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Ecological risk analysis with the help of geographic information systems in fruit growing; Manisa in Türkiye example

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Abstract

With the help of information technologies, which are developing day by day, it has become easier to perform agricultural analyzes. Positional analyses can be performed with the help of Geographical Information Systems by gathering Climate, Soil, Topography and İrrigation data related to Agriculture. These analyses enables to generate analyses for agricultural investment maps, areas of agricultural conformity, plant pattern determination, etc. The purpose of this study is to prepare "Product Based Fruit Growing Risk Analysis Maps". Climate, Soil, Topography and Irrigation data, which are important in the growing of agricultural products are collected, severity and prospects for risk analysis are determined separately and risk values are established for each risk factor. The total risk value was calculated by prioritizing risk factors using the Analytical Hierarchy Process (AHP), one of the multi-criteria decision-making methods. Thanks to AHP, a methodology for calculating scenario-based risk values has been developed taking into account different probabilities. With the developed model, risk maps were created for climate, soil, topography and water constraints. The total risk map was obtained by combining the risk maps created with AHP. In this study, a model was created by selecting the Manisa Province Peach product in Türkiye. As a result of the model, the total risk values were divided into classes as “High Risk Areas”, “Medium Risk Areas”, “Low Risk Areas” and “Strongly Not Recommended Areas” according to the points they received spatially.

1. Introduction

The existing agricultural areas in the world are decreasing by 0.1-0.2% every 5 years, and the world population has increased by 30% in the last 20 years and reached 8 billion. (UN, 2022). In Türkiye, the amount of cultivated area decreased by 12 percent in the last 20 years and decreased to 23.5 million hectares. In the same period, the population of the country increased by 28 percent and reached 84 million.

The increasing world population increases the demand for food, but the disasters caused by climate change and deteriorating agricultural lands cause serious decreases in food supply at the opposite rate. At this point, the way out seems to be to switch from traditional farming methods to smart, planned and precision agriculture, also called Agriculture 4.0, where information systems are used. In smart and planned agriculture, determining what to grow where and how, thanks to the products grown in ideal conditions, it ensures that the products that are least affected by diseases and pests are obtained. However, it is not always possible to choose land with ideal conditions. Thanks to the studies carried out at this point, knowing in advance what kind of risks the existing land has, allows the creation of artificial conditions to correct the factors that cause damage.

Risk is the value determined according to the probability of damage that may be caused by dangerous situations. The purpose of risk management is to control the consequences of this uncertainty. For this, it is necessary to identify and analyze the risk factors. Risk management will be easier when risk factors are analyzed beforehand. As seen in the “risk = severity × probability” formula, the degree of risk revealed by severity and probability values can have the same value for very different conditions. In the first case, systems that will cause less damage should be considered, taking into account the situations that will occur when the event occurs. For the second case, the reasons leading to the occurrence of the event should be determined and an attempt should be made to eliminate them effectively. (Senel et al., 2013).

In this study, land suitability, site selection and ecological risk analysis for the fruit growing sector are discussed with the help of GIS applications. With GIS applications that make a significant contribution to the processing of big data, researchers, practitioners and policy makers are provided with the opportunity to successfully present advanced agricultural analyzes.

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2. Method

The study was developed on the basis of site selection analysis on ArcGIS model builder application. For risk analysis, severity and probabilities were determined and geographical layers that could cause yield loss in crop production were listed on the fault tree with the help of Analytical Hierarchy Process (AHP).

2.1. Dataset

Statistical and digital data obtained from various institutions were transferred to the geographic database created in ArcGIS 10.5 application. By converting statistical data into geographic data format, climate, soil, topography and water presence maps shown in Figure 1 were created.

30 years of statistical climatic data were transformed into geographic data by using “co-kriging” and inverse distance weighting (IDW) methods.

Climate Data	***Soil Data***
Temperature	Soil Depth
Average Temperature on a Monthly	Lithosolic
Maximum Temperature on a Monthly	Very Shallow (0-30cm)
Minimum Temperature on a Monthly	Shallow (30-50cm)
Extreme Maximum Temperature on a Monthly	Medium Deep (50-90cm)
Extreme Minimum Temperature on a Monthly	Deep (90-150cm)
Precipitation	Very Deep (>150cm)
Total Precipitation on a Monthly	Soil Erosion
Summer Months Total Precipitation	Wind Erosion
Total Annual Precipitation	Rain Erosion
Sunbathing	Land Use Capability
Total Sunbathing Times on a Monthly	1-8th Class Land
Annual Total Sunbathing Time	Available Land Use
Evaporation	Absolute Irrigated Farmland
Evaporation Values on a Monthly	Marginal Irrigated FarmLand
Average Annual Evaporation Amount	Absolute Dry Farmland
Humidity	Marginal Dry Farmland
Average Humidity value on a Monthly	Planted Agricultural Land
Spring Months Average Humidity value	Meadow and Pasture Areas
Summer Months Average Humidity Value	Wetlands
Wind	Forest Areas
Average Wind Speed on a Monthly	More Fields
Soil Temperature	Drainage
Water Data	***Topography***
Irrigation	Height
Streams	Slope
Dams and Lakes	Aspect

Figure 1. GIS Datasets

2.2. Agricultural Risk Analysis

Fault tree analysis (FTA) is a tool that can be used to help the analyst identify, evaluate, and analyze all root causes and pathways leading up to the occurrence of a particular event. (Jafarian et al. 2012)

To construct a tree, a top event is placed at the top and then connected to logic symbols representing the conditions for the event to occur, and then connected to the intermediate events that caused the top event.

The risks faced by farmers are grouped under two headings: ecological risks arising from natural events and economic risks arising from financial conditions. Today, risks such as increasing disasters (drought, hurricane, flood, frost, and hail), change of seasons, erosion, diseases and pests due to climate change are grouped under the title of ecological risks. In a recent study, researchers estimated that 23% of field crops were lost due to adverse weather conditions. In horticultural crops, this rate increases remarkably. (Islam at al., 2018).

In this study, spatial risk analysis was performed with a model developed in GIS on the determination of ecological risks in fruit growing. The process proceeds in three steps. The first step is to establish the model with the FTA method, the second step is to enter the intensities and probabilities of the causes, and the third and last step is to run the model developed on the ArcGIS software and create the maps.

In the climate, soil, topography and water presence layers, the values that may pose a risk during the growth of the plant and value of the severity and probability this risk are entered. Suitable areas where a selected plant grows with high yield, that is, with the least risk, will receive the lowest score, while areas where the growing conditions for the plant are unfavorable and contain high risk will receive the highest score in the risk matrix.

In addition, by assigning values between these layers according to their importance, the risk scores from the layers can be re-scored hierarchically thanks to the Weighted Overlay Analysis tool. (Ahmed et al., 2013).

First of all, the process begins with the collection of data and recording it on the database after standardization. Then, the risks that may cause yield loss for each product and the probability and severity values of these risks should be determined. AHP priority values created for each sub-risk value of the risk analysis will be determined. Finally, the final total risk map will be created by combining all sub-risk layers according to hierarchical ranking and scoring according to the fault tree logic in Figure 2.

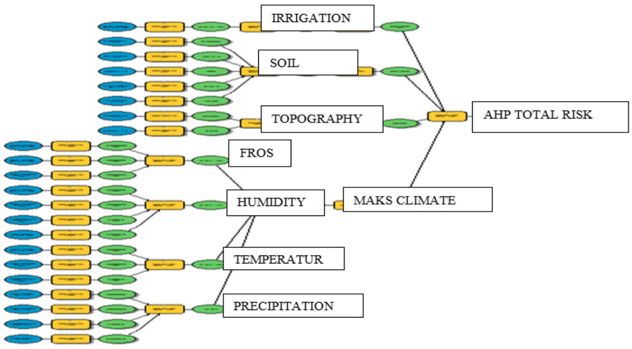

Figure 2. GIS Model Fault Tree

The Risk Matrix was created in table 1 using the formula “Risk= Severity x Probability (Probability)”. According to the scores they got after the entered values;

- Green areas: 1-6 low risk (1 pointless risk)
- Yellow areas: 6 -12 medium risk
- Red areas: 12-25 are determined as high risk (25 irreparable risk).

Table 1. Risk Matrix

MATRIX	**Severity**				
Probability	**Very Light 1**	**Light 2**	**Moderate 3**	**Serious 4**	**Very Serious 5**
Very Small 1	Meanless 1	Low 2	Low 3	Low 4	Low 5
Small 2	Low 2	Low 4	Low 6	Medium 8	Medium 10
Medium 3	Low 3	Low 6	Medium 9	Medium 12	High 15
High 4	Low 4	Medium 8	Medium 12	High 16	High 20
Too High 5	Low 5	Medium 10	High 15	High 20	Irreparable 25

The GIS model assigns the probability values entered for the layers as values into each cell spatially. The average temperature value of a point selected as an example in Manisa in April is -1 °C and the severity of frost damage to the peach trees at this point is moderate 3. The average temperature value of the same point is -5 °C in March and +3 °C in May. Therefore, the average temperature value in March and May will be 4 and 1 frost severity. However, considering the blooming periods of the peach trees at the chosen point, the probability of frost in April, when the flowering is the highest, is 5, and the probability of frost is 3 and 1 due to the low flowering in March and May (Gerçekçioğlu, 2008; Gür et al., 2011).

Table 2. Risk Factors

Selected Point Layers	Temperature	Severity	Probabilities	Risk Severity	Frost Risk Factor
March	-5 °C	Serious 4	Medium 3	4x3 12	**Maximum Risk Severity 15**
April	-1 °C	Moderate 3	Too High 5	3x5 15	
May	+3 °C	Very Light 1	Small 1	1x2 1	

For this reason, for each risk factor, a sample table is filled as in Table 2 and a "Significance Evaluation" is made by using the AHP over the risk factors. AHP is used to prioritize risk factors among risk factors. This is done with the "Weighted Overlay" analysis tool in GIS.

After the criteria and sub-criteria are determined by using the Super Decision program, the criteria that affect each other can be determined by analyzing the interactions between the criteria, and the network structure in Figure 3 is created by making connections between the criteria, internal and external dependencies, and feedbacks with the help of the program.

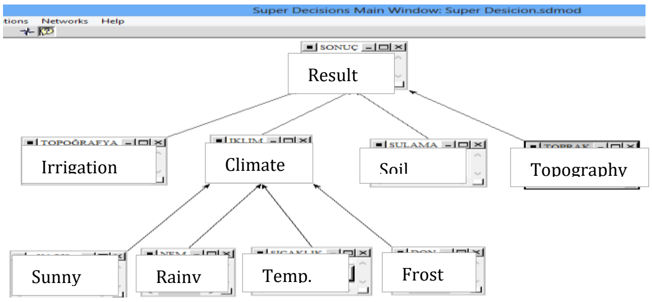

Figure 3. Super Decision Program Interface

After entering the risk probability and severity values of all layers under the climate, soil, topography and irrigation layer groups for the peach crop, the "superiority" importance scores among the risk factors are entered in Table 3.

After this stage, risk factors ranging from 0 to 25 values were obtained in each group. "AHP priority values" between climate, soil, topography and irrigation layers are entered in the "weighted overlay" tool in GIS. Since the sum of the values entered in the AHP is equal to the full value of "1", the final values will be "total risk" values between 0 and 25. In the peach sample, the "frost risk factor" took a value of 15 at a selected point. Again, the same point took the values of "humidity", "temperature", "precipitation" 10, 12, 8 by manual calculation. While calculating the climate risk factor, the value of 15, which is the maximum risk among the subgroups, was taken as shown in Table 3.

Table 3. Total Risk Superiority Table

Risk Factors			Severity Weight	Total Risk
Irrigation			0,10303	**Climate + Topography + Soil + Irrigation = 1**
Soil			0,11887	
Topography			0,29271	
	Layers	**Climate Max Risk**		
Climate	Frost Humidity Temperature Precipitation	Max (Frost, Humidity, Temperature, Precipitation)	0,4809	

Climate Risk Factor=Maksimum[Frost Risk, Humidity Risk, Precipitation Risk, Temperature Risk]

Climate Risk Factor=Maksimum[15, 10, 12, 8]=15

Again, in the manual calculations made for the same point, the soil took the risk value of 8, the topography 12, and the irrigation 18 risk value. The final ecological risk value was calculated by entering the prioritization scores for climate, soil, topography and irrigation with AHP.

Final Risk =Climate x 0,48 + Soil x 0,12 + Topography x 0,30 + Irrigation x 0,10

Final Risk =15 x 0,48 + 13 x 0,12 + 8 x 0,30 + 16 x 0,10 =12,40

3. Results

As a result of the process, it is seen that the point selected for the cultivation of peach crops is "moderate" in the risk matrix according to the calculations. This manual calculation for a single point was automatically performed on the GIS for millions of points and risk maps were generated for all sublayers and group layers separately, as shown in Figure 4.

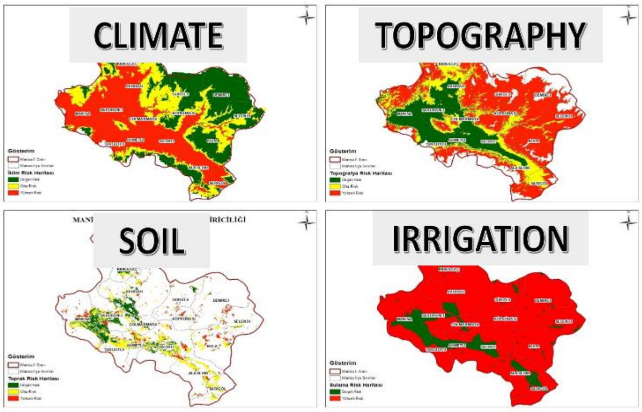

Figure 4. Sublayers Risk Maps

The negative impact of each sub-risk factor on crop yield is different. Therefore, the effect of the sub-risk factor on the total risk will be different according to the AHP priority value. The final risk map of the peach crop in Figure 5 was obtained by combining the climate, soil, topography and irrigation sub-risks as a result of hierarchical scoring.

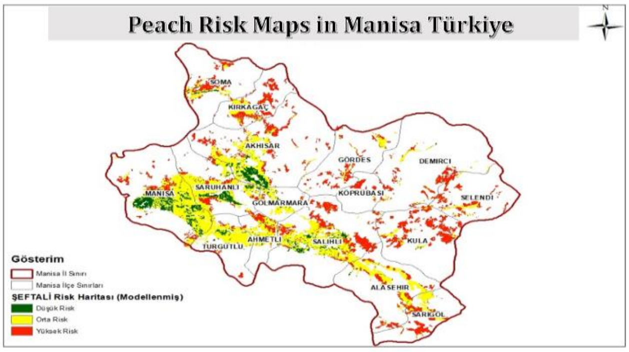

Figure 5. Peach Risk Maps in Manisa Türkiye

4. Discussion

According to the 2020 data of the Turkish Statistical Institute, the maximum peach yield per tree in Türkiye is 85 kg, and the average yield is 49 kg. According to the same data, peach yield is high in Manisa Province Center, Saruhanlı, Akhisar, Turgutlu, Salihli and Sarıgöl districts. In the high-risk red areas in the risk map created as a result of the model, the yield is low in direct proportion to the statistics, while the yield is high in the low-risk green areas. Most of the Manisa Plain appears to be medium risk. When the sub-risk factors are examined, the plain region seems to be low risk in soil, topography and irrigation layers, but climatic factors, which are the main limiting factors in fruit growing, resulted in high risk in the plain.

5. Conclusion

It has been determined that the peach is highly affected by the risk factors coming from the climate and topography layers. Although the soil and topography risk is low in the lands in the plain region, it has been adversely affected by climatic factors. Because in the months of high temperatures, the risks against diseases and pests increase due to climatic conditions. It is evaluated that the risk factors of peach can be reduced by cultural and mechanical climate improvements. As a result of the digitization of the maps, a total of 215.000 hectares of land can be grown in peach, and 27.500 hectares of these areas are low risk, 112.000 hectares are medium risk, and 67,000 hectares are high risk.

Thanks to the risk analysis model developed on GIS; Site selection and risk analysis can be made for all plant products whose climate, soil, topography and irrigation data and ecological demands are known. By examining the risk maps created, the risks that may cause yield loss during the production phase of agricultural activities can be determined in advance, and high yields can be obtained with the measures taken.

This study is a methodology study to encourage the use of developing technologies such as Geographic Information Systems (GIS) in land-based agriculture. It will become a necessity for us to use smart agricultural systems in order to meet the food needs of humanity against all the negativities experienced on our planet. Intelligent farming systems called Agriculture 4.0 will also be possible as a result of the integration of GIS and agricultural activities.

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