Land Suitability Assessment for Cotton Cultivation - A Case Study of Kumkurgan District, Uzbekistan

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Abstract
Optimal land allocation for cotton cultivation requires more expert knowledge since we face increasing land degradation and climate change impact in Uzbekistan over the last years. In addition, because of not taking into account important agro-ecological conditions, crop requirements and crop rotation systems, land productivity is declining year by year. But, how can decision making on land allocation for cotton cultivation be supported? Here, a land suitability assessment models which allow to integrate and weight different spatial data (i.e., criteria) in a Geographic Information System (GIS) can be considered a promising tool. In this research, a land suitability assessment model was implemented on one of the arid areas of Uzbekistan (Kumkurgan district of Surkhandarya region) to identify and classify the suitability of lands for cotton cultivation. In terms of classifying land suitability for cotton cultivation, the Suitability Modeler functionality of ArcGIS Pro 2.7 was utilized. Overall, nine input variables related to important criteria of cotton cultivation such as soil texture, soil salinity, irrigation and collector-drainage networks, groundwater level/ mineralization, slope, current land use and temperature were used for a complex analysis of the area. After combining the data, the result was classified into five suitability classes based on the FAO land suitability classification method. The result delivered show that for Kumkurgan district the following: highly suitable (1.8% of the area; 36.2 km^2), moderately suitable (11.5% of the area; 230.5 km^2), marginally suitable (7.25% of the area; 145.0 km^2), currently not suitable (24.3% of the area; 485.8 km^2) and permanently not suitable (55.09% 55.09% of the area; 1101.1 km^2. Irrigated agricultural land parcel data with vector/shapefile which includes five years of cropping sequences were used for crop rotation system of 2:1 (cotton: wheat/other) to identify exact land parcels for a cotton seeding in the season of 2020-2021 and validating the results. As a result, about 78.5 km^2 of the agricultural area was assessed as very suitable for cotton for the 2020-2021 season. Validation revealed an accuracy of the model at 78% with the current state of cotton fields.

1. Introduction

Cotton is one of the most important agricultural products for Uzbekistan. Nearly 40-50 percent of the overall value of agricultural production refers to cotton. Thus, it is the republic's main source of employment (Djanibekov et al., 2010). According to USDA (United States Department of Agriculture), Uzbekistan is staying among the top 10 cotton producer countries of the world and annually, cotton is planted on 8500-9000 km^2 of irrigated area (Cotton: World Markets and Trade, 2021). However, optimal land allocation for cotton cultivation requires more expert knowledge. This is particularly true as we see an increase of land degradation in Uzbekistan (Azimboyev, 2006). Usually, it is very challenging taking into account all agro-ecological conditions as well as crop requirements and crop rotation systems in terms of optimal allocating and placing crops (Avezbaev, 2006). This challenge that cannot always be met results in n reduction of soil fertility of the valuable lands and the harvest yield year by year (Conrad, 2016, Khaitov et al., 2014 and Wojtaszek et al., 2021). Application of spatial evaluation techniques including remote sensing (RS) and geo-information system (GIS) for land suitability assessment can an promising mean for crop placement management on irrigated agricultural lands in Uzbekistan (Halder, 2013 and Mamatkulov et al., 2021).

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Land suitability assessment is generally explained as evaluation of land performance in specified goal which should involve surveys and studies on soil, climate, topography, vegetation and other parameters of land in order to identify and classify applicability in use (FAO, 1976 and Steiner, 1987). It is an important fragment of the productivity model of lands taking into account agro-ecological parameters for special crop types based on their performance and consequently options (FAO, 1993 and Sathish et al., 2010).

The land suitability is a term that can be defined by the fitness of a particular land parcel for a specific purpose in a region (Kassam et al., 2012 and Rao et al., 1996). Land suitability could be expressed as the ability of specific land parcels to tolerate the production of crops in GIS environment (Yohannes et al., 2018 and Bandyopadhyay et al., 2009). The land suitability evaluation is used to define which types of soil can be more suitable or unsuitable for specific crops (Abdelrahman et al., 2016 and Sys et al., 1991).

2. Background

2.1 Study Object: Land Allocation for Cotton According to its Requirements

So far in Uzbekistan, the land allocation for cotton cultivation have been carried out based on the soil bonitation which assesses soil fertility of the field. Soil bonitation is a comparative assessment of soil quality and natural fertility capacity at a moderate level of agricultural techniques. In terms of cotton, a placement value of more than 40 soil quality bonitation of 100 is accepted in Uzbekistan (Resolution of the Cabinet of Ministers of the Republic of Uzbekistan, 2012). Soil bonitation is calculated taking into account the texture of soil, its humus content, the amount of nitrogen, phosphorus and potassium in the soil, as well as the degree of salinity etc., which are main agro-ecologic and agrochemical soil properties. While cultivating cotton, it is taken into account that soil bonitation must represent more than 80 percent of the yield (Kuziev et al., 2003). Generally, soil bonitation are conducted by regions every 5 years on the basis of a state project, and the fertility values of lands are determined and soil maps are created. In Surkhandarya region, the last soil quality assessment was carried out in 2013 (Report of SRISSA, 2013). Since there are no more current data, all crops including cotton and wheat are still being cultivated according to the 2013 assessment. Naturally, there is a significant change in soil fertility after the harvest, which is constantly taken from the crop fields over the years. As with other crops, cotton requires special agro-ecological conditions for further development. The following conditions are required for cotton cultivation:

2.1.1 Soil

Cotton is a very sensitive crop that requires high productive soils. Generally, to seed and develop cotton loamy and silt, soils with high calcium carbonate are best for cotton cultivation. Fertile soil with high water retention capacity is ideal for cotton. Cotton does not develop well in sandy soils as well as heavy clay soils as this shows problems with the germination of seedlings (Shaykhov, 1990). High levels of salinity and drought of soils are extremely not applicable for cotton cultivation (Clark et al., 2013).

2.1.2 Groundwater

Groundwater level and mineralization are counted as very sensitive agro-ecological parameters for cotton development. In vegetation period, the root of cotton goes down about 1.5-3 meters. Cotton has no tolerance to the high groundwater table and mineralization (Beisenboyev et al., 1993). Both of them are very detrimental to the root system of cotton. If the groundwater level is close to the surface, oxygen transport regime changes and the root system are damaged. Groundwater mineralization (salinity) has a negative effect on the further development of cotton and leads to poor yield (Matyakubov et al., 2020).

2.1.3 Irrigation/drainage network data

The cotton plant performs best in easy watering areas with reasonable drainage system (Khamidov et al., 2019). Depending on soil, climate and length of the overall vegetation period, cotton needs about 700 to 1.300 mm precipitation to meet its water requirements. In the early vegetative period, cotton's water requirements are low, or about 8-10 percent of total. They are high during the flowering period when leaf area is at its maximum, or some 50 to 60 percent of total. Later in the growing period the requirements decline. Water supplying on time gives high harvest. However, if during the vegetation period the groundwater level increases - due to the maximum irrigation - drainage networks help to supply favourable nutrient, moisture, heat, balanced groundwater and air regimes for crops at the same time (Baraev et al., 2010). As cotton is very susceptible to waterlogged conditions, soils with poor drainage should be avoided.

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2.1.4 Topography (slope)

For cotton flat or slight slope areas with 0-3^0 are considered the best choice. If the slope is more than 3^0, erosion risk increases. In sloping terrain where the high-fertile layer of soil can be washed away, there is a lack of nutrients and moisture for crop growth. On such soils, the yield is reduced as a result of the shedding of flowers and stalks of cotton (Makhsudov et al., 2012). Although cotton will be opened early, quality of cotton will be poor.

2.1.5 Crop rotation

Crop rotation is one of the most basic factors for maintaining soil health and increasing its productivity. Several studies show that use of organic and menial fertilizers, creates favourable ecological conditions for sustainable growth, development and qualitative crop yields (Traore et al., 2007, Aziz et al., 2011 and Ouda et al., 2018). Permanent crop cultivation decreases soil fertility. Such negative situations lead to serious damage to the harvest of the main and accompanying crops (Kollas et al., 2015). Before planting crops in a specific area, there should be taken into account biological, physical and other botanical properties of former crops for 4-5 years. Crops should be rationally and correctly dislocated.

2.1.6 Climate

Cotton is also heat demanding as it originates from the hot tropics. The normal (optimal) temperature for normal growth and development of seed germination is 25-35^{0}C. When the temperature drops to 17^{0}C, development slow down. Depending on the type and family of the cotton, the sum of useful temperature reaches 1600-2000^{0}C (Shaykhov et al., 1990).

2.2 Study Area

The Kumkurgan district of the Surkhandarya region (Uzbekistan) is selected as a study area. This district is located in the central part of Surkhandarya province, between 37.8167°N and 67.5833°E coordinates. It is bordering partly the Republic of Tajikistan (Figure 1). The total agricultural area in the district is 1601.54 km^2, including 228.59 km^2 of irrigated land. Irrigated land takes only 14.27% of the total land area. Because 64% of the lands of Kumkurgan district are occupied by mountains, hills, built-up areas and pastures which are mainly used for agriculture and livestock breeding (National Report of Committee of Uzstat, 2019). Detailed information about the land distribution of Kumkurgan region is given in Table 1. The primary income of the district's economy is directly related to agricultural production.

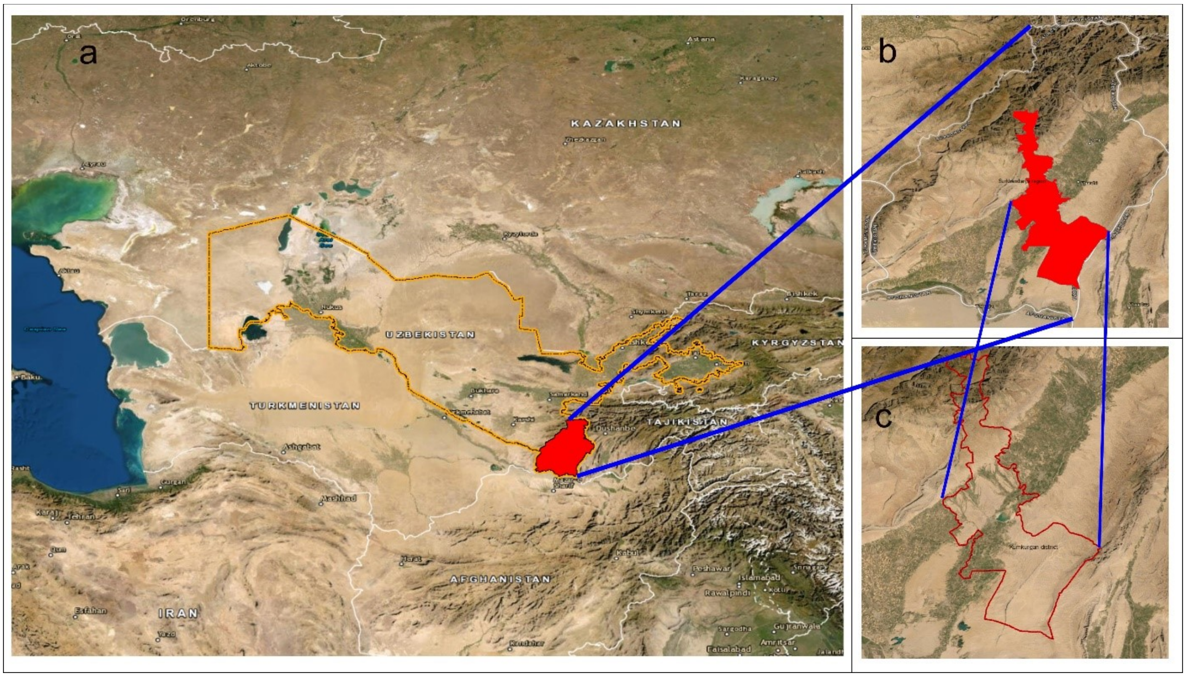

Figure 1: Study area: (a) location of Uzbekistan; (b) location of Surkhandarya region; (c) research conducted area (Kumkurgan district)

Table 1: Land fund categories of Kumkurgan district for 2021 year

Land fund categories, 2021 year	**Total land area, km^2**	**As a percentage of the total area of the district**
Agricultural lands	1.604.54	75.06
Lands of settlements	6.75	0.32
Lands for industry, transportation, communications defence and lands for other purposes	14.51	0.68
Lands for nature protection, healthcare and recreational purposes	-	-
Lands for historical and cultural heritage	-	-
Lands of the forest fund	62.44	2.92
Lands of water fund	80.09	3.75
Lands of reserve	369.19	17.27
Total lands:	2137.52	100

The main part of agricultural irrigated lands is used for cotton and wheat cultivation. Non-irrigated agricultural land is used for livestock and horticulture. The agro-ecological condition of the existing irrigated agricultural lands in the district is varying. In particular, the territory of Kumkurgan district has a great potential for cotton cultivation. At the same time, it provides seasonal employment for the rural population. The district annually uses an average of 70-80 km^2 for cotton cultivation. However, this depends on the state order (Committee of Uzstat, 2019). Surkhandarya region is also the hottest region in the south of Uzbekistan with sum of 235-240 sunny days (Teshaev et al., 2017).

3. Methods

Land suitability assessment contains different steps as presented in Figure 2 including data gathering, pre-processing attribute and spatial data (including soil texture, soil salinity, irrigated soils, irrigation network and reclamation condition, slope, land use map, crop rotation map), application of the suitability assessment functionality. This was done in ArcGIS Pro 2.7.). The suitability assessment model results were divided in five suitability classification for cotton cultivation following the FAO land suitability classification method. Land suitability assessment is an evaluation of productivity of land, which explains the major parameters for planting a particular crop.

3.1 Data Gathering and Pre-Processing

The main tasks were to establish a database that involves all agro-ecological data as raster layers with 10x10 m pixel size for each parameter mentioned above. The data pre-processing was differently for each data set. (e.g., different formats, scales), it. The sources of the data used as well as the pre-processing steps and tasks are presented in Table 2. This data reflects the relevant natural conditions aspects of cotton - described in section 2.1.

3.2 Suitability Modelling and Software

The suitability model is a multi-criteria decision-making process. It implemented in GIS, such as ArcGIS Pro, is allows to find in-depth analytical solutions to problems in many areas. In particular, it is advisable to use Suitability modelling in the placement of agricultural crops and in determining the optimal crop areas for them. In this model, the selection of the optimal plots for cotton crop is based on 9 data layers (as presented in Table 3). The suitability model was implemented through the Suitability modeller panel of ArcGIS Pro 2.7. All data was transferred to suitability scale of 1 to 10. Multiplier algorithm was used for weighting criteria. Weight assignment for the criterions was based on expert knowledge. Agro-ecological parameters such as soil, land use, groundwater condition and slope values were weighted higher than others taking account requirements of cotton. Because they are considered as key indicators in the assessment of soil quality for cotton. Table 3 reveals adjusted weights and transformation functions for each raster data for summarizing values in order to combining criteria's.

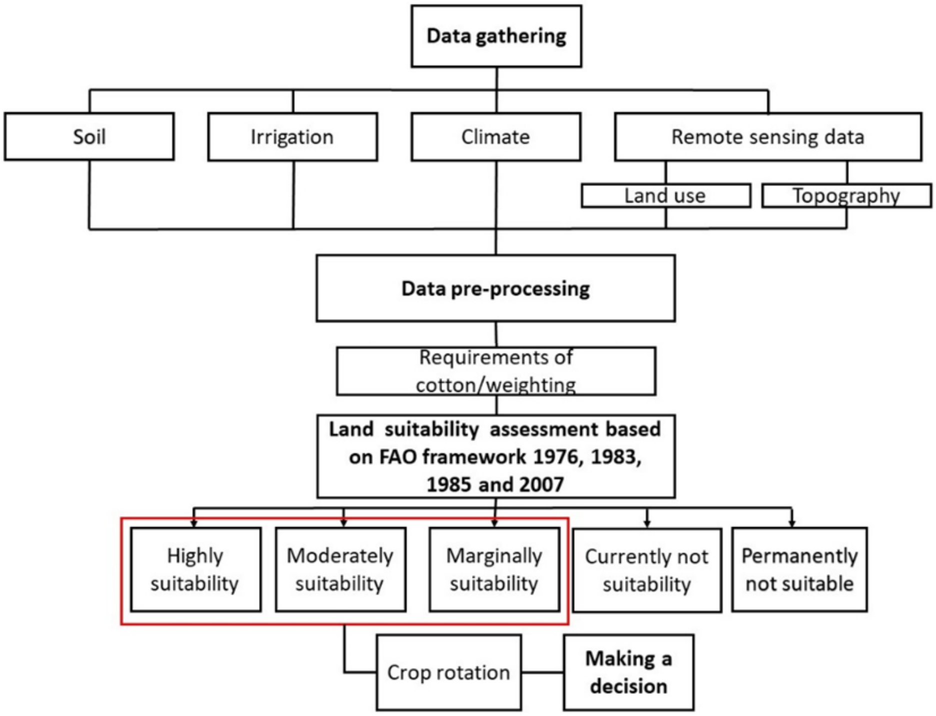

Figure 2: Land suitability assessment workflow

Table 2: Data type/source and transformation

Agro-ecological parameters	Scale	Years	Source of data	Type	Pre-processing/ transformation
Agrosoil map of Surkhandarya region which provides soil texture, soil salinity and soil type (irrigated, partly irrigated or no irrigated)	1:200000	2010	Scientific Research Institute of Soil Science and Agrochemistry (SRISSA), Uzbekistan	paper map	digitize→ symbolize→ rasterize
Irrigation network	1:10000	2020	Ministry of Water Resources, Uzbekistan	vector/ shape	density
Drainage network	1:10000	2020	Ministry of Water Resources, Uzbekistan	vector / shape	density
Groundwater table	GPS based points	2020	Melioration Expedition (ME), Surkhandarya branch	vector / shape	interpolation
Groundwater salinity		2020	Melioration Expedition (ME), Surkhandarya branch	vector / shape	interpolation
SRTM DEM data	~30x30 meter spatial resolution	2000	Open Topography data source web-portal (https://opentopography.org/)	raster/geo tiff	slope
Temperature	N/A	2020	https://power.larc.nasa.gov/data-access-viewer/acquired through	text/CSV	interpolation
Sentinel 2 MSI	10x10 meter spatial resolution	2020	https://earthexplorer.usgs.gov/	raster/ jpeg2000	land use map
Crop sequence map	1:10000	2020	Ministry of Agriculture, Uzbekistan	vector/ shape	crop rotation map

Table 3: Raster transformations and weighting

Data type/Raster layer	Transformation function	Weight
Soil texture	Unique categories/Class	3
Soil salinity	Unique categories/Class	3
Irrigation system proximity	Continues functions/MS Large	1.6
Drainage system proximity	Continues functions/MS Large	1.6
Groundwater table	Continues functions/Large	2
Groundwater salinity	Continues functions/Small	2
Slope	Continues functions/Small	2
Temperature	Continues functions/Large	1
Land use	Unique categories/Class	2

Table 4: Distribution of suitability classes in the study area

Class	Area, km^2	Proportion of the total area, %
Highly suitable	36.2	1.8
Moderately suitable	230.5	11.2
Marginally suitable	145.0	7.6
Currently not suitable	485.8	24.3
Permanently not suitable	1101.1	55.1

3.3 Land Suitability Assessment/Classification Based on FAO Framework

This final land suitability assessment was carried out based on the FAO (1976) system to classifying the suitability of the Kumkurgan District's territory for main agricultural crop type cotton. The FAO framework classifies lands for any land management including land allocation for crops as highly suitable(S1), moderately suitable(S2), marginally suitable(S3), currently not suitable(N1) and permanently not suitable(N2). In order to exclude non-agricultural areas from suitable areas such as rural residential areas, private plots and other irrigated lands which have similar patterns like agricultural areas, land parcels (polygons in shape file) were used to extract only available areas. Land parcels of agricultural areas include five years of crop type sequence for each field. That helped to implementing crop rotation system of 2:1 (cotton/winter wheat/other).

4. Results

As a result of data pre-processing, overall, 9 raster layers figures out through different GIS algorithms (Figure 3). The Suitability map which was created by weighting and combining all above mentioned criteria, is presented in Figure 4. Maximum value of model was equal to 85 while minimum was indicated 25. In the suitability map, which shows the summarizes values of each raster data, higher values indicate suitable and lower values less suitable areas for cotton cultivation. Regarding the FAO land classification method, Table 4 shows the area distribution in the individual classes. As can be seen in Table 4, around 20 percent (411.7 km^2) of total area is considered suitable for cotton, which occupied non-agricultural areas: rural/urban residential areas, individual plots and other irrigated land. After implementing land parcels of irrigated agricultural fields with crop type sequence data for crop rotation of 2:1 method, about 78.5 km^2 (19 % of overall suitable area, 36 % of irrigated agricultural land parcels) was assessed as a very suitable for cotton in 2020-2021 season. According to overlaying analyses, 12 percent (25.8 km^2) of currently used irrigated agricultural areas were assessed non-suitable environment for cotton planting (Figure 5).

5. Conclusion

In the case of making decisions, Land Suitability Model (GIS-based Multi Criteria Approach) provides a vital information for sustainable agriculture and land allocation for specific crops. Therefore, this research has been conducted to support decisions through multi data approach in order to define suitable places for cotton cultivation. In the study area, there is not much coverage of irrigated agricultural area comparison to all area, but the most part of the agricultural areas is not very suitable for cotton cultivations.

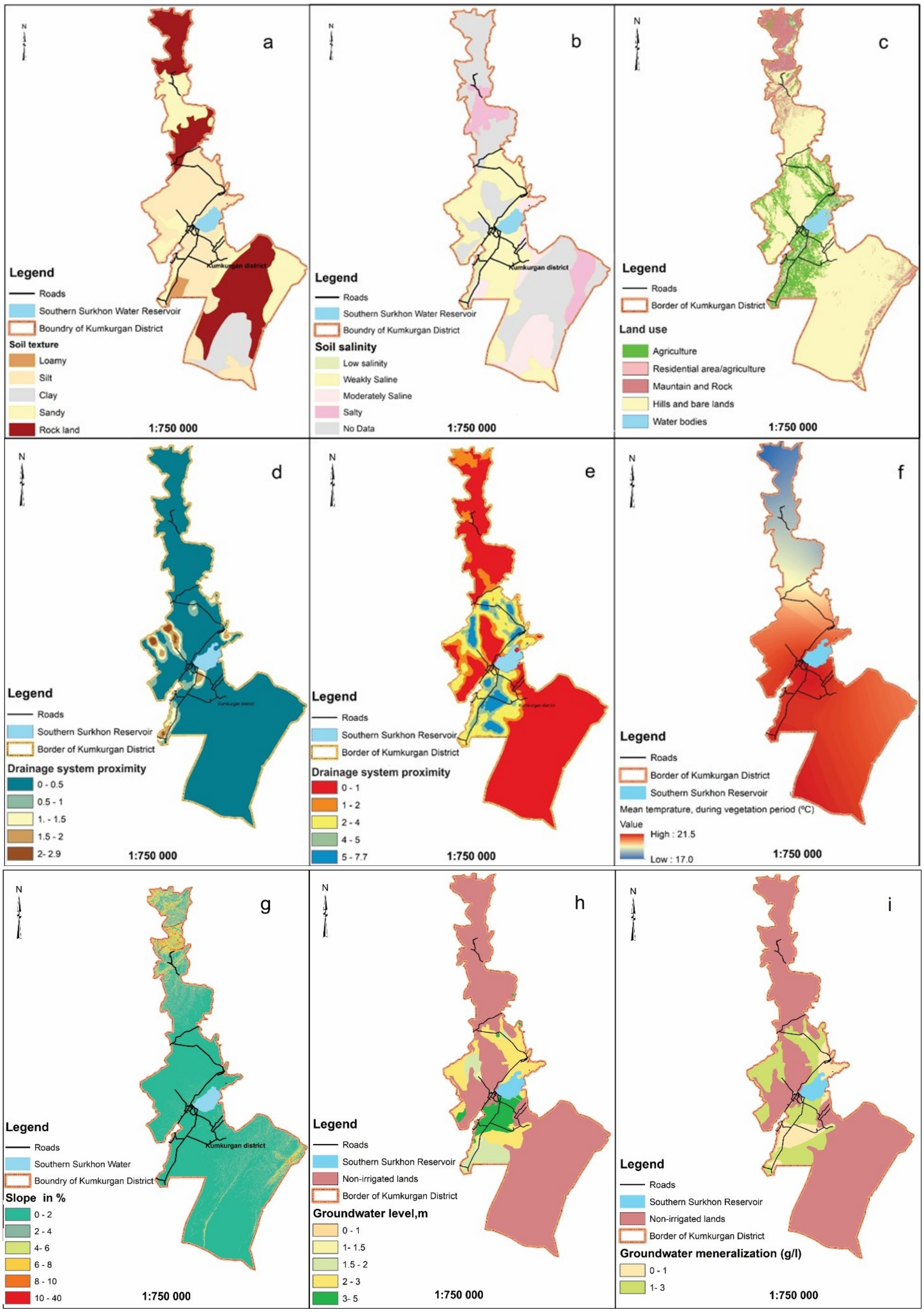

Figure 3: Agro-ecological conditions of Kumkurgan district, (a)Soil texture; (b) Soil salinity; (c) Land use; (d) Drainage system proximity; (e) Irrigation system proximity; (f) Mean temperature; (g) Slope; (h) Ground water table; (i) ground water mineralization

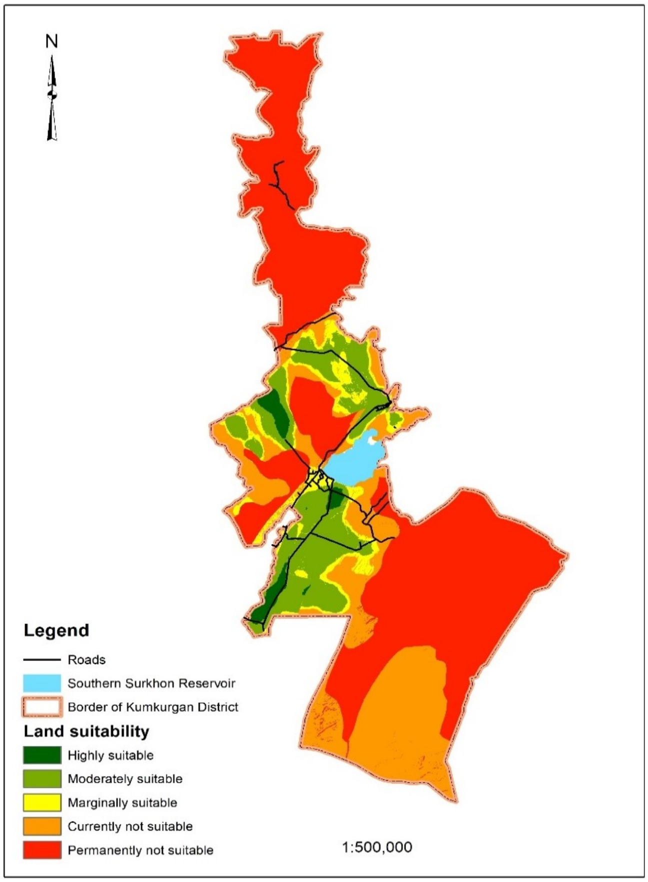

Figure 4: Suitability map of Kumkurgan district for cotton

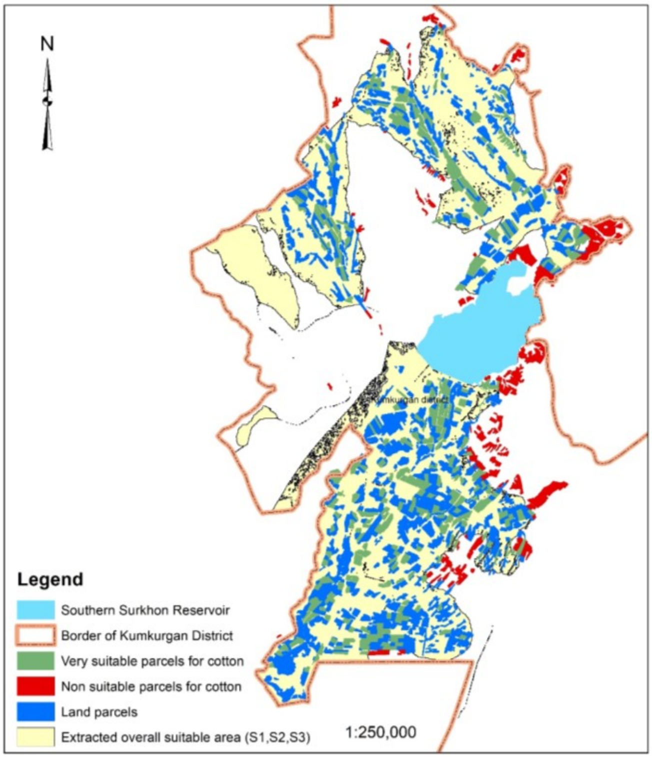

Figure 5: Land allocation for cotton for the season of 2020-2021

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However, moderate suitable lands for cotton are more than other types and evenly distributed through the agricultural area. Most of marginally suitable land for cotton with severe limiting factors such as soil texture, salinity, slope and groundwater conditions which are always prevents good growth of cotton.

GIS environment based analyses are essential tool for evaluating the land suitability with a high accuracy. Land suitability assessment could be utilized in order to develop other sectors of economics beside of agriculture. For applying these kinds of advanced technologies based spatial data models, require a high level of ability to use software devices and computer technologies as well as the high level of theoretical and practical expert knowledge in the application sphere.

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