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Hybrid GIS-MCDM Based Modeling Approach for Determination of Land Suitability of Wheat Cultivation in Konya Closed Basin, Türkiye

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ABSTRACT

In countries with high population growth and migration potential, such as Türkiye, agricultural lands are gradually decreasing due to the increase in food demand and the misusage policies and urbanization applied to the lands. Land suitability activities carried out within the scope of agricultural sustainability in order to increase agricultural production and soil productivity are important. This study focuses on identifying the agricultural lands suitable for wheat cultivation by evaluating the Konya closed basin in the Central Anatolia Region of Türkiye by using a hierarchy developed with the integration of the AHP method, which is one of the GIS and MCDM techniques. Within this framework, 15 criteria were delineated under 4 main headings as meteorological criteria, topographic criteria, soil criteria, infrastructure and economic criteria and their weight values for their sub-criteria were calculated. The most effective criteria were determined as the average temperature of October (0.1379), followed by the average annual temperature (0.1300) and the land use capability (0.1191). Finally, the land suitability map was created for wheat cultivation. According to the suitability map, 0.39% (15 815 km^2) of the study area is found to be very highly suitable for wheat cultivation, 61.24% (2 494 461 km^2) is found to be highly suitable in terms of suitability. The districts of Kadinhani, Sarayonu, Altinekin, Cihanbeyli, Kulu, Karapinar and Emirgazi, which are located in the north of the study area, have been determined as very suitable regions for wheat cultivation. This study aims to contribute to the existing literature by identifying precise and suitable areas by combining GIS and AHP in the wheat cultivation site selection process. In the study, a new research perspective is presented by taking into account the uncertainty in the site selection process and the concept of sustainability in four different dimensions: meteorological, topographical, soil, and infrastructure and economic, thus aiming to guide decision-makers for future studies. According the current literature, that no comprehensive study has yet been conducted that covers such a large basin for the wheat plant, which is the raw material of humanity's basic nutritional needs. In addition, the average annual pressure criterion that is not examined in the literature was discussed in the study and its importance for wheat plant development was also examined. Consequently, the outcome of this study delineates that the methods and criteria used in this study may be guiding for site selection for wheat cultivation in future studies covering such wide areas.

Keywords: Land suitability assessment, Geographic Information Systems (GIS), Analytic Hierarchy Process (AHP), Multi-criteria decision making (MCDM)

1. Introduction

Negative effects on environmental impacts of ever-increasing population pressure, increasing food demand, and misusage policies on land have been increasing. For this reason, it is necessary to switch to a sustainable agricultural policy with good agricultural planning in order to increase agricultural production and soil productivity (Bilgilioglu 2021; Zhang et al. 2015). Land use plans should be developed first in order to ensure that the land can be used in the most efficient way. The prerequisite is the assessment of land suitability, which will determine the best use of the land (Kılıc et al. 2022). Assessment of land suitability (LS) is the first step in designing sustainable land use and management systems to reduce the impact of adverse environmental conditions on fertile lands on agriculture (Ostovari et al. 2019). Performing this analysis is one of the most useful applications of the Geographical Information System (GIS) in the preparation of land usage maps, planning and management of land resources (Maddahi et al. 2017). LS analysis is one of the most important stages of land use planning for the cultivation of a particular crop according to local conditions (FAO 1993; Tashayo et al. 2020). The selection of the most appropriate algorithm for the assessment of LS is important for both current and future land use planning (Zhang et al. 2015). Product-oriented land assessment studies have additional importance especially for countries with high population growth and migration potential such as Türkiye (Dedeoglu & Dengiz 2019). It is necessary to determine to what extent the ecological requirements of the product can be met within the ecological structure of that region in order to use the land in the most appropriate way (FAO 1976). LS analyses are widely used in these evaluations (FAO 1985; Bilgilioglu 2021).

Based on the GIS environment, LS analysis is a process that aims to determine the most appropriate development locations by considering environmental and agricultural sustainability (Ostovari et al. 2019). In determining the importance of the criteria used in this process and in calculating the weights of the factors, GIS tools should be integrated with other methods in order to improve the results of LS analysis. In this case, MCDM methods are strong approaches to assess LS (Bagheri et al. 2013; Aburas et al. 2017).

Modeling the suitability of agricultural lands for certain products on a regional scale plays an important role in designing the best sustainable management systems (Tashayo et al. 2020). The aim of the study is to investigate the LS assessment for the production of wheat, which is the raw material for bread, the staple food of people, throughout Konya Province, which is the first center of wheat production in Türkiye.

Wheat has been the most basic nutritional source for humans throughout history. It is known that wheat was first domesticated in southeast Türkiye. Although it is known that there are many wheat species today, wheat is generally divided into three groups. These are defined as pasta, bread, and biscuit wheat (Aydin 2022). Since wheat is the raw material of many staple foods, it has always been of special importance in agricultural products and its consumption has been increasing in recent years. Accordingly, it is also extremely important to increase the production of wheat. In addition, since the production amounts of the countries differ depending on the climatic conditions, the fact that some countries need much more wheat than they can produce in some years increases the wheat trade. European Union (EU) countries ranked first with a share of 20.3% of total wheat production in the world, followed by China (17.4%), India (13.5%), Russia (9.7%) and the USA (6.8%) in 2019. Türkiye ranks 10^{th} by meeting 2.5% of the world wheat production (Tarhan & Dellal 2021).

Although wheat is a plant with a strong adaptive ability, it is a grain suitable for growing in a cool climate that does not like too much heat and humidity. While 8-10 °C is suitable for germination period, 10-15 °C and partly cloudy and underlit weather are suitable (RTMAF 2015).

It is expressed as MCDM process including different qualitative and quantitative information and at the same time evaluating more than one criterion for a specific purpose. This process helps decision makers determine the most logical choice in evaluating many parameters and analyzing the relationship between these parameters. Because not all criteria handled have equal importance and the contribution of each criterion to suitability is at different levels (Prakash 2003; Kılıc et al. 2022). GIS and MCDM integration allow the preparation of a comprehensive spatial database to be used by multi-criteria methodologies in land assessment and suitability analysis and is also an excellent spatial analysis tool that enables users to evaluate different criteria on the basis of multiple and contradictory goals (Karaca et al. 2021; Orhan 2021; Kılıc et al. 2022; Sarğın et al. 2024).

MCDM methods offer structured approaches to informed decision-making in situations where multiple criteria are present. Each method possesses distinctive strengths and is better suited to different types of problems. Consequently, it is crucial to select the method that aligns with the specific decision context. In order to maintain the use of land for a long time without deterioration, it is necessary to consider not only the natural capacity of the land, but also its socio-economic and environmental conditions. Therefore, it is extremely difficult to assign relative weights to the different criteria involved in decision making regarding land use. Therefore, a technique for estimating weights needs to be adopted. This is possible with the MCDM techniques, such as AHP method (Saaty 1977; Chuong 2011). The AHP method is an important technique used to determine LS today and is classified under the multi-criterion decision analysis approach. It is also an effective technique that helps planners and decision makers analyze all data before making a decision on future land use alterations (Bagheri et al. 2013; Aburas et al. 2017). The AHP method involves multiple choices based on the importance and weight of the relevant criteria relative to each other within a hierarchical system (Saaty 1980). It is a useful method in cases where it is difficult to reveal the exact relationship and result between a vast number of criteria. In addition to the classical methods like AHP, Fuzzy Analytic Hierarchy Process (F-AHP), Fuzzy Ideal Solution Similarity Ranking Performance Technique (F-TOPSIS), Fuzzy VIKOR (F-VIKOR), Fuzzy PROMETHEE (F-PROMETHEE) methods are also alternatives of the same methods that are solved with the support of fuzzy logic (Mutlu & Sari, 2017; Mutlu & Sari 2022). To affords decision-makers greater freedom to express their opinions in a realistic manner, the linguistic terms employed in FMCDM (Fuzzy MCDM) techniques a converted to numerical values by using fuzzy sets can be applied by integrating different innovative combinations of FMCDM techniques interval-valued Pythagorean fuzzy sets (PFS)s and interval type-2 fuzzy sets (IT2FS)s (Mutlu et al. 2024). However, since the process steps in these methods are complex and the decision-making process is difficult and time-consuming for decision makers, it is seen that the AHP method is often preferred in the literature, as in this study.

A plethora of studies in the literature have employed the MCDM method to evaluate the suitability of specific areas. To illustrate, rice cultivation in the Amol Region of Iran (Maddahi et al. 2017), wheat cultivation (WC) in the Tozanlı region (Kılıc et al. 2022), Antalya, citrus fruit in Türkiye (Tercan & Dereli 2020), corn cultivation in Iran (Tashayo et al. 2020), for paddy fields in Tanzania (Al-Hanbali et al. 2021), Ethiopia sorghum crop (Tadesse & Negese 2020), olive cultivation in Mersin, Türkiye (Bilgilioglu 2021), saffron (*Crocus sativus L.*) cultivation in Khost Province of Afghanistan, (Wali et al. 2016) corn production in Ondonesia (Habibie et al. 2021), coffee in Peru (Lopez et al. 2020), Mersin, Türkiye for citrus (Orhan 2021), many LS studies for example tobacco in China (Zhang et al. 2015; Bilgilioglu 2021), wheat-barley cultivation in Tusba district of Van (Sargın & Karaca 2023), Sogulca Basin for wheat (Dedeoglu & Dengiz 2019) are studies conducted with the integration of AHP method and GIS technique. Dedeoglu & Dengiz (2019), evaluated mostly soil-related physical and chemical criteria in their study. In this study, meteorological, topographical, soil, infrastructure and economic criteria were evaluated. There are many studies in the literature within the scope of LS assessment. However, there has not been a comprehensive study conducted on a provincial basis for the wheat plant, which is the raw material for the basic nutritional needs of humanity. It was aimed to fill this gap in the literature with current study.

Türkiye is a very suitable country for WC both geographically and climatologically. Konya ranks first among the provinces that grow wheat the most. This study aimed to determine the most suitable regions for WC with the AHP-GIS method throughout Konya province. If the soil is used in accordance with the correct policy within the scope of the LS assessment studies to be carried out, the natural resources will be used in the most beneficial way without deterioration and will be transferred to future generations in the most efficient way.

Combination of AHP-GIS, it was aimed to obtain the agricultural lands suitable for WC by evaluating the whole of Konya province in the Central Anatolia Region in Türkiye within the scope of the study. In this context, the current farmers in Konya province and the relevant literature were taken into consideration, and 15 criteria and their sub-criteria were determined under four main headings. The weight values of these criteria were calculated in order to obtain suitable areas for WC.

1.1. Study area

Konya basin is the largest province of Türkiye in terms of surface area and consists of 31 districts. Its surface area is 39 000 km^2 and it is located in a plain in the Central Anatolia Region of Turkey, between the coordinates 4050000–4350000 N and 345000 630000 E (WGS-84, Universal Transverse Mercator UTM-m, 36 Regions) (Figure 1). Continental climate is seen in Konya. The summers are dry and hot, the winters are cold and snowy. The temperature difference between night and day is between 16-22 degrees in summer. This difference decreases to 9-12 °C due to humidity in spring and winter. Another feature of the Konya climate is that summers start very late and winters end very late. Summer drought, which is a characteristic of steppe climate, makes it possible to grow the best quality wheat in Türkiye. The Province of Konya meets 11% of the wheat need of Türkiye. The economy of Konya province depends on agriculture especially wheat agriculture. The main agricultural products are wheat, sugar beet, sunflower, potato, onion, and poppy.

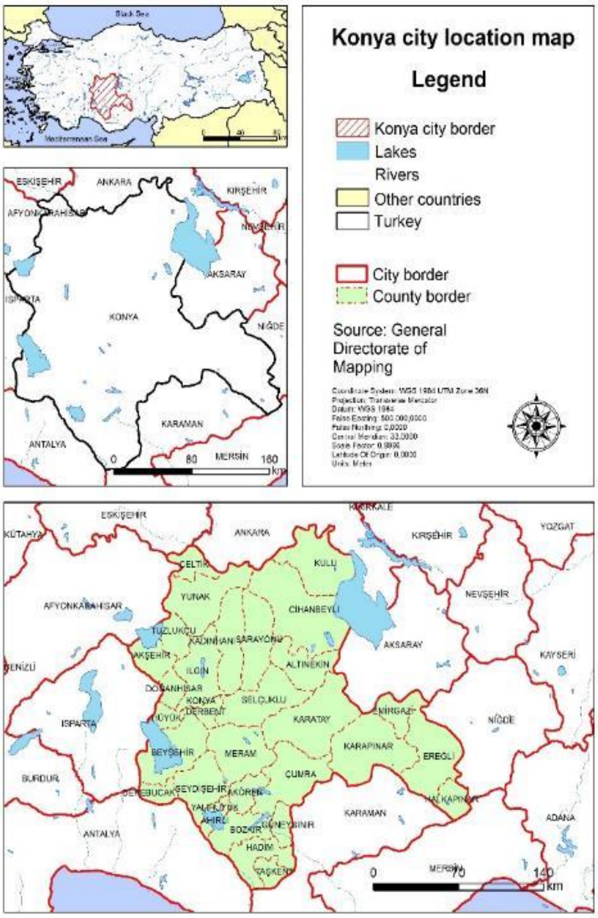

Figure 1- Study area

2. Material and Methods

In this study, the aim is to determine potential WC areas based on Konya province wide. First of all, the factors that are thought to affect the growing conditions of the wheat plant were determined, and then an exclusion analysis was made in order to except the not suitable regions for WC. The weights for each criterion in the hierarchy were computed by using the AHP technique. In the final stage of this study, a LS map was created for wheat growing throughout Konya province. Climatic conditions, topographic conditions, soil, and economic conditions suitable for WC were determined in consultation with 20 farmers and 5 agricultural engineers in Konya province, and at the same time, previous literature studies and current practices were benefitted from.

The 15 criteria, which were divided into four main headings and further subdivided into sub-criteria, were evaluated within the scope of the hierarchy created in the study (Figure 2). The first of these criteria are meteorological criteria such as average annual temperature, average temperature of October, average annual relative humidity, average annual pressure, average annual precipitation criteria. Elevation, slope, and aspect criteria were evaluated among the topographic factors, which are the second main criteria in the hierarchy. Thirdly, land capability and soil depth criteria including soil conditions were evaluated. Finally, the criteria of proximity to lakes, proximity to rivers, proximity to roads and proximity to settlements, which are infrastructure and economic factors, were evaluated. Then, the level of importance for each evaluation criterion and sub-criteria were defined. General evaluation criteria are given in Table 1. All evaluation and exclusion criteria were resampled to 30 m spatial resolution in the WGS-84 Universal Transverse Mercator (UTM) region 36 coordinate system and included in the AHP hierarchy for LS analysis.

2.1. Exclusion and evaluation criteria

Among the excluded factors, protected areas, areas where meteorological parameters are not suitable for WC, economically and topographic unsuitable areas for WC were excluded, and the rest of the study area was classified as 50.32% (2049.82 km^2) suitable areas for WC. Heights with an average temperature below 5 °C and above 2600 m, VI, VII and VIII class lands according to the LS map and places below 30 m distance according to the road proximity map were selected as inappropriate areas (Figure 2). To define the suitable areas for WC throughout Konya province, 4 main criteria as meteorological criteria, topographic criteria, soil criteria, and infrastructure and economic criteria were received for consideration (Figure 2) (Table 1).

Table 1- Data types and sources of evaluation criteria

Criteria	*Unit*	*Data type*	*Scale/resolution*	*Data source*
Average annual temperature	°C	Raster	30 arc second	Turkish State Meteorological Service
Average temperature of October	°C			
Average annual humidity	(%)	Point	Observation data obtained from meteorological stations	
Average annual pressure	(hPa)			
Average annual precipitation	(mm)			
Elevation	(m)	Raster	30m	SRTM
Slope	(%)			
Aspect	Categorical			
Land use capability	Categorical	Polygon	1/100000	RTMAF
Soil depth	(m)			
Proximity to roads	(km)	Polyline	1/100000	Environmental plan obtained from MEU (2021)
Proximity to settlement	(km)	Polygon		
Proximity to rivers	(km)	Polyline		
Proximity to lakes	(km)	Polygon		
Groundwater depth	(m)	Raster		DSI Konya Regional Directorate

*: RTMAF Republic of Türkiye Ministry of Agriculture and Forestry; **: MEU Türkiye Ministry of Environment and Urbanization

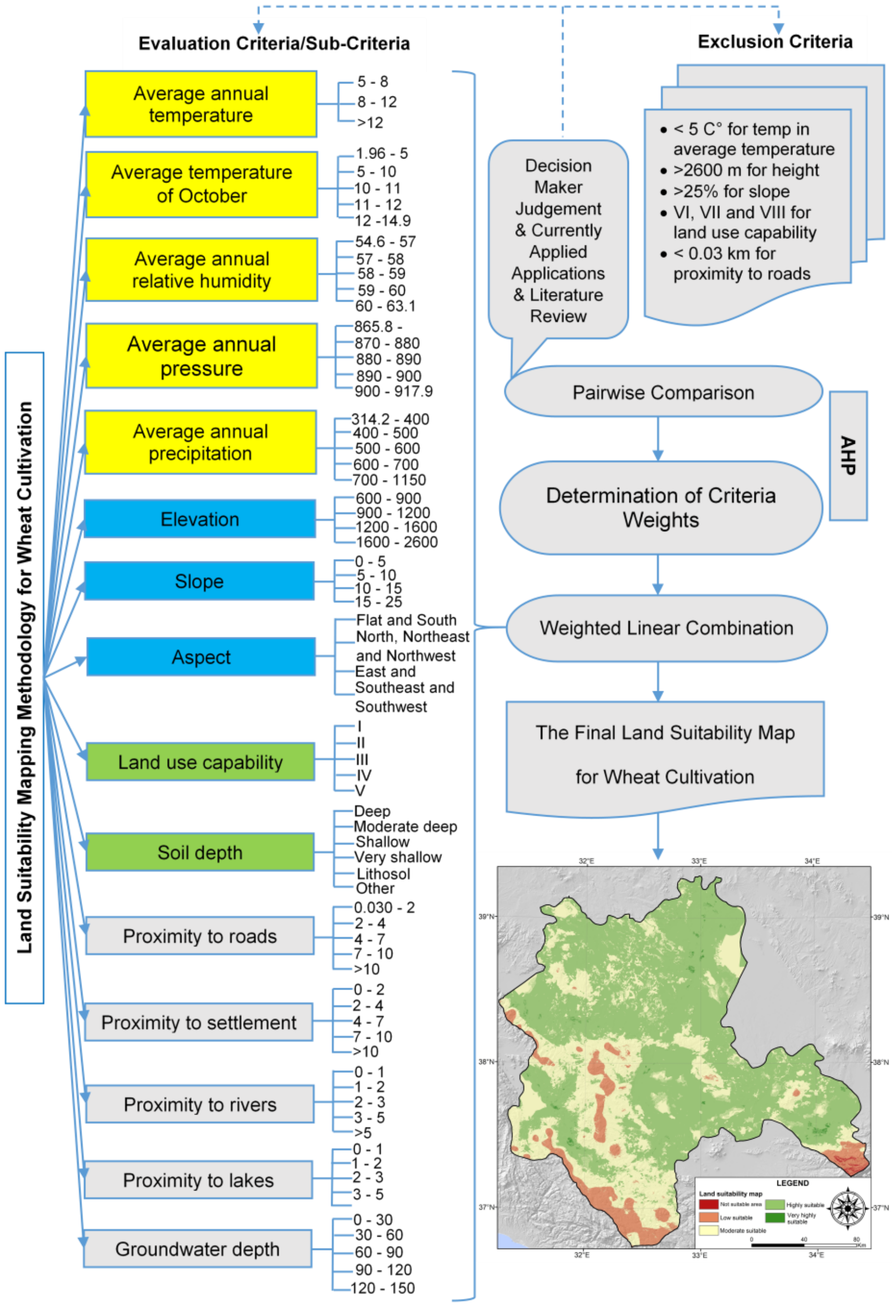

Figure 2- The flowchart of the GIS-MCDM-based LS mapping hierarchy

2.2.1. Meteorological criteria

Average temperature of October, average annual precipitation, average annual relative humidity, average annual pressure, average annual temperature, criteria are important for the meteorological criteria for WC. The average annual pressure criterion that is not examined in the literature was discussed in the study and its importance for wheat plant development was also examined. The meteorological data used in this study were provided from the Regional Directorate of Meteorology. For each of these stations, data collected from the date the stations started collecting data (January 2000 for the Konya Airport station, January 2004 for the Konya regional station, January 2016 for the Konya Meram/Urban Forest station) to December 2023 were used. The locations of meteorological stations are shown in Figure 3. Meteorological data were evaluated using the inverse distance weighted (IDW) interpolation method and necessary maps were created. IDW approach has been regarded as one of the deterministic spatial interpolation techniques (Lu & Wong 2008; Tercan & Dereli 2020). The principle of the IDW is that the unknown value of estimated point is calculated by computing the value as a distance weighted average of sampled points in a defined neighbourhood (Rahmouni et al. 2017), where a higher degree of influence assigned to nearby points and consequently more far points presents less effect (Gouareh et al. 2021). In this study, IDW was chosen as the interpolation method, as in many studies in the literature (Hossain & Das 2010; Ayehu & Besufekad 2015; Roy & Saha 2018; Mokarram & Miesoleimani 2018; Souidi et al. 2020; Tercan & Dereli 2020; Bilgilioglu 2021; Orhan 2021; Ozsahin & Ozdes 2022; Pathan et al. 2022; Salifu et al. 2022; Sarkar et al. 2023; Ozegin et al. 2024).

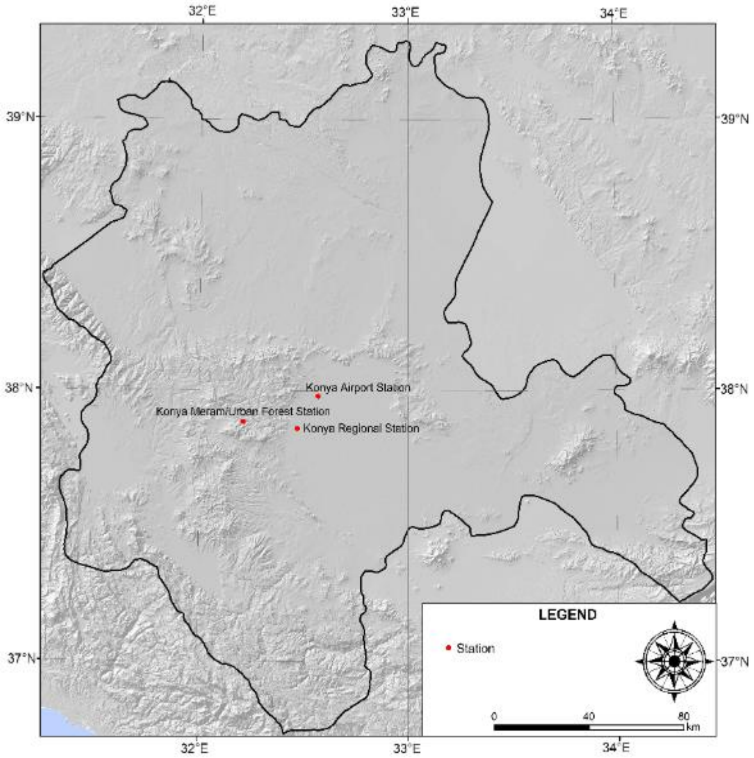

Figure 3- The location of meteorological stations

When the literature review is made for classified in accordance with the literature.

2.2.2. Average annual temperature

Temperature is an important criterion for climate conditions for WC. Wheat needs the appropriate temperature to complete its development period after being planted as a seed. The appropriate temperature for the growth and development of the wheat plant is the temperature range between 10-15 °C (Porter & Gawith 1999; Wang et al. 2023). Wheat is a plant that is sensitive to extreme temperatures during critical developmental periods. These extreme temperatures cause freezing of leaves and roots, winter deaths, internodes and cause the flowers to be damaged by frost and high temperatures also damage them. It has been observed that an increase in temperature leads to a decrease in grain weight of wheat plants due to heat stress (Asseng et al. 2011). The wheat plant does not like high temperatures in the early stages of its development, such as germination. During these periods if the temperature is 5-10 °C it continues to develop normally. Therefore, in the average annual temperature map, regions of 5 °C and below were excluded and the residual areas were classified into 3 groups (Figure 4a).

2.2.3. Average temperature of october

One of the most important elements to determine the planting time in wheat farming is the soil temperature in the seed bed. When the soil temperature is 8-10 °C if the planting process is performed, the root development is fast, and the root crown is deep. This convenient planting process increases resistance of wheat to cold and drought. Early planting process and late planting process are ill-favored as they will cause damage to the plant due to severe colds in the winter period. The study results indicate that wheat sown on both 20th and 30th October produced longer spikes and a higher number of grains (Baloch et al. 2012; Komer et al. 2014). For this reason, the most appropriate WC time in Konya Province and Central Anatolia Region is October in order to maintain the normal development of wheat. Meteorological data were also obtained from the regional directorate and the average temperature map for October was divided into 5 classes (Figure 4b)

2.2.4. Average annual relative humidity

Moisture comes second among the climatic conditions in WC. Moisture is the most important determinant of yield in dry farming areas where wheat farming is widespread. Relative humidity has a direct impact on the water relations of plants and indirectly affects leaf growth, photosynthesis, pollination, disease occurrence, and ultimately economic yield. If the relative humidity is above 60% in the early stages of wheat development, wheat continues to develop normally (Sandhu & Dhaliwal 2016). Wheat requires relatively high humidity before earing. In the study, an annual average relative humidity map was produced and divided into five classes (Figure 4c).

2.2.5. Average annual pressure

Pressure values are among the least noticeable of the climate criteria. Although changes in air pressure occurring hourly and daily are felt less by people, especially those occurring in a short time play a very important role in the development and change of weather events (Ircan 2020). Upon examination of the studies in the literature, it was determined that low pressure was effective in the germination and growth of wheat plant and that this plant also could grow in standard atmosphere (Massimino & Andre 1999; Rodríguez-Puebla et al. 2007; Guo et al. 2008). The pressure map created was divided into 5 classes (Figure 4d).

2.2.6. Average annual precipitation

Water is the leading element among the essential elements for plants to continue their vital activities. The water required for the plants is met by agricultural irrigation and precipitation. The water source in the cropland is precipitation. For the development period of wheat plant, annual precipitation of 350-1150 mm is sufficient for a quality and abundant product (Marijanović et al. 2010; RTMAF 2015; Jolánkai et al. 2018; Dogan & Kan 2019). The annual average precipitation map was divided into 5 classes (Figure 4e).

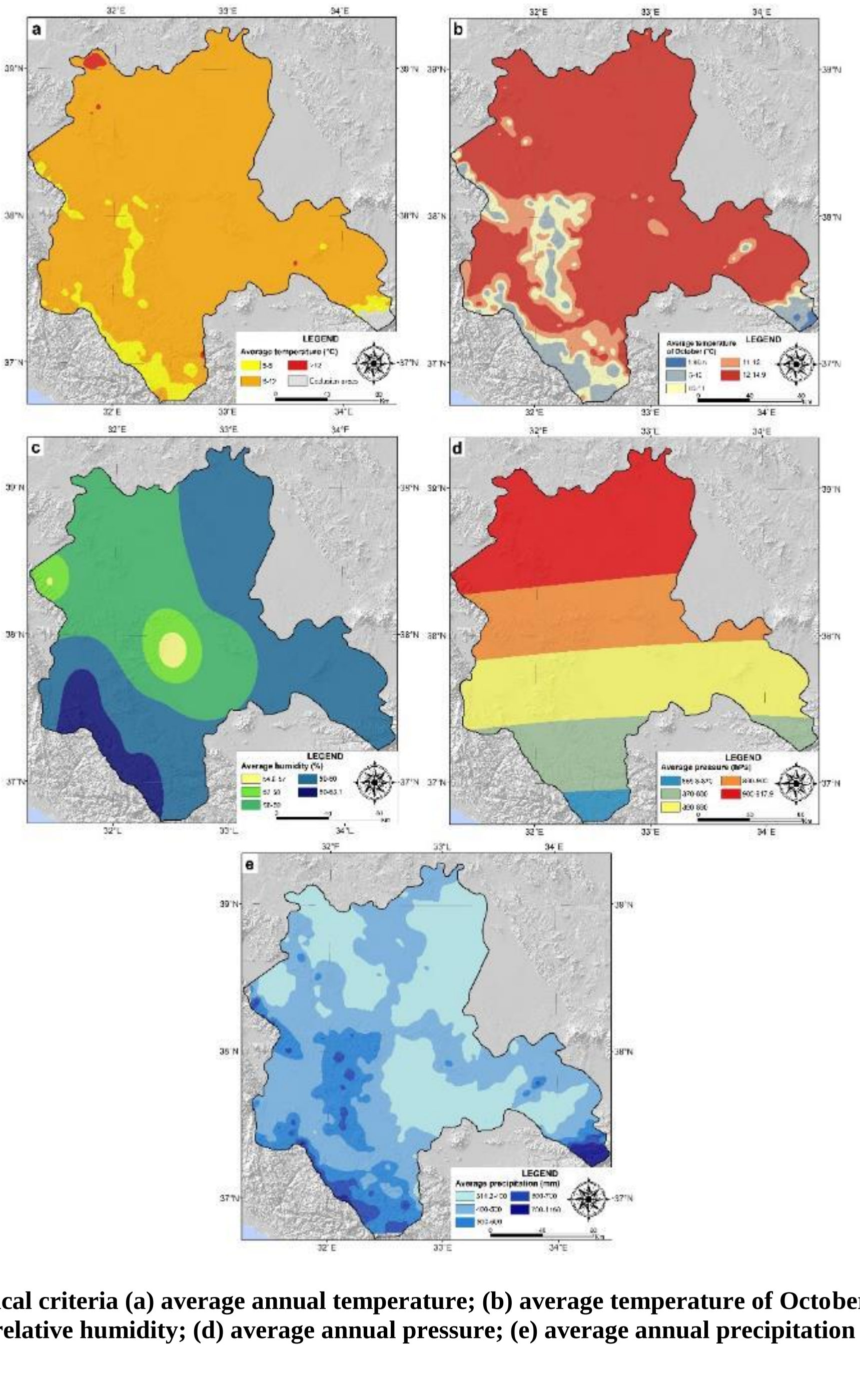

Figure 4- Meteorological criteria (a) average annual temperature; (b) average temperature of October; (c) average annual relative humidity; (d) average annual pressure; (e) average annual precipitation

2.2.2. Topographical criteria

Elevation

Altitude is a crucial factor in agricultural production and diversity. The elevation increases as we move from the coast to inland regions. This variation in altitude also affects the duration of winter and summer months, making the former longer and the latter shorter and cooler (Kapluhan 2013). Due to the changing climatic conditions with altitude, the same plant species may exhibit physiological and morphological differences (Ozkan & Kantarci 2008). Therefore, one plant of the same species matures faster than the other due to differences in their vegetation period. The duration of vegetation directly affects the harvest time and profitability of crop production (Everest et al. 2021).

Wheat is the leading cereal among the cereals in terms of being able to grow in high altitude regions. The most suitable elevation for wheat is between 2000-2600 m (Fekadu & Negese 2020; Kılıc et al. 2022). The elevation map was disunited into 4 classes according to the literature and the areas above the 3000 meters' elevation were selected as the exclusion area (Figure 5a). SRTM data were used as elevation data source.

Slope

The degree of slope negatively affects irrigation and machine use, and as this value increases, the risk of erosion increases accordingly. At the same time, this situation leads to the loss of organic matter and nutrients in the soil. For these reasons, slope is considered a limiting factor in the approach to land evaluation for wheat. (FAO 1977; Sauer et al. 2010; Begum et al. 2013; Dedeoglu & Dengiz 2019).

Wheat prefer slopes less than 8% forthe highest productivity (Sys et al. 1991; Fekadu & Negese 2020). It has been specified that slope levels below 25% are suitable for WC, taking into account the expert opinions in Konya province and at the same time, in order for the machines used to work efficiently (Bilgilioglu 2021). In this context, areas with a slope of more than 25% are taken as exclusion areas (Figure 5b). The slope data which presented in Figure 4b are generated from SRTM elevation data.

Aspect

Plants need sunlight at regular intervals to achieve proper vegetative growth. Since plants need sunlight in periods such as root and shoot development, flowering, fertilization, total yield, and quality are also directly affected by sun exposure (Begum et al. 2013; Dedeoglu & Dengiz 2019). Although the duration of the need for sunlight varies according to the type of plant, most cultigens show optimum growth in the south and west directions that receive sunlight for a significant part of the day (Akıncı et al. 2013). For this reason, direction of cropyard is one of the important factors affecting plant development in receiving sufficient amount of sunlight and it has been considered as a criterion in LS assessment for wheat in the study (Dedeoglu & Dengiz 2019). SRTM data were used to state the view in the study region (Figure 5c).

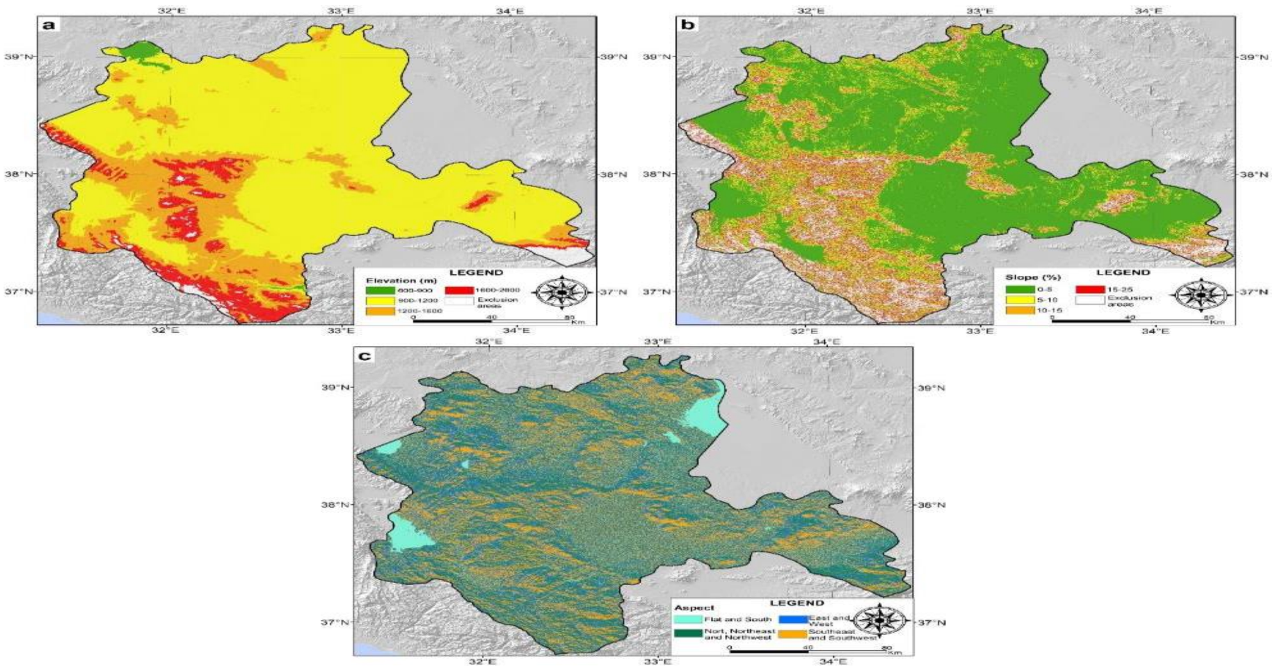

Figure 5- Topographic criteria (a) elevation; (b) slope; (c) aspect

2.2.3. Soil criteria

Land use capability

In determining the land use capability, land characteristics affecting soil and land usage such as drainage, land slope, geological and geomorphological location, soil structure, vegetation, stoniness, texture, erosion, groundwater, and salinity were taken into consideration (Cengiz & Akbulak 2009; Akıncı et al. 2013; Pramanik 2016; Orhan 2021). The study region is divided into 5 classes according to land use capability. First class areas have been selected as areas where there is no risk of erosion and where agricultural activities can be conducted in the most efficient and economical way. Areas with land use capability suitable for WC are divided into 5 classes, and areas that are not suitable for agricultural activities are excluded based on expert opinions. Land usage capability data of the study region were retrieved from the Republic of Türkiye Ministry of Agriculture and Forestry (Figure 6a).

Soil depth

Soil depth is a crucial factor in the hydrological dynamics of soils and plant growth (Rhoton & Lindbo 1997; Hirzel & Matus 2013; Kılıc et al. 2022) and a significant criterion for soil classification. Although wheat plants can grow in different soil species under suitable climatic conditions, they usually grow efficiently in places with the best soil depth that will provide effective root development (Dedeoglu & Dengiz 2019). In order for the wheat to be planted properly and grow efficiently, it is sufficient to plough the soil at a depth of 15-20 cm during the planting process. For this reason, the depth areas in the soil map of the study area are divided into 6 classes (very shallow <15 cm, shallow 15-20 cm, medium deep 20-50 cm, deep >50 cm) (Orhan 2021; Kılıc et al. 2022). In the classification, areas with unsuitable lithosol soil without vegetation have also been evaluated. Soil depth data for the study region were retrieved from the Republic of Türkiye Ministry of Agriculture and Forestry (Figure 6b).

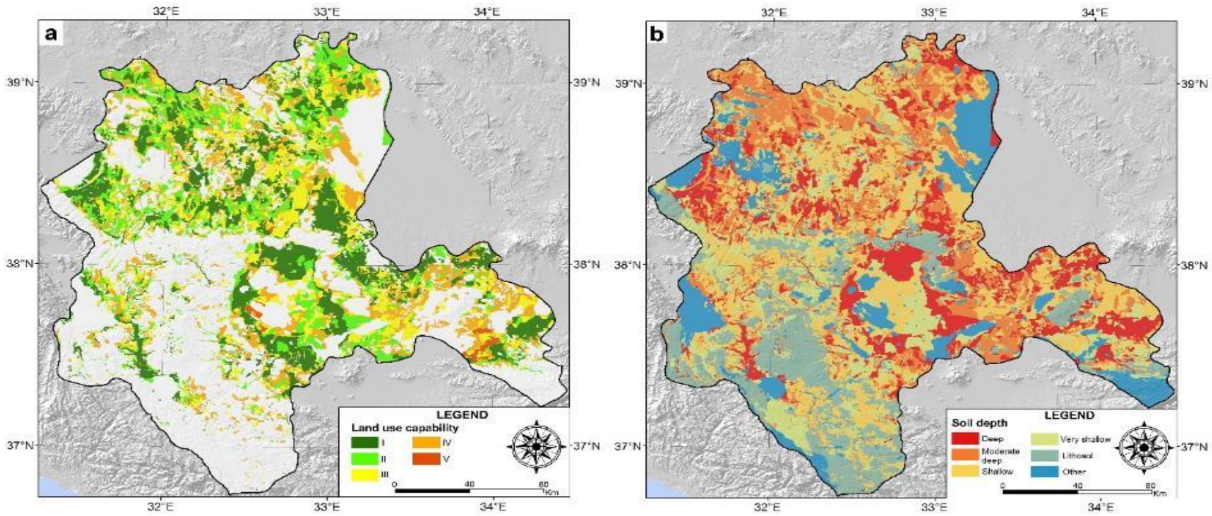

Figure 6- Soil criteria (a) land use capability; (b) soil depth

2.2.4. Infrastructure and economic criteria

Proximity to roads (km)

It is expected that the potential areas suitable for WC will be close to the roads in order to reduce the related agricultural costs such as transportation, production and maintenance. Furthermore, the short distance between fields and roads facilitates access for more convenient transport during crop production and harvesting (Morelli 2011; Habibie et al. 2021). When the infrastructure and economic criteria are evaluated, the criterion of proximity to roads is important. In addition, a certain amount of buffer zone should be created in order to minimize the impact of road expansion studies and unfavorable environmental impacts (Tercan & Dereli 2020; Orhan 2021; Bilgilioglu 2021). A 30 m buffer zone was created and removed from the study area for this purpose. The map showing the proximity of the areas divided into 5 classes to the roads is shown in Figure 7a.

Proximity to settlement (km)

It is an important criterion that the areas suitable for wheat production should be as close as possible to the settlement areas in order to carry out the transportation operations at the lowest cost possible after the wheat is harvested from the cropyard (Bilgilioglu 2021; Orhan 2021). In addition, the map showing the proximity of suitable regions for WC to the settlements is divided into 5 classes and presented in Figure 7b.

Proximity to rivers, irrigation ponds and lakes (km)

An annual precipitation of 350-1150 mm is sufficient for the development of the wheat plant. However, the criterion of proximity to rivers and lakes is important in order to meet the water needs easily for times when precipitation is insufficient (Massawe et al. 2019; Bilgilioglu 2021; Orhan 2021). Figure 7c shows the proximity to rivers; Figure 7d shows the proximity maps to lakes.

Groundwater depth (m)

The measurements of static water levels in observation wells indicate that the groundwater level in Konya closed basin has decreased by up to 46.88 meters from the ground surface. This suggests a serious and ongoing decline, with some areas of the basin already reaching critical levels (Worqlul et al. 2017; Orhan & Makineci 2023; DSI Konya Regional Directorate 2024). Therefore, it is recommended to promote dry agriculture in the Konya closed basin, which is self-contained and not reliant on external sources. It is advisable to cultivate crops that require less water, such as wheat. This study considers this criterion to be significant and has included it in the analysis. The locations of groundwater boreholes throughout the Konya closed basin are shown in Figure 8 (DSI Konya Regional Directorate 2024).

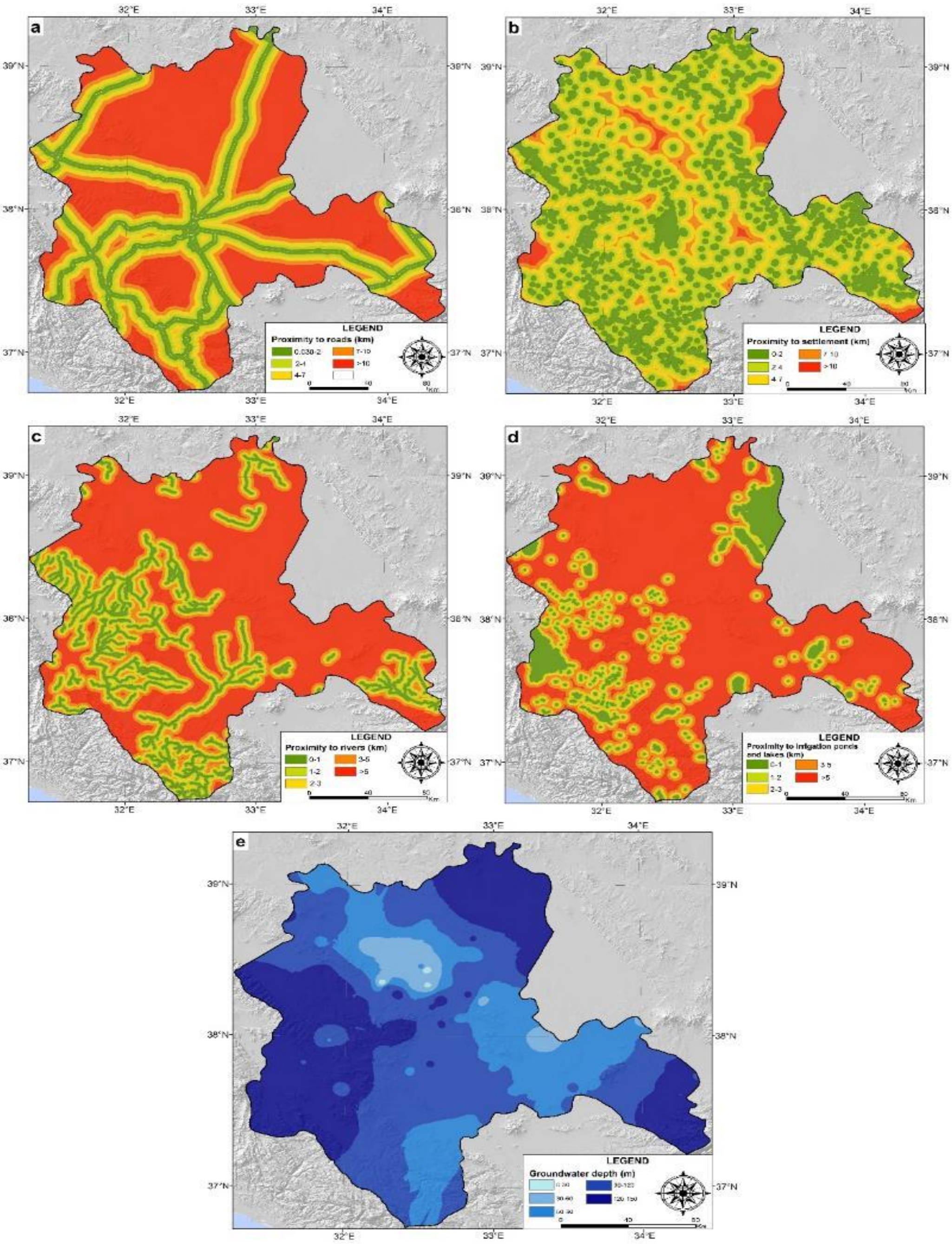

Figure 7- Infrastructural and economic criteria (a) proximity to roads; (b) proximity to settlements; (c) proximity to rivers; (d) proximity to rivers, irrigation ponds and lakes; (e) groundwater depth

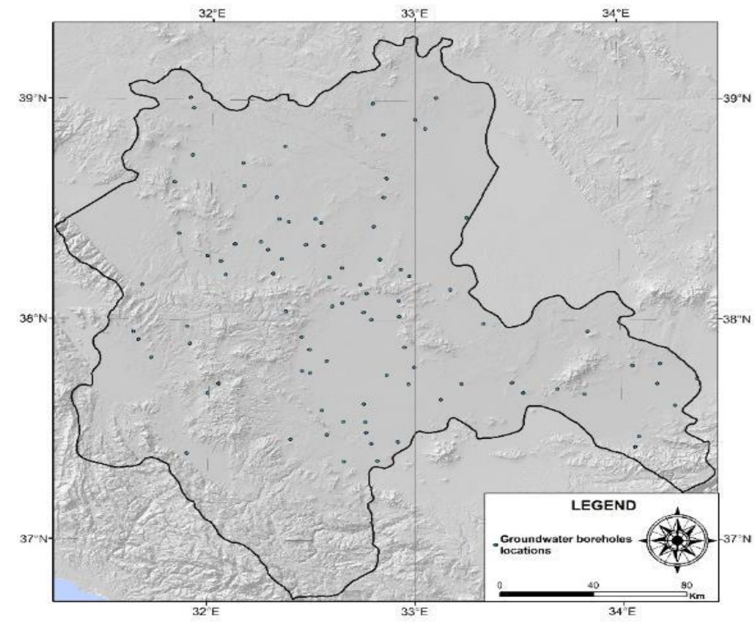

Figure 8- The locations of groundwater boreholes throughout the Konya closed basin

2.3. Analytic hierarchy process (AHP)

MCDM provides the choice of the best decision to achieve final goal with multiple criteria. The selection of a limited number of alternatives is usually expressed as mathematical models that are scaled, complex and formed by the use of a large number of criteria for the purpose of sorting, classifying, weighting or selection (Yoon & Hwang 1995). These methods stand out due to their use in terms of providing the decision maker with the opportunity to choose in a short time and easily. In MCDM, many different techniques can be used to rank alternatives according to more than one criterion (Mutlu & Sari 2017). In this study, a GIS-based MCDM model was enhanced to determine the suitability of land for WC by employing the AHP method, which is one of the MCDM techniques.

The AHP method is the most well-known an MCDM technique for dealing with MCDM problems that was first proposed by T. L. Saaty in 1970s firstly, and finalized in 1980. The AHP method is based on the determination of the problem and the creation of a top-down hierarchy, the creation of comparative decision making, the creation of a preference matrix in general, and the synthesis of multiple criteria and priorities (Saaty 1977; Saaty 1980). In complex MCDM problems, this method that evaluates qualitative and quantitative variables together, taking into account the priorities of decision makers. The most powerful aspect of the AHP method is that it breaks the problem down into meaningful sub-parts. Thus, it helps decision makers choose the most appropriate one when there are more than one goal or criterion (Karaca et al. 2023).

The information about all equations and steps involved in the AHP method can be found in various papers (Saaty 1980; Kursunoglu & Onder 2015; Kasap & Subasi 2017; Bilgilioglu 2021; Mutlu & Sari 2022); therefore, it is not explained in detail here. If the computed Consistency Ratio (CR) value ≤ 0.10 which is calculated for matrices in the AHP hierarchy, comparisons can be accepted for the algorithm done by researchers (Wind & Saaty 1980; Saaty 1990; Saaty et al. 2003; Mutlu & Sari 2022).

The weights of all criteria were computed using the MS Excel program. The next stage after the completion of the weight calculations for the criteria is the production of the LS map. The method generally used at this step is the weighted linear combination (WLC) method (Malczewski 1999; Bilgilioglu 2021; Bilgilioglu et al. 2022).

The WLC technique is the most prevalent in multi-criteria evaluation analysis, wherein the suitability of a given option is determined by the relative importance of the criteria. This technique is also referred to as the "scoring method." In this approach, the analyst or decision-maker directly quantifies the weights in accordance with the relative importance of each criterion under consideration. Subsequently, the relative weight assigned to this attribute is multiplied to yield a final value for each alternative. Once the final value has been determined for each option, it can be concluded that the alternatives with higher values will be the optimal choice for the desired purpose (Malczewski 2004). In this method, total weights should be equal to 1. The output will be a number between 0 and 1 (Malczewski 1999; Shenavr & Hosseini 2014; Ghosh & Das 2019). The weighted linear combination method provides a means of evaluating different criteria concurrently, in addition to offering a straightforward, comprehensible, and adaptable approach. Moreover, this method can be applied by leveraging the overlapping capabilities of GIS and the system. This functionality enables the integration of the layers comprising the criteria map, thereby facilitating the generation of a composite map layer (Dai et al. 2001; Zhang et al. 2013; Myagmartseren et al. 2017). The evaluation is made with the values calculated using the following formula (Equation (1)) (Malczewski 1999).

$$WCSI_i = \sum_{j=1}^{n} W_j \times x_{ij} \quad (1)$$

$WCSI_i$ in the formula refers to the wheat cultivation land suitability index, n criteria number, W_j the weight of $j$criteria, and x_{ij}expression refers to the sub-criteria weight corresponding to i cell of the j criterion.

Finally, by using ArcGIS software, the site suitability map was derived to select the most suitable place for WC by evaluating the calculated weights for all criteria in the hierarchy in five different classes (very high suitable, high suitable, medium suitable, low suitable areas, and areas not suitable) for WC according to the calculated weighted climatic suitability index ($WCSI$) values and integrated into the GIS Model Builder.

3. Results and Discussion

A GIS-based MCDM hierarchy was developed under 15 criteria, determined under 4 main headings and their sub-criteria. This hierarchy was used to produce 15 weighted raster maps, which were then combined with the WLC technique to create a LS map for the latest WC within the scope of this study. The pairwise comparison matrices were constructed as a result of interviews with experts on the subject within the scope of the hierarchy. The weights of the aforementioned criteria and sub-criteria, which are believed to be effective in location selection, were calculated in the Microsoft Excel program using the AHP method (Table 2 and 3).

It was determined that all of the CR values calculated for the pairwise comparison matrices of the criteria in the hierarchy designed for the purpose of the study were below 0.10, and that all of the comparisons made were consistent. The pairwise comparison matrix created for the main criteria and the calculated weight values are shown in Table 2 (Figure 9). Similarly, separate matrices were created for the sub-criteria of each main criterion. The complete set of CR values and criterion weights calculated for the pairwise comparison matrices of the main criteria and sub-criteria is presented in detail in Table 2 and Table 3.

When the main criteria were examined, it was seen that the weights of the meteorological criteria for WC come to the fore (Figure 9). When the weights computed for the main criteria in the hierarchy were evaluated, it was determined that the most effective main criterion was the average temperature of October (0.1379), followed by the average annual temperature (0.1300) and land use capability (0.1191). The average annual precipitation (0.1063) can be said to be the 4th most important criterion. As a result of the weight calculations made for the sub-criteria, when the average annual temperature for WC is 8-12 °C (0.7380), south-facing regions (0.4688) with an altitude of 900-1200 m (0.5894) with a slope of 0-5% (0.6402) and regions within 1 kilometer of rivers and lakes (0.4432; 0.4338) were determined as the most suitable conditions for WC (Table 3). When the appropriate time and suitable regions for WC are selected, sustainability will be ensured in WC for Konya province.

Table 2- The pairwise comparisons matrix and calculated weights of the main criteria

Pairwise comparison	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*K*	*L*	*M*	*N*	*O*	*Weights*
Average annual temperature (A)	1	2	3	5	1	2	3	3	1	2	3	2	4	4	4	0.1300
Average temperature of October (B)	1/2	1	3	3	1/2	3	4	3	3	4	3	3	3	3	5	0.1379
Average annual relative humidity (C)	1/3	1/3	1	1	1/4	1/2	1/2	1/3	1/4	1/2	1/3	1/2	1/2	1/2	1/5	0.0238
Average annual pressure (D)	1/5	1/3	1	1	1/4	1/4	1/3	1/2	1/3	1/2	1/3	1/3	1/2	1/2	1/6	0.0217
Average annual precipitation (E)	1	2	4	4	1	1	2	3	1/2	2	3	2	3	2	2	0.1063
Elevation (F)	1/2	1/3	2	4	1	1	1	1/2	1/2	2	1/2	1/2	1/2	1/2	1	0.0487
Slope (G)	1/3	1/4	2	3	1/2	1	1	1/2	1/3	1/2	1/2	1/2	1/2	1	1/3	0.0358
Aspect (H)	1/3	1/3	3	2	1/3	2	2	1	1/3	2	1/2	1/2	1	1/2	1/2	0.0462
Land use capability (I)	1	1/3	4	3	2	2	3	3	1	4	4	2	3	2	3	0.1191
Soil depth (J)	1/2	1/4	2	2	1/2	1/2	2	1/2	1/4	1	2	1/2	2	1/2	1/2	0.0442
Proximity to roads (K)	1/3	1/3	3	3	1/3	2	2	2	1/4	1/2	1	1/3	2	2	1	0.0554
Proximity to settlement (L)	1/2	1/3	2	3	1/2	2	2	2	1/2	2	3	1	2	2	1	0.0708
Proximity to rivers (M)	1/4	1/3	2	2	1/3	2	2	1	1/3	1/2	1/2	1/2	1	1/2	1/3	0.0393
Proximity to lakes (N)	1/4	1/3	2	2	1/2	2	1	2	1/2	2	1/2	1/2	2	1	1	0.0521
Ground water depth (O)	1/4	1/5	5	6	1/2	1	3	2	1/3	2	1	1	3	1	1	0.0687

λ_{max}= 16.1509
CI = 0.0822
CR = 0.0517 ≤ 0.1

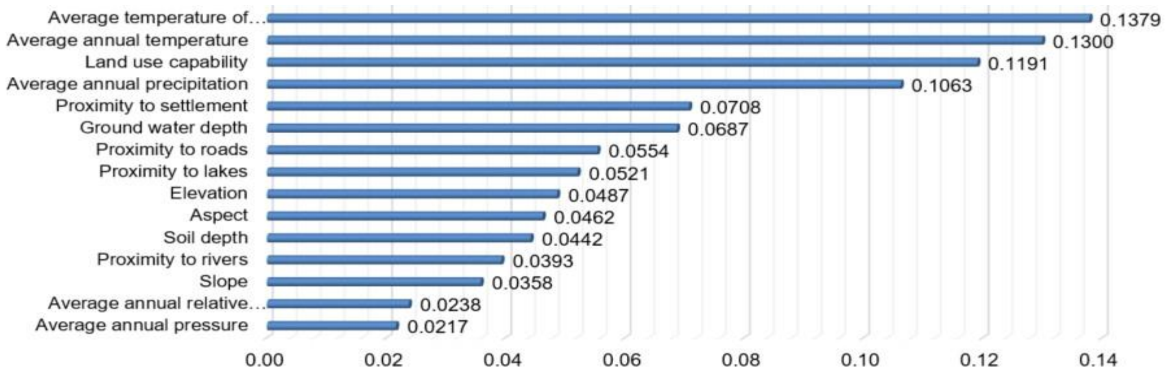

Figure 9- The final AHP weights of the main criteria

Table 3- The AHP model weights of the sub-criteria and the CR values for pair-wise comparison matrix

Criteria	*Sub-criteria*	*AHP weights*	*CR values*
Average annual temperature (°C)	5 - 8	0.1676	0.0122 < 0.10
	8 - 12	0.7380	
	> 12	0.0944	
Average temperature of October (°C)	1.96 - 5	0.0489	0.0254 < 0.10
	5 - 10	0.0629	
	10 - 11	0.2361	
	11 - 12	0.2928	
	12 - 14.9	0.3593	
Average annual humidity (%)	54.6 - 57	0.0665	0.0650 < 0.10
	57 - 58	0.1036	
	58 - 59	0.2272	
	59 - 60	0.2626	
	60 - 63.1	0.3401	
Average annual pressure (hPa)	865.8 - 870	0.1078	0.0436 < 0.10
	870 - 880	0.1433	
	880 - 890	0.1867	
	890 - 900	0.2422	
	900 - 917.9	0.3200	
Average annual precipitation (mm)	314.2 - 400	0.3803	0.0210 < 0.10
	400 - 500	0.3427	
	500 - 600	0.1572	
	600 - 700	0.0734	
	700 - 1150	0.0464	
Elevation (m)	600 - 900	0.0479	0.0754 < 0.10
	900 - 1200	0.5894	
	1200 - 1600	0.2172	
	1600 - 2600	0.1455	
Slope (%)	0 - 5	0.6402	0.0419 < 0.10
	5 - 10	0.1074	
	10 - 15	0.1798	
	15 - 25	0.0726	
Aspect	Flat and South	0.0630	0.0293 < 0.10
	North, Northeast and Northwest	0.1493	
	East and West	0.3189	
	Southeast and Southwest	0.4688	
Land use capability	I	0.2147	0.0439 < 0.10
	II	0.1939	
	III	0.2323	
	IV	0.3049	
	V	0.0542	
Soil depth	Deep	0.1150	0.0926 < 0.10
	Moderate deep	0.1987	
	Shallow	0.1447	
	Very Shallow	0.2824	
	Lithosol	0.1775	
	Other	0.0817	

Table 3 (continued)- The AHP model weights of the sub-criteria and the CR values for pair-wise comparison matrix

Criteria	*Sub-criteria*	*AHP weights*	*CR values*
Proximity to roads (km)	0.030 - 2	0.4162	0.0153 < 0.10
	2 - 4	0.2618	
	4 - 7	0.1610	
	7 – 10	0.0986	
	> 10	0.0624	
Proximity to settlement (km)	0 - 2	0.4204	0.0159 < 0.10
	2 - 4	0.2448	
	4 - 7	0.1641	
	7 - 10	0.1078	
	> 10	0.0629	
Proximity to rivers (km)	0 - 1	0.4338	0.0485 < 0.10
	1 - 2	0.2347	
	2 - 3	0.1743	
	3 - 5	0.0965	
	> 5	0.0607	
Proximity to lakes (km)	0 - 1	0.4432	0.0283 < 0.10
	1 - 2	0.2399	
	2 - 3	0.1585	
	3 - 5	0.0971	
	> 5	0.0613	
Groundwater depth (m)	0-30	0.4233	0.0193 < 0.10
	30-60	0.2954	
	60-90	0.1616	
	90-120	0.0767	
	120-150	0.0430	

According to Figure 10, 49.68% (2 023 615 km^2) of the area is not suitable for WC.

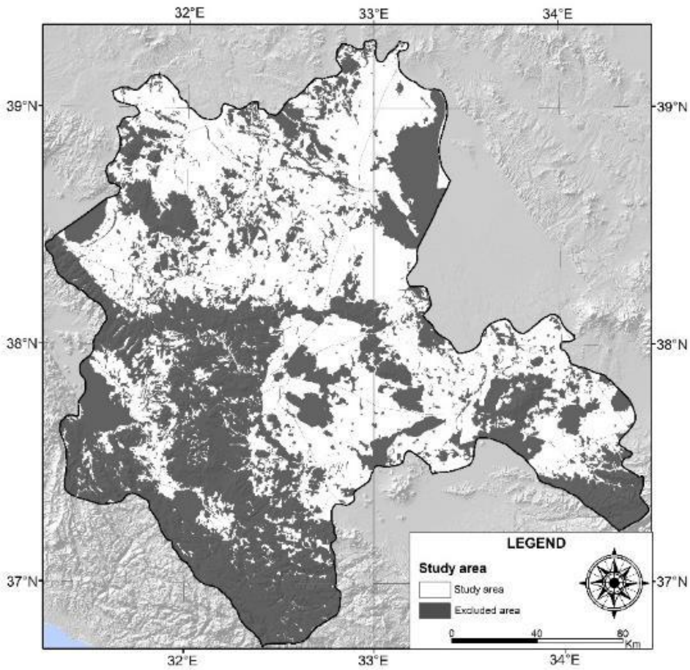

Figure 10- Excluded and study areas

The calculated weights of all the criteria in the hierarchy were taken into account and integrated into the GIS Model Builder in ArcGIS 10.0 software and combined with weighted linear combination overlay analysis and the final LS map was produced for WC shown in Figure 11. The derived LS map was divided into 5 classes as very highly suitable, highly suitable, moderate suitable and low suitable areas and areas not suitable for agricultural activities within the scope of the study. When the LS classification on the basis of Konya province is evaluated, the study region is categorized as very highly suitable 0.39% (15 815 km^2), highly suitable 61.24% (2 494 461 km^2), moderate suitable 31.01% (1 263 350 km^2), low suitable 7.14% (290 717 km^2) for WC. Besides, it was concluded that 0.22% (9 094 km^2) the study region is not suitable for WC (Table 4). According to the

LS map, very highly and highly suitable areas for WC in Konya province are determined as Kadinhani, Sarayonu, Altinekin, Cihanbeyli, Kulu, Karapinar and Emirgazi districts (Figure 11).

Table 4- Suitability classification of wheat cultivation

Land Suitability for wheat cultivation	*Area (km^2)*	*Ratio of area (%)*
Very highly suitable	15 815	0.39
Highly suitable	2 494 461	61.24
Moderate suitable	1 263 350	31.01
Low suitable	290 717	7.14
Not suitable area	9 094	0.22
Total area	4 073 436	100.00

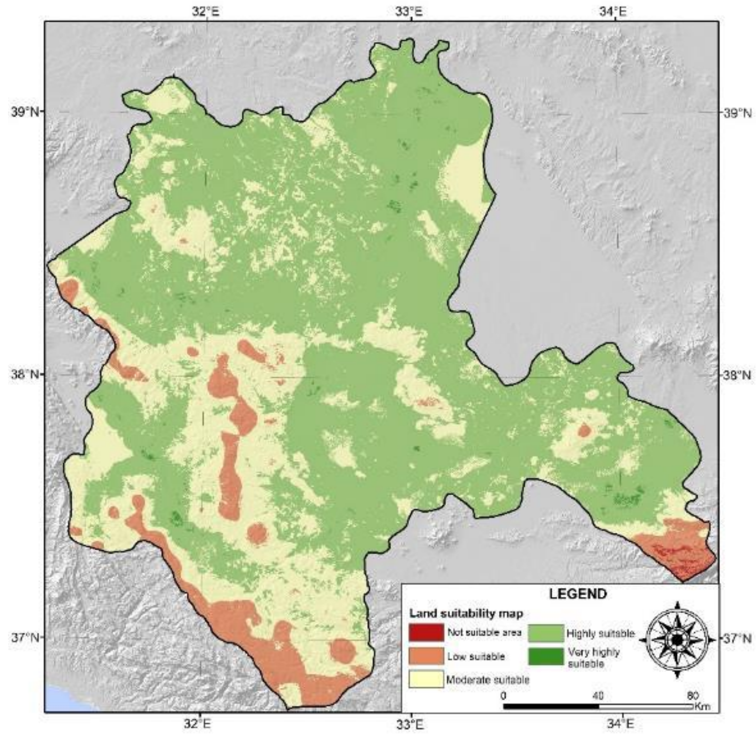

Figure 11- The final land suitability map for wheat cultivation

When the studies in the literature are examined, it is seen that the land suitability map is evaluated as 2-class (Fekadu & Negese 2020; Günal et al. 2022), 3-class (Akıncı et al. 2013; Ayehu & Besufekad 2015; Chivasaa et al. 2019; Pilevar et al. 2020; Tercan & Dereli 2020; Salifu et al. 2022), 4-class (Mendas & Delali 2012; Roy & Saha 2018; Dedeoğlu & Dengiz 2019; Souidi et al. 2020; Tuğaç 2021; Kılıc et al. 2022; Sarkar et al. 2022; Sarğın & Karaca 2023; Makar et al. 2024; Almayyahi & Al-Atab 2024) and 5-class (Pramanik 2016; Otgonbayar et al. 2017; Mandal et al. 2020; Bilgilioğlu 2021; Sarkar et al. 2023; Rangzan et al. 2024). In this study, the land suitability map was evaluated in accordance with the existing literature and divided into five classes in order to provide a more detailed analysis.

When the LS map (Figure 11) and the land productivity map (Figure 12) for the whole Konya closed basin are analyzed, it is seen that the areas with dry farming in the land productivity map overlap with the areas that are very suitable, suitable and moderately suitable for WC in the suitability map. Since Konya closed basin is a basin that is not dependent on external resources, it is important to encourage dry agriculture in this region. For this reason, it is recommended to grow crops that require less water such as wheat in areas suitable for WC according to the LS map.

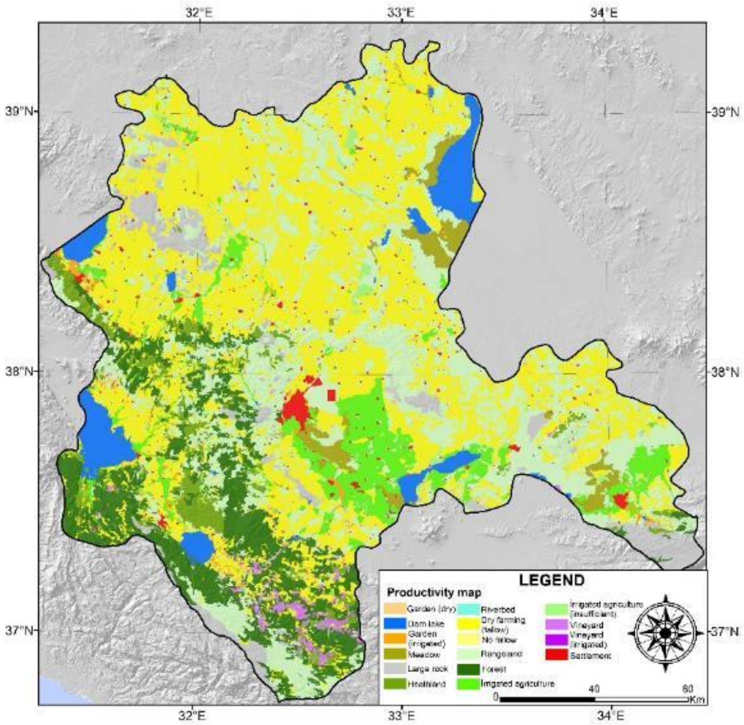

Figure 12- The land productivity map

When the studies on land suitability for wheat cultivation in the literature are examined, it is seen that (Makar et al. 2024) aimed to evaluate the land suitability of wheat in a selected area in El-Beheira Governorate of Egypt. The study employed an evaluation of five principal criteria. It was observed that the temperature criterion was the most significant factor. Sarğın & Karaca (2023) conducted a land suitability assessment in the Van province located in the Eastern Anatolia region and used 13 criteria in this context. It was observed that meteorological criteria were not used in the study, and the slope came to the fore among the criteria used, followed by the organic matter content. Kılıc et al. (2022), conducted a land suitability assessment in the Tozanlı region (located in the upper part of Yeşilırmak basin) in their study. In this context, nine criteria were evaluated, and it was determined that soil depth and elevation were the most pertinent. Dedeoglu & Dengiz (2019), in their study, they considered the Soğulca basin of Ankara province (central Anatolia regional of Turkey), used 10 criteria, and stated that soil depth is an important parameter for wheat production. In a study conducted by Pilevar et al. (2020), a land suitability assessment was carried out for wheat and corn production in the semi-arid regions of eastern Iran. The evaluation was based on 11 sub-criteria, grouped under three main headings. The results demonstrated that the soil texture criterion emerged as the most significant factor. Mendas & Delali (2012) selected the Mleta region in Algeria for wheat production in their study. The study examined ten criteria, and it was found that the drainage and soil criteria were salient. In their study, Fekadu & Negese (2020) conducted a suitability analysis for wheat and barley production on a basin basis in the Lay-Gayint region. A total of 15 criteria were employed in the studies, with pH and soil texture criteria emerging as the most prominent, followed by rain and slope criteria. It is stated that the most important criteria are climatic, topographic and soil parameters in their study. In their study, Rangzan et al. (2024) concentrate on the identification of the most appropriate regions for wheat cultivation in the northwestern part of Khuzestan Province in southwestern Iran. In the study, meteorological, topographic and soil criteria were evaluated, and precipitation and average temperature were identified as the most significant factors among these criteria.

A review of the literature revealed that, in studies conducted for wheat, the selected study areas were predominantly basins, districts, or specific regions. In this study, the entire province of Konya, which is the largest province in Turkey in terms of surface area, was evaluated as the study area. In addition, when the criteria discussed were evaluated, it was seen that 4-15 criteria were evaluated in the studies, soil criteria came to the forefront among them, and in the studies where soil criteria were not used, precipitation and average temperature criteria, which are very important for wheat plant development, came to the fore. In this study, the average temperature criterion came to the fore and it was observed that it was compatible with other studies. In addition, in this study, the average annual pressure criterion was discussed and its importance for the development of wheat plants was investigated. The fact that the soil criterion was not considered in this study is among the limitations of the study and this criterion will be taken into consideration in future studies.

4. Conclusions

The consumption of wheat, which always has a special importance in agricultural products, has been increasing in recent years. At the same time, due to poor land usage policies, the areas suitable for wheat production are gradually decreasing. Considering the rapidly changing environmental impacts, Effective and good agricultural planning is needed to increase agricultural production efficiency. Wheat production has both economic and strategic importance in Türkiye. The share of WC area in the total cultivation area in Türkiye is 49.7% and Konya closed basin is in the first place with 9.1%.

In this study, areas suitable for WC throughout Konya province were determined by using a hierarchy developed with the integration of the AHP method, which is one of the GIS and MCDM techniques. For this purpose, 15 criteria and their sub-criteria were determined under 4 main headings, weight calculations were made, and a LS map was created with the WLC technique according to expert opinions and literature studies on the subject. The LS map derived is divided into 5 classes as very high suitable 0.39%, high suitable 61.24%, medium suitable 31.01%, low suitable 7.14% and areas not suitable for agricultural activities 0.22%. The AHP method used in this study is appropriate, easy to understand and flexible about possible future planning. This process saves time for decision makers and quick results can be obtained for different goals.

Although sustainable agriculture is very important for countries like Türkiye with high population growth and migration potential, demand for wheat, which has strategic importance for Türkiye and is the raw material for staple foods such as bread, flour, and pasta, has been increasing. Therefore, it is important to cultivate and produce according to the suitability of the land. It is thought that the criteria used in this study will be taken into consideration in WC in the Konya closed basin in the future.

Declarations

Data availability Not applicable.
Code availability Not applicable.
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Conflict of interest The authors declare that there is no conflict of interest.

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