154/32	*Row/Path* 155/32	
1994	21.08	12.08	Landsat TM5
1999	19.08	10.08	Landsat TM5
2005	13.08	10.08	Landsat ETM+ 7
2010	13.08	21.08	Landsat ETM+ 7
2014	12.08	19.08	Landsat 8 OLI

Annex 2. Climate data of Mirzachul (retrieved from Hydrological Meteorological Service of Uzbekistan [Uzhydromet, 2019])

Dustlik meteo-station

TEMPERATURE, Celsius													
Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Av/Year**
1994	0,8	-1,1	9,6	13,7	22,1	28,1	27,5	26,3	17,6	14,0	11,7	3,0	**14,4**
1995	1,4	4,9	8,5	16,2	21,6	27,1	29,0	26,3	20,6	13,1	10,4	1,8	**15,1**
1996	-0,5	0,6	6,2	14,1	21,1	26,3	27,9	25,7	21,0	12,1	5,1	5,6	**13,8**
1997	2,9	2,1	9,6	17,4	20,6	27,9	29,1	25,9	20,6	17,7	4,5	2,6	**15,1**
1998	0,6	1,2	7,5	16,9	19,9	26,1	29,1	26,9	21,8	13,4	8,5	5,0	**14,7**
1999	2,3	1,4	7,5	14,4	22,2	26,1	27,2	28,0	20,9	14,7	7,0	3,9	**14,6**
2000	2,9	3,5	9,3	19,2	22,9	26,3	28,6	27,6	20,9	12,0	6,4	4,8	**15,4**
2001	0,0	4,9	11,6	17,9	25,8	28,4	27,4	26,1	19,5	13,1	9,9	4,3	**15,75**
2002	4,4	6,1	11,6	15,0	20,4	26,3	29,3	27,3	21,4	16,7	10,0	-2,4	**15,5**
2003	4,9	5,3	8,7	13,9	19,7	25,3	28,4	27,0	21,5	16,3	8,7	2,7	**15,2**
2004	4,8	8,1	10,3	15,1	22,8	27,4	28,0	26,5	21,7	13,5	11,7	4,0	**16,2**
2005	2,2	0,0	12,6	16,6	21,5	28,2	29,2	26,1	22,7	15,2	8,3	4,4	**15,6**
2006	-2,8	7,3	11,6	17,9	23,8	27,2	27,4	26,6	20,2	17,5	9,7	0,0	**15,5**
2007	2,1	5,8	8,8	18,6	22,3	27,8	28,9	26,8	21,3	12,0	9,1	2,7	**15,5**
2008	-9,1	-0,8	14,8	17,6	24,0	28,5	29,4	27,5	20,3	14,9	8,1	3,0	**14,9**
2009	2,8	7,0	11,1	13,4	21,7	25,6	28,3	26,2	21,2	15,0	8,1	4,9	**15,4**
2010	4,7	2,9	11,3	17,3	22,0	27,1	28,2	27,2	20,9	16,8	9,0	3,0	**15,9**
2011	0,7	3,0	9,2	18,0	24,1	28,0	28,3	27,1	21,4	15,3	5,5	0,7	**15,1**
2012	-0,1	-0,7	7,8	20,1	23,1	27,9	28,8	27,8	20,8	14,9	6,9	-0,4	**14,75**
2013	4,4	4,8	11,5	15,7	22,4	27,3	28,5	26,3	22,6	14,6	8,4	3,4	**15,8**
2014	2,1	-4,1	9,4	14,1	23,6	27,8	27,1	26,7	21,0	13,1	5,4	3,0	**14,1**
2015	2,3	6,3	8,0	18,0	23,5	28,5	29,4	25,8	20,3	14,3	8,1	5,5	**15,8**
2016	5,8	6,9	13,0	16,4	23,5	27,8	29,1	27,3	23,6	11,8	5,4	5,1	**16,3**
2017	4,7	5,7	8,6	20,4	23,2	27,1	29,2	27,5	20,8	13,7	5,2	4,6	**15,9**
2018	-0,9	0,0	7,2	18,5	22,9	28,4	28,9	26,8	17,1	14,4	6,3	0,1	**14,1**

PRECIPITATION, mm													
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum/Year
1994	38,2	51,1	26,4	69,9	8,1	4,3	0,0	0,0	2,4	0,3	68,8	82,7	352,2
1995	39,4	25,4	43,3	9,3	11,6	2,6	0,0	0,0	0,0	15,6	0,4	26,5	174,1
1996	11,0	50,2	68,2	46,4	2,5	0,4	0,0	0,4	30	8,9	4,6	6,6	229,2
1997	68,3	25,4	35,2	47,1	55,2	43,7	0,0	0,0	0,0	1,3	33,1	25,0	334,3
1998	72,1	84,9	62,4	86,7	56,3	52,5	8,9	51,4	3,4	10,8	22,7	21,4	533,5
1999	44,5	58,9	23,2	29,9	5,3	32,5	0,0	0,0	9,6	10,1	67,5	7,1	288,6
2000	41,4	16,0	29,4	12,3	0,0	7,4	0,0	0,0	0,8	36,3	40,4	44,2	228,2
2001	9,4	41,6	39,9	17,2	0,0	0,0	13,3	0,3	0,0	54,0	37,4	49,7	262,8
2002	39,4	97,9	66,8	83,4	34,1	8,5	0,0	0,0	0,0	0,6	9,9	77,3	417,9
2003	6,3	40,6	92,1	78,3	42,9	30,5	0,0	0,0	0,0	0,8	59,6	58,7	409,8
2004	82,6	20,7	90,3	33,0	33,9	0,0	7,5	0,9	0,0	14,9	96,3	68,0	448,1
2005	56,3	23,3	37,6	28,4	37,9	0,0	0,8	0,0	0,0	1,1	24,3	8,8	218,5
2006	48,4	32,6	38,7	27,7	5,4	0,0	10,1	0,0	1,0	15,4	42,1	26,3	247,7
2007	20,1	36,6	62,7	79,0	33,0	0,8	0,0	0,0	0,0	5,6	22,0	83,4	343,2
2008	14,0	30,5	24,5	17,7	19,6	0,0	0,0	0,0	10,7	24,2	45,0	34,5	220,7
2009	27,3	77,2	66,2	99,0	27,1	20,2	0,0	6,6	7,4	0,1	20,8	44,0	395,9
2010	36,3	69,6	36,6	36,5	63,7	23,4	2,2	0,8	5,2	0,9	17,2	1,2	293,6
2011	9,2	60,7	44,0	25,5	11,7	9,8	0,0	0,0	1,6	18,3	129,2	35,8	345,8
2012	20,5	64,1	61,1	5,6	15,8	8,0	0,0	0,0	0,0	11,4	25,1	35,7	247,3
2013	29,6	12,3	107,4	55,2	3,6	10,6	0,0	5,7	0,0	18,3	16,4	42,5	301,6
2014	40,4	21,1	95,3	50,0	3,2	0,4	0,0	2,2	1,2	32,2	60,3	7,7	314,0
2015	52,0	79,3	34,6	7,1	15,6	8,0	0,4	1,3	0,0	70,0	33,1	14,1	315,5
2016	64,5	6,1	75,2	34,4	50,9	26,8	7,0	1,0	1,2	35,4	12,7	44,4	359,6
2017	38,6	54,7	48,1	66,4	21,1	0,0	0,0	0,0	6,1	33,7	56,3	64,9	389,9
2018	50,9	74,5	86,8	27,1	4,5	0,0	0,8	0,0	0,1	19,3	44,6	80,5	389,1

WIND SPEED, m/sec														
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	av/year*
1994	1,9	3,3	5,6	7,8	6,4	2,4	1,3	1,3	4,3	8,1	6,2	3,1	6,4
1995	2,2	3,3	5,8	7,4	6,2	2,7	1,5	1,4	5,1	8,3	7,6	3,0	6,8
1996	1,8	4,1	5,7	8,4	6,6	2,3	1,5	1,7	5,1	8,3	7,0	3,1	6,9
1997	2,1	3,8	5,9	7,7	6,7	2,6	1,3	1,3	4,2	7,1	7,3	3,1	6,5
1998	1,9	3,8	5,8	7,8	6,9	2,5	1,1	1,2	4,2	7,2	6,3	2,6	6,4
1999	1,0	3,3	5,4	7,2	6,2	2,2	1,1	0,9	4,2	7,8	7,5	2,9	6,4
2000	1,9	3,4	5,6	7,0	7,2	1,9	0,4	0,4	5,8	8,1	7,1	2,8	6,8
2001	1,3	3,6	5,5	7,5	7,1	2,2	1,2	1,4	5,2	8,8	7,6	3,3	7,0
2002	1,9	4,2	5,9	7,5	6,5	2,7	1,3	1,5	4,4	7,3	7,5	2,6	6,4
2003	1,7	4,7	5,9	7,9	7,9	2,5	1,4	1,3	5,5	7,4	8,0	2,9	7,1
2004	1,3	4,3	5,7	8,5	7,6	2,7	1,4	1,4	5,7	8,4	7,7	2,5	7,3
2005	1,7	3,6	6,3	7,9	7,0	2,5	1,0	1,3	5,1	7,1	7,2	2,7	6,8
2006	1,3	4,2	5,5	7,4	6,4	2,4	1,6	1,5	5,6	8,6	6,8	2,2	6,7
2007	1,4	3,9	5,6	7,8	7,7	2,4	1,5	1,4	4,3	8,3	6,8	3,0	6,8
2008	1,1	4,1	6,1	7,7	6,6	2,2	1,1	1,2	5,2	8,3	7,5	2,2	6,9
2009	1,4	3,8	5,7	7,7	6,7	2,8	1,2	1,1	4,2	8,4	6,9	3,1	6,6
2010	2,0	3,9	6,4	7,8	8,0	2,7	1,7	1,3	4,3	7,9	6,3	2,6	6,8
2011	1,4	4,4	5,7	7,9	6,8	2,8	1,2	1,2	4,4	8,4	6,4	2,2	6,6
2012	1,4	3,8	6,2	8,0	7,7	2,7	1,5	1,3	5,3	7,3	6,4	2,5	6,8
2013	2,5	3,6	6,2	7,4	6,5	1,6	1,2	1,2	5,2	8,2	7,2	2,7	6,8
2014	1,5	3,1	5,7	7,7	6,4	2,2	1,2	1,2	5,2	8,1	7,1	2,5	6,7
2015	1,5	3,4	5,4	7,7	6,4	2,3	1,1	0,9	4,9	8,0	6,7	3,3	6,5
2016	1,3	3,0	5,3	7,2	6,3	2,1	0,9	0,8	4,9	8,5	6,3	2,9	6,5
2017	1,8	4,6	6,8	8,9	7,5	2,8	1,4	1,6	5,7	8,9	7,7	3,1	7,6
2018	1,4	4,1	7,1	8,3	7,4	1,9	0,7	1,1	5,2	8,7	7,9	2,4	7,5
			FIRST WINDY SEASON						SECOND WINDY SEASON				

Av/year* = calculated based on the average wind speed in two windy seasons

Jizakh meteo-station

TEMPERATURE, Celsius													
Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Av/Year**
1994	0,9	-0,9	9,8	13,1	21,8	28,2	27,7	26,6	18,0	14,7	11,9	3,2	**14,5**
1995	1,4	4,3	8,6	16,1	21,5	27,2	29,2	26,8	20,6	13,2	10,5	2,4	**15,1**
1996	-1,1	1,1	6,1	14,0	21,0	26,3	28,2	25,1	21,3	13,3	5,3	6,1	**13,9**
1997	3,1	1,8	8,9	16,8	20,4	27,8	28,2	25,8	21,0	17,6	5,4	2,6	**14,9**
1998	0,9	1,3	7,8	16,8	19,5	25,9	29,0	26,9	21,7	13,7	9,3	4,7	**14,8**
1999	2,8	4,5	7,4	14,1	21,4	25,7	24,8	27,6	21,0	15,5	6,9	4,6	**14,7**
2000	3,6	3,2	9,1	17,0	22,5	26,1	28,2	27,1	21,0	12,1	6,5	5,1	**15,1**
2001	0,4	5,3	11,5	17,7	25,2	27,8	26,8	25,6	19,3	13,4	10,0	4,2	**15,6**
2002	4,5	6,1	11,6	14,7	20,0	26,0	27,7	26,9	20,9	16,8	10,3	-1,9	**15,3**
2003	5,0	5,2	8,2	13,6	19,1	24,6	27,7	26,4	21,0	16,1	8,4	2,2	**14,8**
2004	5,4	7,9	10,0	14,5	22,2	26,9	27,8	26,4	21,4	13,2	11,8	3,7	**15,9**
2005	2,2	0,7	12,5	16,1	20,8	27,9	28,8	25,9	22,0	14,5	8,3	4,7	**15,4**
2006	-2,3	7,5	11,0	16,9	23,3	26,6	27,0	26,0	20,0	17,3	9,6	0,8	**15,3**
2007	2,8	5,9	8,8	18,1	21,6	27,2	28,3	26,0	20,2	11,0	9,6	2,3	**15,1**
2008	-7,6	-0,3	14,4	17,0	23,2	27,5	28,5	26,9	19,7	14,6	7,3	3,1	**14,5**
2009	3,4	7,1	11,0	12,9	20,8	24,7	27,3	25,4	20,4	14,0	7,7	4,9	**15,0**
2010	5,3	2,6	11,3	16,8	21,5	26,7	27,9	27,0	20,5	16,3	9,0	3,1	**15,7**
2011	1,3	2,9	9,2	17,6	23,7	27,9	28,2	27,0	21,0	14,9	5,7	-0,7	**14,9**
2012	0,0	-0,5	7,6	19,2	22,4	27,3	28,0	27,2	20,3	14,2	7,1	-0,3	**14,4**
2013	4,3	4,3	11	15,0	21,6	27,1	28,4	26,3	22,5	14,3	8,2	2,9	**15,5**
2014	2,2	-3,4	8,8	13,5	23,1	27,2	26,7	26,8	20,9	12,8	5,3	2,8	**13,9**
2015	2,8	6,0	7,7	17,3	23,2	28,4	29,3	25,9	20,4	14,4	8,4	5,3	**15,8**
2016	0,9	4,5	9,1	15,6	21,2	26,8	28,4	25,7	19,5	15,2	7,3	1,4	**14,6**
2017	3,0	1,8	7,8	14,8	24,0	27,4	29,2	26,3	21,5	15,0	9,6	1,6	**15,2**
2018	0,7	3,1	13,1	15,8	21,1	27,5	28,1	25,4	20,3	13,9	8,7	2,2	**15,0**

PRECIPITATION, mm													
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum/Year
1994	36,5	83,1	35,5	85,5	9,3	0,6	0,0	0,0	8,1	0,8	75,8	90,7	425,9
1995	38,7	37,8	46,6	9,7	13,5	31,5	0,0	0,0	0,6	28,3	0,0	32,8	239,5
1996	32,5	58,1	107,7	28,8	2,6	1,1	0,3	0,0	30,2	7,6	7,5	1,1	277,5
1997	68,9	37,1	43,0	68,2	87,5	24,5	0,0	0,0	0,0	0,5	46,7	40,8	417,2
1998	64,1	131,3	70,5	77,2	91,1	15,5	20,6	14,4	2,3	16,4	39,0	16,8	559,2
1999	39,3	77,1	84,0	53,4	25,7	1,6	8,1	0,0	3,6	20,1	91,5	9,0	413,4
2000	27,0	30,8	29,0	41,0	0,4	5,1	0,0	0,0	1,8	41,6	42,0	49,0	267,7
2001	16,0	29,7	26,1	16,9	0,4	0,0	1,1	0,2	0,0	48,0	30,4	53,7	222,5
2002	73,3	87,6	94,5	89,5	41,1	5,2	0,8	0,0	0,0	0,2	47,9	116,9	557,0
2003	14,2	44,6	96,6	92,2	37,8	37,2	0,3	0,2	0,0	1,3	60,7	60,9	446,0
2004	76,2	23,1	94,5	40,1	49,7	0,1	12,1	1,0	0,0	24,1	113,2	92,3	526,4
2005	43,0	44,4	62,5	33,9	115,9	14,3	0,0	0,0	0,0	7,4	61,3	18,0	400,7
2006	59,9	44,7	40,6	33,9	19,8	0,1	19,4	0,0	9,3	7,9	53,6	21,9	311,1
2007	16,2	38,1	100,8	69,1	44,4	0,7	0,0	0,0	0,0	3,9	28,9	64,2	366,3
2008	20,8	34,6	31,0	36,8	41,9	0,0	0,0	0,0	3,5	29,8	41,1	49,7	289,2
2009	24,2	43,5	82,7	148,7	33,9	57,8	0,0	0,0	5,5	1,1	35,2	85,9	518,5
2010	63,5	87,0	55,6	40,2	63,2	14,2	0,8	0,4	10,6	5,2	25,4	2,2	352,2
2011	8,6	85,9	45,1	22,6	11,7	9,4	0,0	0,5	15,9	47,5	139,4	34,2	420,8
2012	20,4	76,4	86,0	14,2	27,9	0,6	1,0	0,0	0,0	10,2	57,2	49,1	343,0
2013	29,5	17,9	126,1	102,2	3,8	5,1	0,0	9,6	0,1	9,9	28,1	50,8	383,1
2014	57,0	38,8	100,4	86,0	52,2	2,1	0,0	3,9	2,6	49,0	19,3	15,2	464,6
2015	76,1	84,5	52,0	7,0	14,0	0,1	0,0	3,2	1,7	83,7	61,7	11,2	395,2
2016	39,1	77,2	65,4	48,7	23,8	6,5	7,3	0,0	0,0	50,9	88,9	31,5	439,3
2017	46,5	132,8	87,6	67,0	13,8	0,5	1,0	0,0	21,6	7,6	19,6	35,3	433,3
2018	4,9	58,2	75,8	20,8	37,7	18,4	0,0	0,0	0,8	14,7	112,1	69,3	412,7

WIND SPEED, m/sec													
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	av/year*
1994	1,7	3,6	7,0	10,4	6,9	2,7	1,8	1,6	4,5	7,4	4,9	2,7	6,9
1995	1,6	3,6	7,8	9,8	7,3	2,9	1,7	1,7	4,3	7,3	5,4	3,3	7,0
1996	1,2	3,6	7,5	9,9	6,8	2,8	1,7	1,6	4,5	6,5	5,1	2,6	6,7
1997	2,0	3,6	8,0	9,9	6,7	2,7	1,4	1,3	4,1	7,1	5,3	3,3	6,9
1998	1,6	4,3	7,2	9,1	6,3	2,5	1,4	1,5	4,3	7,3	5,4	2,6	6,6
1999	1,6	3,4	7,6	9,9	6,5	2,6	1,5	1,4	4,4	7,0	5,6	3,3	6,8
2000	1,5	3,4	7,7	9,5	6,5	2,6	1,6	1,4	4,4	7,3	5,1	3,4	6,8
2001	1,6	4,6	7,7	9,5	6,3	2,3	1,1	1,5	4,4	6,9	5,3	3,4	6,7
2002	1,4	3,9	7,9	9,7	6,5	2,8	1,4	1,3	4,4	7,0	5,3	3,3	6,8
2003	1,6	4,2	7,7	9,7	6,8	2,6	1,4	1,3	4,2	7,2	4,5	3,3	6,7
2004	1,4	3,9	7,7	10,2	7,7	2,6	1,3	1,5	4,3	7,2	5,4	3,4	7,1
2005	1,7	3,4	7,6	9,6	6,5	1,5	1,5	1,5	4,1	7,1	5,2	3,2	6,7
2006	1,3	3,6	7,5	9,5	6,5	2,4	1,6	1,3	4,3	7,3	5,4	3,1	6,8
2007	1,3	3,5	7,4	9,6	6,5	2,5	1,5	1,4	4,1	7,0	5,3	3,4	6,7
2008	1,0	3,5	7,5	9,9	6,5	1,5	1,3	1,3	4,1	7,4	4,8	2,9	6,7
2009	1,3	3,8	7,6	9,6	6,5	2,6	1,3	1,3	4,1	7,4	5,6	3,2	6,8
2010	1,5	4,5	8,0	10,5	7,0	2,7	1,7	1,3	4,2	7,4	5,0	3,2	7,0
2011	1,2	3,8	7,6	9,7	6,7	2,7	1,5	1,4	4,3	7,2	5,6	2,6	6,9
2012	1,5	3,6	8,1	9,8	7,1	1,7	1,5	1,4	4,6	7,1	5,5	3,3	7,0
2013	1,9	4,3	7,6	9,5	6,5	2,6	1,5	1,2	4,0	7,1	4,9	3,4	6,6
2014	1,3	3,2	7,5	9,8	6,6	2,5	1,4	1,2	4,3	7,1	5,1	2,2	6,7
2015	1,3	3,3	7,4	9,9	6,7	2,7	1,4	1,3	4,3	7,3	5,0	3,0	6,8
2016	1,4	3,6	7,9	9,2	7,1	2,2	1,6	1,2	4,4	7,6	4,8	2,7	6,8
2017	1,3	3,3	7,6	9,9	6,5	2,5	1,7	1,6	4,5	7,4	5,1	3,0	6,8
2018	1,2	4,0	7,3	9,6	6,7	1,9	1,3	1,5	4,4	7,2	5,3	3,1	6,8
			FIRST WINDY SEASON						SECOND WINDY SEASON				

Av/year* = calculated based on the average wind speed in two windy seasons

Sirdarya meteo-station

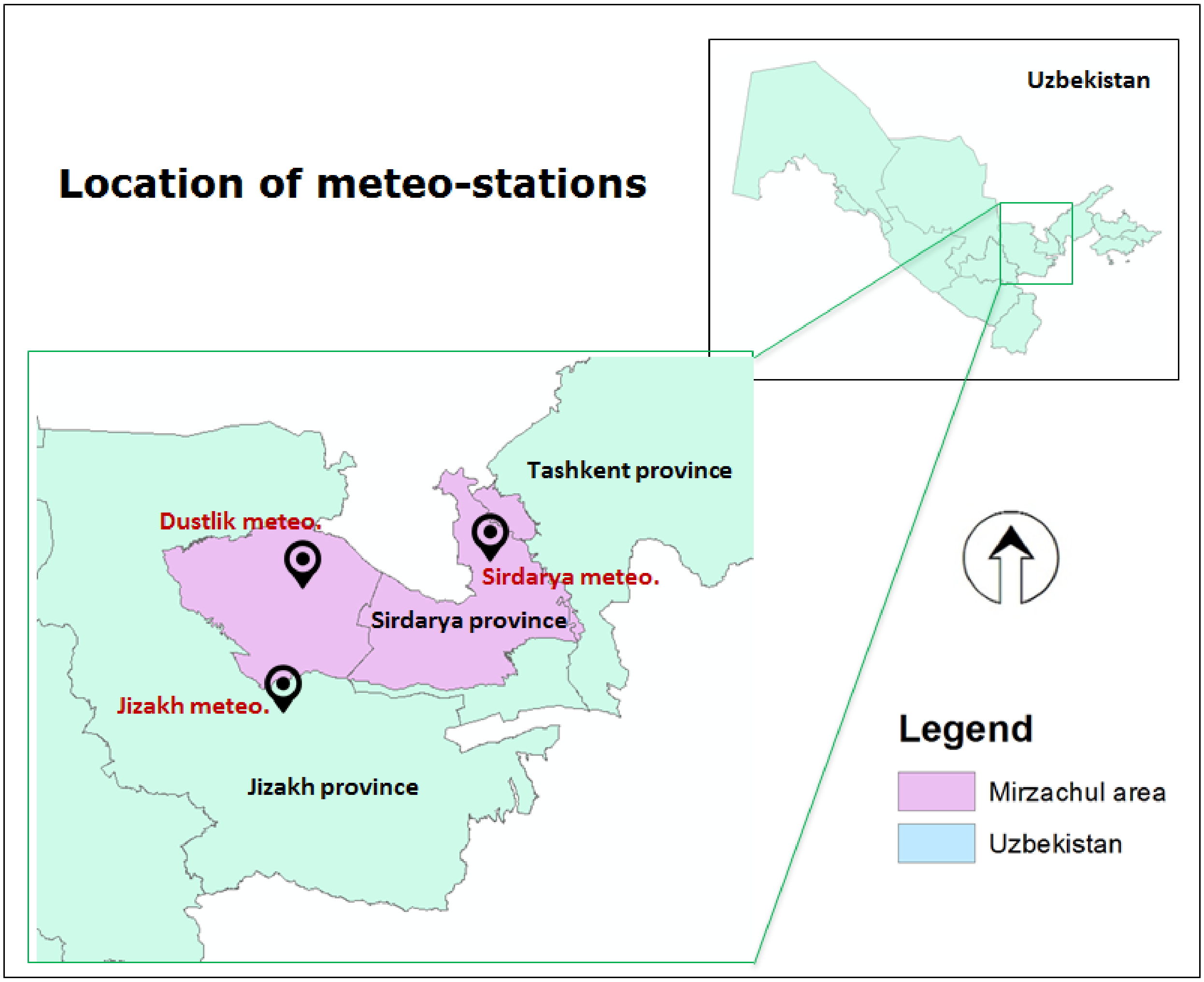
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Av/Year
						TEMPERATURE, Celsius							
1994	-0,4	-1,7	9,5	13,2	21,7	27,6	27,2	25,5	17,0	13,6	10,6	2,0	13,8
1995	-0,4	3,8	8,4	15,8	21,2	26,6	28,2	25,5	19,7	12,3	8,9	0,0	14,2
1996	-1,4	-3,1	5,3	13,9	20,5	26,0	27,3	24,2	20,2	12,6	4,4	3,3	12,7
1997	2,0	1,2	9,3	17,1	20,6	27,4	26,2	24,9	20,1	26,8	4,3	1,4	15,1
1998	-0,2	-0,3	7,2	16,7	19,6	24,8	28,5	26,4	20,7	12,8	7,5	3,8	13,9
1999	1,1	7,4	7,3	14,0	21,6	25,5	27,1	27,2	20,7	15,1	6,1	2,0	14,6
2000	1,8	2,6	9,0	10,8	22,8	26,1	28,0	26,4	20,3	11,2	5,7	3,4	14,0
2001	-1,2	4,1	10,7	17,1	25,0	27,8	26,8	25,2	18,9	12,4	8,5	2,5	14,8
2002	2,9	5,2	10,9	14,6	19,7	25,3	27,1	26,4	20,3	15,7	8,5	-4,2	14,4
2003	3,2	4,8	8,5	13,4	19,3	25,2	27,6	25,7	20,5	15,3	7,7	1,0	14,3
2004	4,0	7,3	9,8	14,8	22,4	26,9	27,2	25,9	21,0	12,5	10,9	2,9	15,5
2005	1,6	-1,0	12,2	16,0	21,0	27,9	28,5	25,6	21,8	14,4	7,3	2,8	14,8
2006	-3,0	5,8	11,3	17,1	23,8	27,1	27,1	25,7	19,7	16,9	9,0	-1,1	14,9
2007	0,4	5,3	8,7	18,3	21,6	27,5	28,4	25,9	20,4	11,4	8,4	1,7	14,8
2008	-10,2	-2,1	14,4	17,3	23,8	28,2	28,9	26,9	20,0	14,5	6,9	2,4	14,2
2009	1,5	6,7	11,1	13,4	21,2	25,2	28,0	25,8	21,0	14,4	7,1	3,7	14,9
2010	3,9	2,6	11,3	17,4	21,7	26,9	27,8	27,0	20,8	16,5	7,8	1,3	15,4
2011	0,1	2,6	9,1	17,8	24,0	27,7	28,2	26,9	21,1	15,0	5,2	1,2	14,9
2012	-1,0	-1,9	7,6	19,9	22,9	27,5	28,3	27,0	20,3	10,1	6,2	-1,8	13,8
2013	2,3	4,8	11,5	13,5	22,0	27,1	28,5	26,2	22,3	14,1	7,6	2,5	15,2
2014	1,2	-4,6	9,1	14,2	23,3	27,6	26,9	26,3	20,6	12,8	5,1	1,6	13,7
2015	1,7	6,2	8,1	17,7	23,3	28,0	29,1	25,6	20,1	14,1	7,4	4,4	15,5
2016	4,6	6,4	13,0	16,4	23,0	27,5	28,7	27,0	23,3	11,3	4,5	3,9	15,8
2017	2,4	5,1	10,7	17,2	22,3	27,6	27,9	25,1	20,4	13,3	6,1	-1,4	14,7
2018	0,9	2,8	7,6	12,4	21,2	26,7	27,3	24,9	19,7	12,5	4,8	1,1	13,5

PRECIPITATION, mm													
Year	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Sum/Year
1994	42,2	51,2	26,4	52,3	42,3	10,0	0,0	0,0	23,6	1,6	37,3	62,5	349,4
1995	33,9	26,7	42,6	10,2	19,6	1,6	0,0	0,0	0,0	10,0	3,0	27,5	175,1
1996	13,4	68,1	61,5	53,3	2,7	7,8	0,0	0,0	22,0	5,2	9,6	7,7	251,3
1997	56,1	33,2	30,6	42,1	74,5	10,3	0,0	0,0	0,0	0,1	32,7	36,9	316,5
1998	88,9	92,2	61,7	69,3	50,1	2,6	12,8	1,2	7,4	12,1	20,9	30,3	449,5
1999	50,6	70,7	47,0	24,1	27,9	5,5	9,0	0,3	8,8	7,7	67,1	6,9	325,6
2000	30,8	16,6	25,5	17,2	4,0	2,8	0,0	0,0	2,0	49,0	39,2	50,4	237,5
2001	17,6	39,1	44,4	28,0	1,7	0,0	2,6	10,3	0,0	52,8	25,5	61,5	283,5
2002	41,7	73,9	58,1	78,3	54	15,4	0,0	0,0	0,0	0,0	5,1	97,9	424,4
2003	19,8	63,5	80,2	80,5	32,8	31,3	0,0	0,0	0,0	4,8	90,8	44,9	448,6
2004	68,8	25,5	90,9	31,6	21,8	0,1	18,9	1,3	0,0	12,9	73,8	83,5	429,1
2005	47,3	48,9	53,2	28,9	25,3	0,5	0,0	0,0	0,0	7,8	38,3	25,1	275,3
2006	64,2	23,3	51,1	33,8	1,6	0,5	5,2	0,0	2,9	23,4	42,4	43,5	291,9
2007	30,9	49,6	70,1	64,9	39,2	0,8	1,7	1,5	0,0	2,0	13,4	72,4	346,5
2008	32,1	48,6	16,8	30,5	33,4	0,0	2,7	0,0	17,0	19,1	33,3	37,8	271,3
2009	25,1	64,4	76,3	78,5	31,8	10,5	0,3	2,2	6,0	0,8	9,1	62,0	367,0
2010	45,9	104,4	27,2	86,2	55,9	22,7	1,7	1,3	4,6	4,9	17,9	8,3	381,0
2011	15,9	52,5	45,5	18,5	8,3	11,0	0,0	0,0	2,0	24,9	142,5	24,8	345,9
2012	24,5	96,3	69,5	16,6	21,8	0,0	0,0	0,0	0,0	9,1	40,8	44,6	323,2
2013	31,8	30,0	110,5	52,7	6,4	3,8	2,0	0,4	11,7	21,9	54,7	68,8	394,7
2014	26,6	81,1	50,0	14,5	4,2	0,0	0,0	4,5	0,0	33,0	52,2	21,6	287,7
2015	58,1	95,7	49,8	14,1	27,1	9,3	0,0	2,3	0,1	71,3	43,8	18,2	389,8
2016	57,1	1,3	67,1	33,6	36,4	15,2	6,4	0,0	2,9	30,7	20,9	62,0	333,6
2017	49,2	76,9	81,2	22,4	20,6	10,5	0,0	0,0	3,7	9,4	53,1	48,7	375,7
2018	29,4	34,2	97,6	50,4	33,6	2,3	0,0	0,0	0,0	18,1	28,5	69,8	363,9

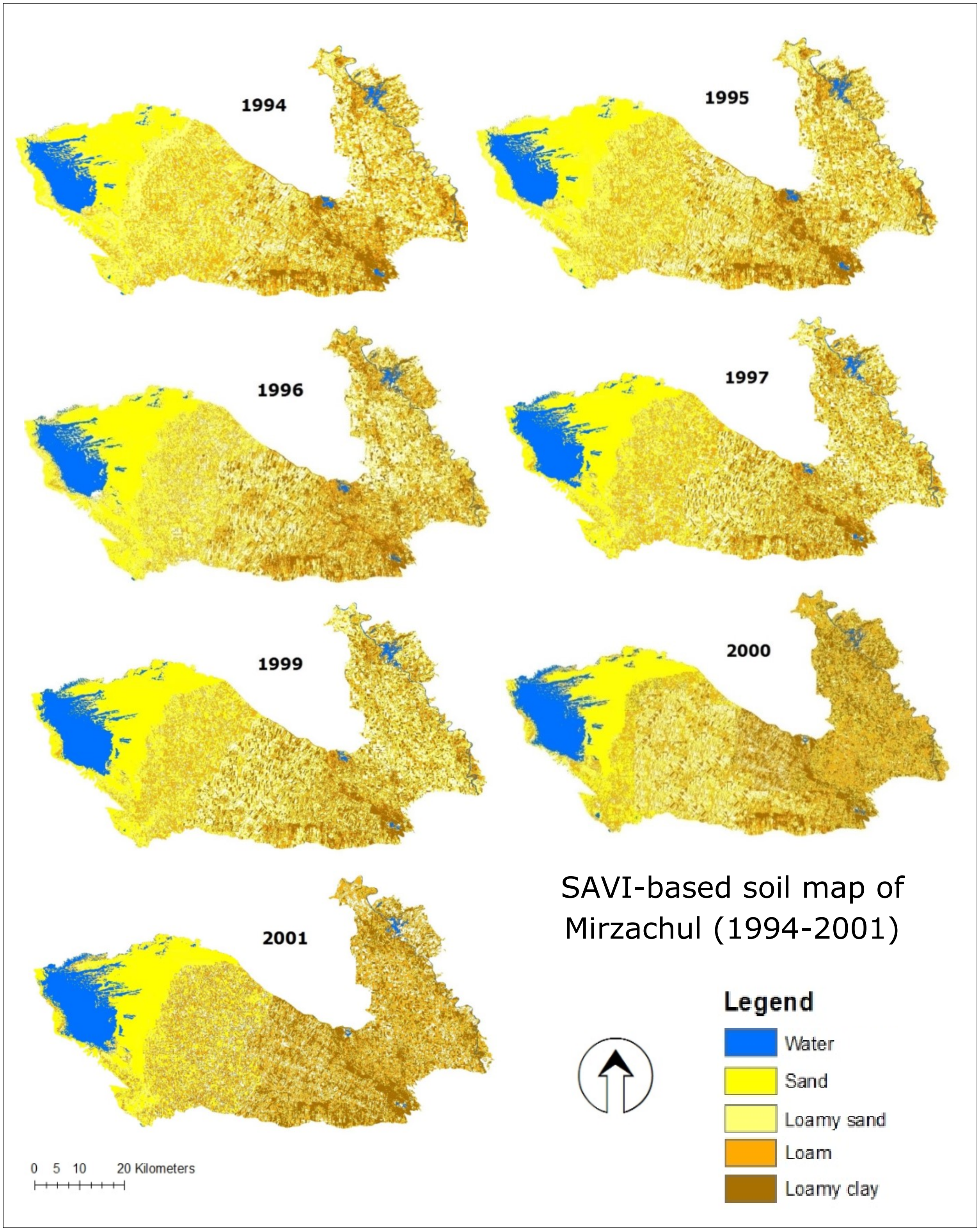
WIND SPEED, m/sec													
Year	**Jan**	**Feb**	**March**	**April**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Av/Year***
1994	1,2	1,6	3,5	5,6	4,4	2,4	1,5	1,4	3,2	5,1	2,6	1,4	**2,8**
1995	1,2	2,3	2,6	6,4	3,6	1,5	1,5	1,4	3,3	5,0	3,2	1,4	**2,8**
1996	1,3	1,6	3,3	5,7	3,5	1,5	1,4	1,4	3,2	5,1	2,6	1,1	**2,6**
1997	1,5	1,5	2,6	5,6	3,5	1,7	1,4	1,4	3,2	5,0	3,1	1,1	**2,6**
1998	1,1	2,4	3,4	6,5	3,6	1,5	1,3	1,3	2,3	5,0	3,2	1,3	**2,7**
1999	1,2	1,5	2,8	5,7	3,6	2,4	1,4	1,3	3,1	5,0	3,4	0,9	**2,7**
2000	1,4	2,3	2,7	5,5	3,5	2,4	1,3	1,3	3,2	4,8	2,9	1,2	**2,7**
2001	1,1	2,2	3,3	6,3	4,2	2,2	1,4	1,1	3,3	5,3	3,3	1,5	**2,9**
2002	1,5	1,9	3,0	6,6	3,6	1,7	1,4	1,6	3,3	5,3	3,2	1,3	**2,9**
2003	1,6	2,0	2,7	6,6	3,6	1,5	1,5	1,5	2,4	5,3	3,4	1,4	**2,8**
2004	1,5	1,9	2,8	5,9	3,6	2,6	1,6	1,6	3,3	5,3	2,5	1,3	**2,8**
2005	1,6	2,5	2,7	5,7	3,6	1,8	1,6	1,5	3,3	5,3	3,2	1,4	**2,9**
2006	1,6	1,8	2,7	5,6	3,6	1,6	1,9	1,6	2,5	5,4	2,5	1,2	**2,7**
2007	1,2	1,9	2,8	5,9	3,5	1,9	1,7	1,5	3,5	5,2	3,5	1,5	**2,8**
2008	1,0	1,5	2,8	5,8	3,7	1,9	1,6	1,7	2,5	5,2	3,2	1,1	**2,7**
2009	1,3	1,6	2,7	5,7	3,5	1,7	1,4	1,5	2,4	5,2	3,4	1,4	**2,7**
2010	1,5	1,6	3,0	5,6	3,6	1,7	1,7	1,4	3,4	4,6	3,0	1,2	**2,7**
2011	1,1	1,6	3,4	5,5	4,2	2,2	1,0	1,0	3,0	5,2	3,2	1,2	**2,7**
2012	1,2	2,4	2,5	6,2	4,3	2,0	0,9	1,0	3,0	4,4	3,1	1,1	**2,7**
2013	1,3	2,3	3,4	6,2	4,0	2,2	1,4	1,4	3,3	5,3	3,2	1,5	**3,0**
2014	1,4	2,4	2,6	5,8	4,5	1,5	1,7	1,5	2,5	5,4	3,3	1,2	**2,8**
2015	1,7	1,6	2,7	5,8	3,7	1,7	1,7	1,4	2,4	5,3	2,6	1,7	**2,7**
2016	1,5	2,4	3,5	5,6	3,6	1,5	1,6	1,5	3,3	5,5	3,5	1,7	**2,9**
2017	1,4	1,9	3,3	6,1	4,4	2,1	1,4	1,5	2,6	4,9	3,3	1,6	**2,9**
2018	1,5	2,1	3,5	5,9	4,8	1,9	1,4	1,4	3,2	5,6	3,5	1,7	**3,1**
			FIRST WINDY SEASON						**SECOND WINDY SEASON**				

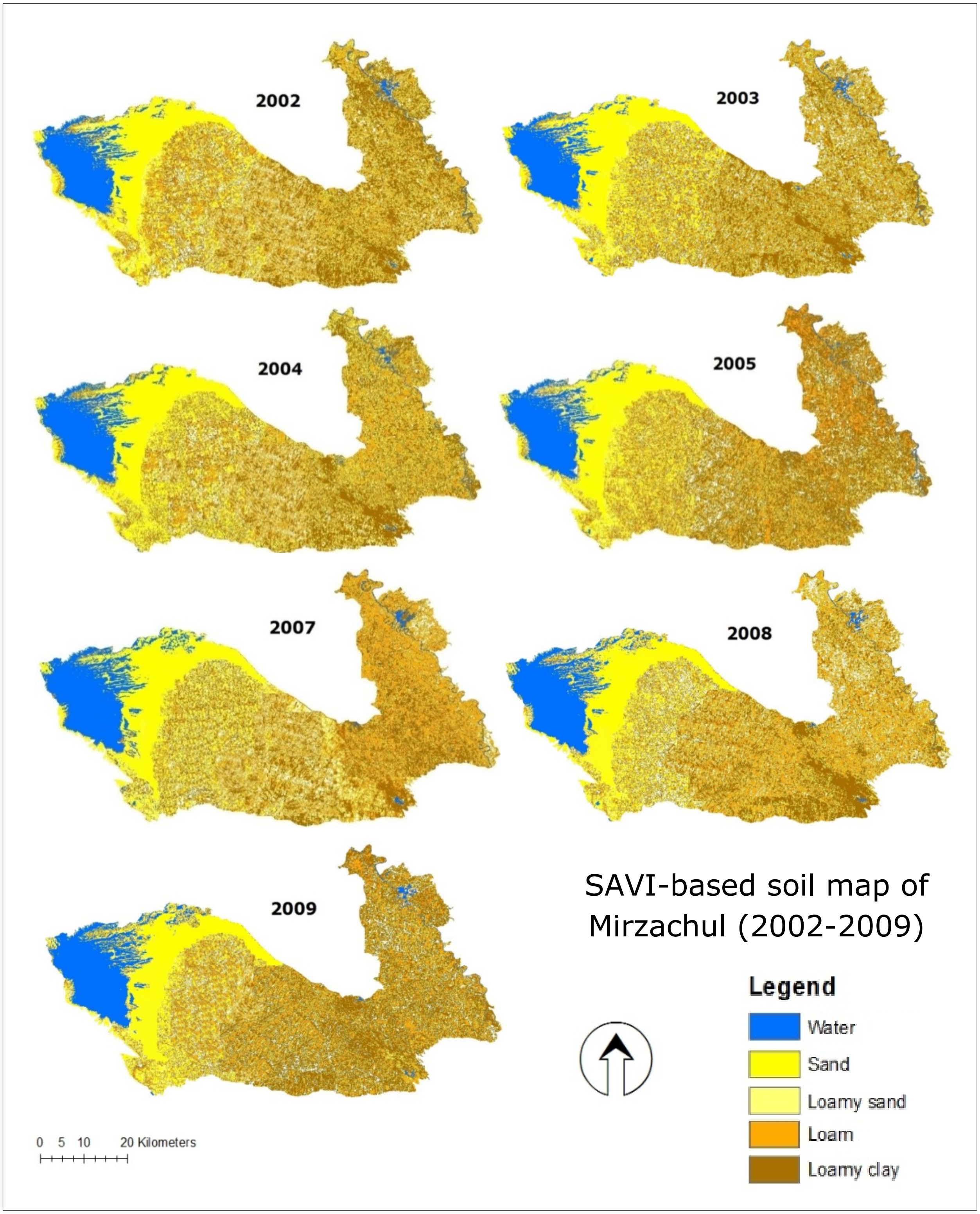
Av/year* = calculated based on the average wind speed in two windy seasons

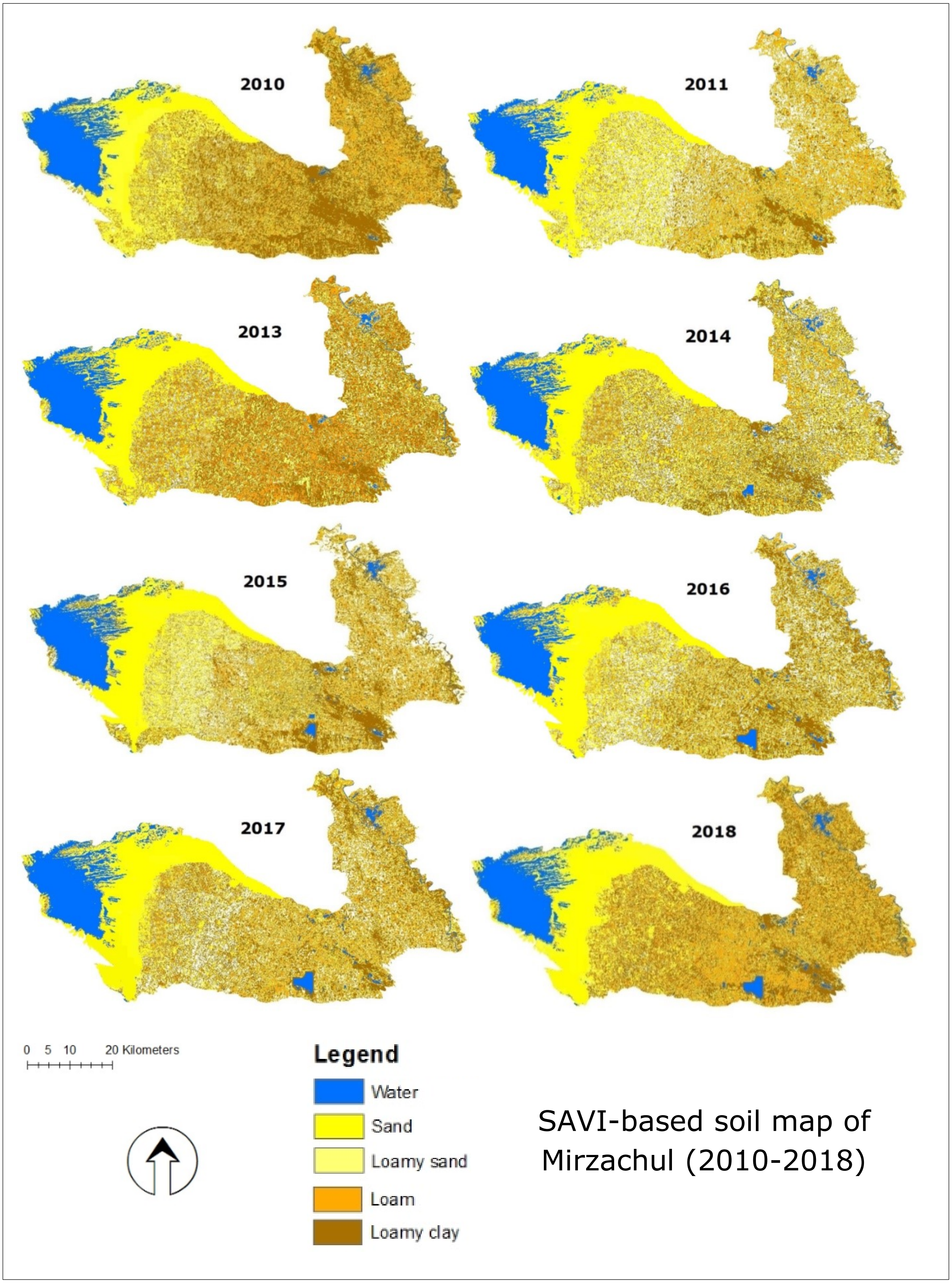
Annex 3. Location of meteo-stations in Mirzachul



Annex 4. All SAVI-based soil type maps of Mirzachul over the period




2002
2003
2004
2005
2007
2008
2009
SAVI-based soil map of Mirzachul (2002-2009)
Legend
Water
Sand
Loamy sand
Loam
Loamy clay
0 5 10 20 Kilometers



SAVI-based soil map of Mirzachul (2010-2018)

Annex 5. Item list for expert interviews

Goal: To understand the perception of specialists who work at Uzgeocadaster on the choice of the GIUs in soil salinity assessment method

Target group: At least two specialists, each is working in the departments of ‘Remote Sensing, Geodesy and Cartography’ and ‘Monitoring of Land and Soil Fertility’ in Uzgeocadaster.

Instructions: Maximum 30 minutes should be spent for interview. Keep asking the relevant questions, if necessary ask additional short questions to support the idea. Key words are to guide the conversation. Interviewees will be kept anonymous based on their permission.

Opening	**1. Explain why the interviewee is selected and what will be done with the answers of the interview.** **2. Ask for their permission to record** **3. Explain the main goal and specific objectives of the thesis report.** **4. Explain the structure/lay-out of the interview and maybe indicate how much time it will take.** **5. Confidential disclosure agreement**

Topics	**Concepts**	**Aspects**
In-situ soil salinity assessment	Comparison	Validity Costs Time Monitoring interval and scale
	Issues or threats	Finance Knowledge Others
GIS-based soil salinity assessment	Role	In agriculture Soil salinity assessment
	Comparison	Validity Costs Time Monitoring interval and scale
	Issues or threats	Finance Knowledge Others
Ending	Thank them for participating	

List and date of interviews:

Representative of Uzgeocadaster, July 18, 2019

Representative of Uzgeocadaster, July 31, 2019

Recordings are included.

Annex 6. Salt-affected areas in Mirzachul

Jizakh province

Year	Name of districts	Salt affected and bare soil areas based on NDVI values (ha)				
		Bare soil	No salinity	Low salinity	Moderate salinity	High salinity
1994	Arnasay	24437.2	-	3093.8	12109.5	9580.5
	Zafarabad	23523.7	-	2828.3	8284.5	5550.7
	Mirzachul	24414.3	123.7	3582.1	12476.8	7953.4
	Dustlik	14805.4	-	5685.2	15828.6	8727.8
	Pakhtakor	6414.8	9.4	3073.3	9389.4	4376.9
1999	Arnasay	20425.4	720.1	3822.8	15801.2	8451.6
	Zafarabad	21019.2	549.1	2976.4	9949.8	5692.7
	Mirzachul	21543.7	751.5	3876.8	15027.5	7575.1
	Dustlik	14843.2	1032.9	5269.5	16074.7	7827.4
	Pakhtakor	5676.4	679.5	3498.1	9479.8	3928.5
2005	Arnasay	22972.5	510.7	4383.4	11146.5	10208.9
	Zafarabad	19206.1	1118.3	4554.8	8034.6	7274.2
	Mirzachul	29318.4	448.1	4594.5	7098.2	7042.8
	Dustlik	14818.2	1712.5	7258.9	11479.2	9778.1
	Pakhtakor	4916.9	1282.5	3740.8	8177.4	4740.7
2010	Arnasay	22059.2	1050.8	5059.1	11343.5	9617.2
	Zafarabad	20040.7	1246.4	4661.3	7925.2	6313.9
	Mirzachul	33655.1	766.2	3283.6	5756.8	5589.5
	Dustlik	14609.2	3542.9	6740.4	9161.7	10993.1
	Pakhtakor	6630.5	2002.7	4572.1	6203.9	3854.3
2014	Arnasay	24592.3	1557.7	4699.5	9340.1	9091.8
	Zafarabad	22945.8	1710.1	5724.9	6377.0	4429.5
	Mirzachul	35204.4	1287.5	3299.7	4571.4	4187.7
	Dustlik	14742.1	5518.2	8287.2	8934.7	7564.2
	Pakhtakor	5361.6	3271.8	5988.4	5464.3	4177.4

Sirdarya province

Year	Name of districts	Salt affected and bare soil areas based on NDVI values (ha)				
		Bare soil	No salinity	Low salinity	Moderate salinity	High salinity
1994	Sardoba	18843.7	6.8	2351.2	12087.1	9522.4
	Ak-altin	19568.2	11.3	6270.9	16222.5	10757.6
	Mirzaabad	42855.7	-	1278.1	9317.3	11495.8
	Gulistan	13160.1	76.5	2036.4	10966.5	8167.2
	Sayhunabad	17757.3	2.3	4072.5	13358.4	9477.6
	Sirdarya	21762.8	1316.2	6930.3	16346.9	7371.4
1999	Sardoba	15903.4	195.7	4011.2	12006.1	10694.2
	Ak-altin	19926.8	459.1	6012.7	14728.5	11704.5
	Mirzaabad	33567.3	101.2	2623.5	12996.3	15567.9
	Gulistan	9182.4	360.1	5580.6	12051.9	7233.5
	Sayhunabad	11897.9	1242.6	8381.2	14010.7	9292.5
	Sirdarya	15885.0	2561.2	12611.5	15391.2	7273.3
2005	Sardoba	16071.2	192.3	3597.7	15889.4	7150.4
	Ak-altin	16872.2	523.7	8090.8	19781.1	7461.5
	Mirzaabad	28397.1	87.8	4063.5	22781.6	9667.3
	Gulistan	10608.5	519.8	5834.2	13344.5	4099.1
	Sayhunabad	13351.5	2188.4	8514.9	15472.3	5141.1
	Sirdarya	17016.6	3356.9	13866.4	14273.1	5212.5
2010	Sardoba	16026.2	609.7	5052.4	14819.8	6302.6
	Ak-altin	18397.3	1729.4	7988.5	17325.8	7389.5
	Mirzaabad	30811.2	618.4	5156.6	17716.9	10642.5
	Gulistan	9850.1	995.8	5215.1	12469.0	5876.7
	Sayhunabad	13036.7	3239.3	9110.2	14407.5	4873.4
	Sirdarya	13288.9	6079.7	11299.3	16538.4	5519.2
2014	Sardoba	17824.4	635.2	5092.9	13231.6	6026.9
	Ak-altin	20464.5	2638.1	9205.7	13132.1	7390.1
	Mirzaabad	33840.8	1075.5	6081.8	13773.7	10375.0
	Gulistan	10408.6	1764.6	7153.0	8520.2	6560.3
	Sayhunabad	13790.4	3444.7	10053.1	12384.5	4994.8
	Sirdarya	16076.2	6807.2	11847.5	13391.9	5602.7

Annex 7. Correlation between average NDVI and SQI values per district

Jizakh province

Year	Arnasay		Zafarabad		Mirzachul		Dustlik		Pakhtakor	
	Average NDVI	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*
1994	0.447	42.0	0.506	48.0	0.454	42.8	0.509	49.3	0.514	50.1
1999	0.461	44.0	0.527	50.0	0.458	45.0	0.513	51.0	0.526	52.7
2005	0.424	43.5	0.512	50.4	0.471	45.5	0.534	52.0	0.521	52.0
2010	0.459	45.2	0.554	52.0	0.483	46.5	0.552	53.6	0.568	55.3
2014	0.455	45.0	0.580	53.1	0.489	47.0	0.539	54.2	0.593	57.6
Correlation	0.444		0.924		0.919		0.898		0.978	

Sirdarya province

Year	Sardoba		Ak-altin		Mirzaabad		Gulistan		Sayhunabad		Sirdarya	
	Average NDVI	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*	*Average NDVI*	*SQI values*
1994	0.416	44.0	0.493	51.0	0.383	42.0	0.502	51.0	0.453	47.0	0.505	51.0
1999	0.422	45.0	0.514	53.0	0.395	43.0	0.485	50.0	0.498	51.0	0.539	52.0
2005	0.443	48.0	0.542	55.5	0.421	46.0	0.526	53.0	0.527	54.0	0.566	54.0
2010	0.458	49.0	0.545	54.0	0.418	46.0	0.521	51.0	0.544	57.0	0.612	58.0
2014	0.452	49.0	0.571	56.0	0.433	47.0	0.559	54.0	0.542	56.0	0.617	61.0
Correlation	0.988		0.942		0.994		0.927		0.992		0.953	