Using Open Source GIS Based RUSLE Model in Erosion Risk Assessment

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***Abstract*— Soil erosion is an increasing problem, particularly in agricultural areas, where soil erosion not only leads to a reduction in agricultural productivity, but also reduces the availability of water. Revised Universal Soil Loss Equation (RUSLE) is the most popular empirically based model used globally for erosion prediction and control. The techniques of the Geographic Information System (GIS) have become valuable tools, particularly when evaluating erosion on a larger scale due to the amount of data required and the greater coverage of the area. The current area of study is a part of the region of Thrace with an undulating topography, with a risk of soil erosion. An attempt was made in this study to evaluate the annual soil loss caused by water and wind in Tekirdag province using RUSLE within the GIS framework. In identifying priority areas for the implementation of erosion control measures, such information can be of immense help. The soil erosion rate was determined in the province using the RUSEL equation with GIS techniques as a function of land topography, soil texture, land use/land cover, rainfall erosivity, and crop management, and practice. RUSLE's rainfall erosivity R-factor was found to be between 40,48-375,00 and the soil erosivity K-factor varied between 0,00-0,40. Provincial elevations ranged from 10 to 1031 m, with LS factor values ranging from 0 to 17.34. Using the CORINE 2018 data, the C factor was found. The P-value was calculated in the province from existing cropping patterns. The estimated annual soil loss in the province using RUSLE is 10.25 tons/ha/yr.**

***Keywords*— Soil erosion, RUSLE, Tekirdağ, CORINE, QGIS**

I. Introduction

Today, soil degradation is a serious problem due to erosion due to rainfall and wind, particularly in developing tropical and subtropical countries. Erosion is a natural geomorphic process that continually takes place on the surface of the earth. Accelerating this process through anthropogenic degradation, however, can have serious effects on the quality of the soil and the environment.

56% of our country consists of mountainous lands [1]. Turkey's topography and climatic dynamics of this aspect, it is quite susceptible to erosion formation. In order to take control measures, which have an important place in combating erosion, areas where erosion is effective should be determined quickly. Erosion studies carried out on large lands with methods based on traditional land surveys are labor-intensive and costly and take a long time [2].

Most Remote Sensing (RS) and Geographic Information System (GIS) techniques have been used in agriculture in light of technological developments. In the better planning of the country's agriculture [3], the determination of the quantity and distribution of available agricultural land in agricultural activities plays an important role.

There are negative economic and environmental effects of soil erosion [4]. The economic impact is due to the loss of farm income due to the decrease in on-site and off-site income and other damage that negatively affects the production of plants / animals. Soil erosion has effects on productivity both on-site and off-site. The loss of soil erosion efficiency in situ is due to three factors. Short-term productivity losses are the first of these, and these are factors such as crop yield loss, seed loss, input loss (seed, fertilizer), water loss, extra tillage, time loss due to delayed planting. The second is long-term losses of productivity and these are losses such as loss of top soil, decrease in soil structure, decrease in organic matter content of soil, erosion of soil cultivation. The third factor is the reduction in the quality of the soil, and these are factors such as the temporary reduction in the quality of the soil, the temporary pollution of surface water by sediment chemicals.

Three reasons also depend on the non-situational economic impact of soil erosion. The first of these is the deaths of seedlings due to short-term effects, low floor area flooding, chemical impacts on seedlings, delayed planting. Its long-term effects are infertile soils burying the top soil, altering drainage conditions and altering the slope with tillage erosion. The third and final effect is the decrease in the quality of land / soil, including a temporary decrease in the quality of land / soil due to floodplains, changes in the soil-water system and water layer, and additional water management (irrigation, drainage, etc.).

Agricultural land acquisition, excessive and irregular grazing, forest destruction, etc. Anthropogenic impact and erosion are accelerated, in addition to natural factors, by the increasing violence in Turkey [5].

Erosion is one of the significant environmental issues that must be addressed by our nation. While erosion is observed in the countries of the European Union in an area of approximately 25 million hectares per country, 57 million hectares are seen in our country. Although erosion alone is regarded as an ecological issue, it sometimes causes hunger and migration. Every year, approximately 500 million tons of fertile soil is lost. It shows how great a threat to our nation is that 99% of our soils are affected by water erosion and 1% by wind erosion [6].

In the 2014 study of the calculation of soil loss using the RUSLE and GIS equations for the Tekirdağ region, the soil loss value was reported to be 5,26 tons/ha/yr [7].

This study will create databases of erosion caused by precipitation and wind in the province of Tekirdağ. All data will be processed using open sources GIS software (QGIS 3.16) and the results obtained will be accessed on the internet. Source research and definitions are included in the first part of the study, which consists of three primary parts. The material and the method used in the study are explained in the second part. The results obtained in the study were summarized, suggestions were made and presented for debate in the third part.

II. MATERIALS AND METHOD

A. *Research Area*

Tekirdag is one of the three cities in the northwest of the Marmara Sea, located on the European continent, less hilly, on alluvium-enriched land. The province of Tekirdağ has coordinates of 26˚43'- 28˚08 'east longitudes and 40˚36'- 41˚31' north latitudes. It is surrounded by Istanbul to the east, Edirne and Çanakkale to the west, the Marmara Sea to the south, and Tekirdağ to the north, and the Black Sea's short coast (Fig.1).

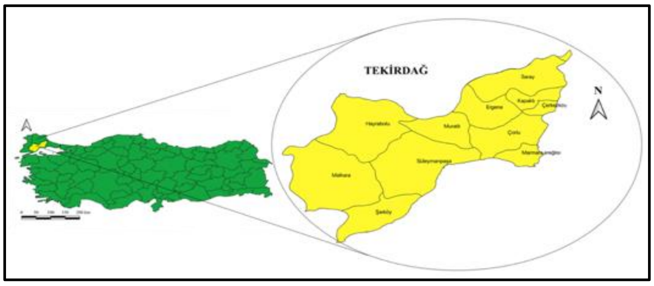

Fig. 1. *Research area*

B. *What is QGIS & Why QGIS?*

QGIS is a user-friendly Open Source Geographic Information System (GIS) licensed under the GNU General Public License. QGIS is an official Open Source Geospatial Foundation (OSGeo) project. It runs on Linux, Unix, Mac OSX, Windows and Android and supports multiple vector, raster, and database formats and features. That means you can read or modify the code, should you choose to but you don't have to. QGIS is an open source, community-driven GIS desktop software that allows a variety of ways for users to visualize and analyze spatial data. There are many reasons to use QGIS, but here are a few:

- It's a robust, powerful desktop GIS
- Runs on all major platforms: Mac, Linux, & Windows
- Free of charge, all access (no paid add-ons or extensions)
- Frequent updates & bug fixes
- Responsive, enthusiastic community
- Integration with other geospatial tools & programming languages like R, Python, & PostGIS
- Access to analysis tools from other established software like GRASS and SAGA

Native access to open data formats like geo JSON & Geo Package Comes in a more than 40 languages, making it easier to work with a larger variety of collaborators [8], [9].

C. *CORINE Land Cover Data*

Coordinated by the European Environment Agency (EEA), the pan-European component produces information on land cover/land use (LC/LU) in the CORINE Land Cover, High Resolution Layers, Biophysical Parameters and European Ground Motion Service data. CORINE Land Cover is given for the years 1990, 2000, 2006, 2012, and 2018. In this vector-based dataset, 44 land cover and land usage classes are included. . The high-resolution layers (HRL) are raster-based datasets which provides information about different land cover characteristics and is complementary to land-cover mapping (e.g. CORINE) dataset (Table-1) [10].

D. *Preparation of Data Elevation Model - DEM Map*

The Tekirdağ DEM maps were produced using NASA-ALOS satellite images. To prepare DEM maps for the province of Tekirdağ, the 'SRTM Downloader' plugin in QGIS was used. The resolution of the ALOS satellite images, consisting of 6 sections covering the whole of Tekirdağ province, is 16.5x16.5 m. With the help of the 'Raster / Miscellaneous / Merge' command, DEM images, each consisting of 6 pieces, were combined as one object. The DEM map was determined in the next step by the command “Raster / Extraction / Clip Raster By Mask Layer" according to the provincial borders (Fig.2).

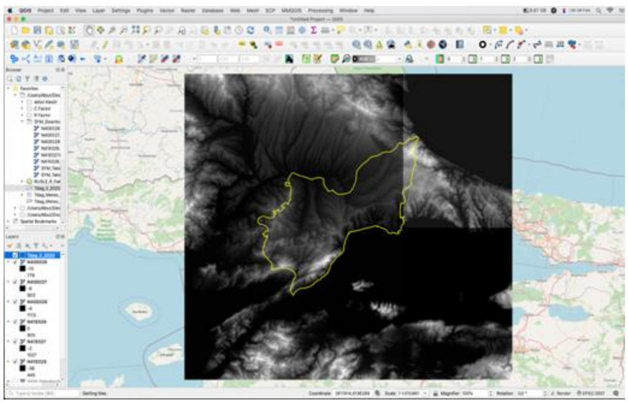

Fig. 2. Preparation of Tekirdağ DEM map

E. *Potential Estimation of Soil Loss Distribution (A)*

According to the RUSLE model, the potential soil loss of the area was multiplied by the GIS method, and thus the potential soil loss of the province of Tekirdağ was estimated as (tons/ha/yr) (1).

$$A = R * K * LS * P * C \qquad (1)$$

As a single sheet in the GIS environment, the slope and slope length factor (LS), precipitation erosion factor (R), soil erosion sensitivity factor (K), plant management factor (C) and soil protection factor (P) were obtained. According to Morgan, soil loss appropriate for agricultural production is 10 tons/ha/yr [11]. When determining soil loss rates for the classes, this tolerable amount was taken into consideration.

The main method of this research is to model the soil erosion process using the Open Source GIS technique based on the integrated RUSLE equation (using QGIS software and its add-ons). In particular, the QGIS software is used to prepare and standardize certain input data; the GRASSGIS plugin also fulfills the main tasks of analysis, estimation, creation, conversion, incorporation into the model of map coefficients, statistics, current situation, potential erosion. The flowchart for the following research method is shown in Fig. 3 [12, 13, 14, 15].

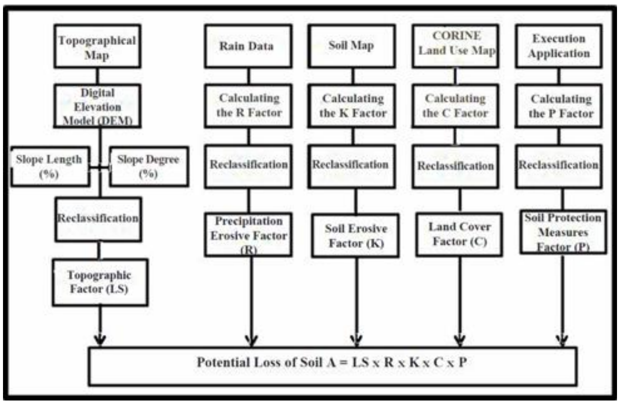

Fig. 3. Modelling flowchart fort he soil erosion.

F. *Calculating Precipitation Erosion Factor (R)*

In the calculation of the R coefficient in the RUSLE model, meteorological data of several years were used, taken from 13 meteorological stations in and around the province of Tekirdağ, which is a research field of the Directorate-General of Meteorology. The Arnoldous (1980) Modified Fournier Index (MFI) formula, one of the formulas developed to find the value of the "Erosion Index," was used to measure the R value (2) [16, 17, 18, 19].

$$MFI = \sum_{i=1}^{12} \frac{pi}{p} \qquad (2)$$

Equality; “pi” monthly precipitation (mm) is expressed as annual precipitation (mm) average of “p”. Equation used in the Erosive Factor (R) calculation for precipitation (3);

$$R = (4{,}17 * MFI) - 152 \qquad (3)$$

G. *Calculating soil erosion sensitivity (K)*

The soil's erodibility is largely due to the soil's physical and chemical properties that form its internal structure. In other words, the soil's hydraulic permeability depends on the properties, texture and structure of the organic material. Although some soils are resistant against the same erosive forces, some other soils are easily dissolved and eroded [20]. K Factor is the expression of soil lost from hectare in tons with unit erosion index on a land with a slope of 9% and a slope length of 22.1 m.

Using silt and very fine sand (percent), sand (percent), organic matter (percent), structure and permeability parameters of the soil [15, 21], a method for determining the K value was developed.

In the K factor calculation, the soil map obtained from the Kırklareli Atatürk Research Institute for Soil, Water, and Agricultural Meteorology was used. In the QGIS software, a map is opened numerically and simplified according to the Major Soil Groups function from the Attributes Table options. This process is achieved by combining the values of the same class category with the aid of the QGIS software plugin "Vector / Geoprocessing Tools / Dissolve".

The Tekirdağ Province classification process is conducted based on soil erodibility values (K factor). Finally, the K-factor values for the province of Tekirdağ, the areas covered by them, and the proportional distributions were calculated.

H. *Calculating Land Cover Factor (C)*

When calculating the C coefficient in the RUSLE model, an approach using remote sensing technology and GIS from the CORINE 2018 data is recommended. This data makes it easier to calculate the C coefficient in the RUSLE model. In general data on soil, land use, topography, vegetation, and climate are the data required for the analysis. The literature on the subject was reviewed, providing information on remotely sensed data and geographic information systems in Turkey and the world of erosion modeling, soil loss assessment models and modelling. Using GIS techniques, our land was chosen, and research was carried out on it [20],[22].

I. *Calculating soil erosion sensitivity (LS)*

The Tekirdağ DEM model was developed with the aid of NASA-ALOS satellite images to produce the Tekirdağ Slope Length and Slope Degree Factor Factor (LS). The sub-module operation in the GRASS extension raster sub-module of the QGIS application was added to the improved DEM map of the Tekirdağ DEM model [17].

J. *Potential Soil Loss Distribution (A) Calculation*

The potential basin soil loss (A = R * K * LS * P * C) has been multiplied by replacing the potential basin soil loss (A = R * K * LS * P * C) in the GIS setting according to the RUSLE model and the potential soil loss of the province of Tekirdağ is estimated as (tons/ha/yr). The appropriate loss of soil for agricultural production is 10 tons/ha/yr, according to [11]. When defining classes of soil loss rates, this tolerable limit was taken into consideration.

The resolution values are corrected as 30 m * 30 m for all images in raster format to be used to measure possible soil loss.

In the Geotiff raster format, the values of R, K, LS, C factors and images in the RUSLE formula and measured in the QGIS application are used with the command 'Raster / Raster calculator' in the QGIS application Raster command.

Instead of the values in the equation 'A = R * K * LS * P * C' that we use to measure the A value, the Geotiff formatted maps were written in the process window that opens, and the R factor was visually measured in raster data format (Fig.4).

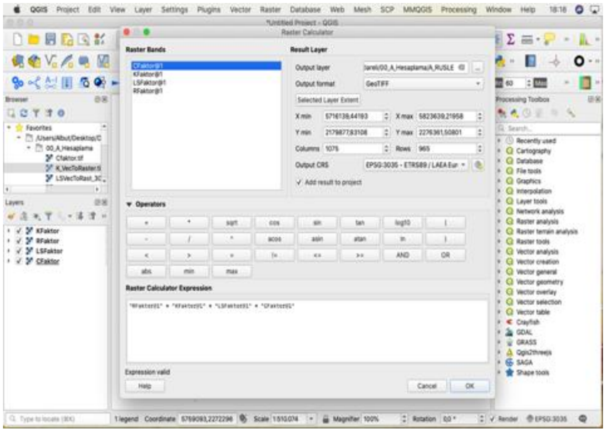

Fig. 4. *Calculate with the "Raster Calculation" command from the QGIS application Raster Info.*

III. RESULTS AND DISCCUSSION

Results of factors R, K, C, LS and P in the RUSLE equation obtained from the research are given in this section.

A. *Factor R*

The locations of the meteorological stations in the province of Tekirdag region, station altitude in metres, latitude and longitude, and annual average rainfall in mm type, Arnoldous formula (1980), MFI values and R factor values are all given in Table 1 and Fig.5.

Accordingly, the values in the R factor map belonging to the Tekirdağ province area range from 32,975 to 275,929 MJ ha-1 year-1 x mm h-1. Although the R map is similar to the precipitation map of the research area, it has been observed that as the altitude increases, the amount of rainfall increases, the R factor of the research area has emerged to confirm the relationship between precipitation and altitude.

In relation to the R values, elevation plays an important role. When we compare the region's elevation map and R factor map, it is seen that the high R parts correspond to the high places in the province, which is

TABLE I. MFI VALUES AND R FACTOR VALUES TEKİRDAG METEOROLOGY STATIONS

Station ID	Station Name	Average Precipitation	MFI (mm)	R Factor
17056	Tekirdag	585,03	56,62	84,133
17640	Cerkezkoy	567,65	47,80	47,331
17634	Malkara	694,57	65,74	122,169
18107	Sarkoy	484,11	44,36	32,975
18108	Hayrabolu	593,20	54,18	73,918
17054	Corlu	616,81	56,52	83,678
18422	Muratli	591,08	64,49	116,934
18423	Saray	665,38	76,91	168,705
19122	Kapakli	522,40	51,79	63,965
18804	Banarli	681,20	67,86	130,979
18806	Ganos Dagi	1011,60	102,62	275,929
18805	Dogankoy	598,07	59,53	96,241
19121	Vakiflar	556,60	58,80	93,188

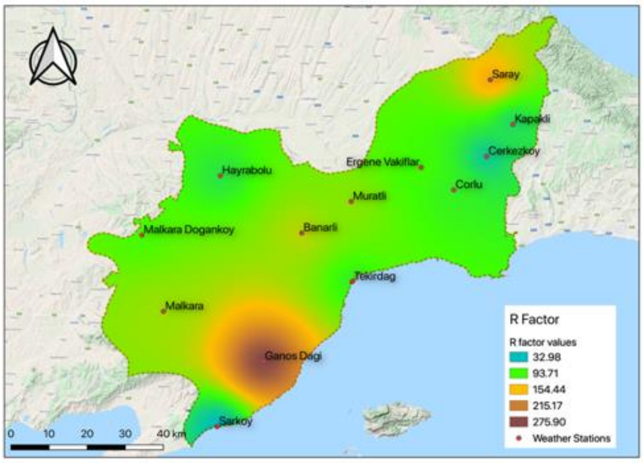

Fig. 5. R factor map of Tekirdağ province

to say, it decreases as we go from north to south. In the high portions of the Ganos Mountains of the province, the areas with the highest R value appear. Also if precipitation is presumed to increase due to the rise in altitude, this relationship will be seen to be normal. Again, R values show a slight rise around the village of Cerkezkoy in the central part of the province. The drop in the values of Sarkoy district is remarkable. On the slopes of the mountains, values fall.

B. *Factor K*

The areal and proportional distributions of the K factor classes obtained were computed for the province of Tekirdağ. In the following table, the results are given (Table 2).

The highly erodible K factor has been identified as the majority of the field of research (Grade 4). In terms of erosion (class 2), moderately erosive (class 3) balls, very little soil erosion (class 1), very little and very high soil erosion, there is little erosion (class 2) (5th class).

TABLE II. SOİL ERODİBİLİTY VALUES ACCORDİNG TO K FACTOR CALCULATİONS

No	Soil Erosion Class	Soil erodibility values	Area	
			km²	*%*
1	Slight	0,00 – 0,05	145,71	2,30
2	Moderate	0,05 – 0,10	112,33	1,77
3	High	0,10 – 0,20	747,04	11,78
4	Very High	0,20 – 0,40	5.337,42	84,15
TOTAL			6.342,50	100,00

It can be said that the most important factor in the fact that the K Factor values are very close to each other and the value obtained is highly erodable (Grade 4) in the province of Tekirdağ is the lithology (main rock) and the soils formed accordingly. Rocks originating from the same origin sprout in almost all of Tekirdağ.

When the K Factor distribution map (Fig. 6) is examined, although Tekirdağ soils are in the 4th class, there are differences within this class in the distribution throughout the region. High values are found in the central and northern parts of the region with K values. On the other hand, in the region where the slope and elevation are decreased, low K values are seen in the southern residential areas of the region.

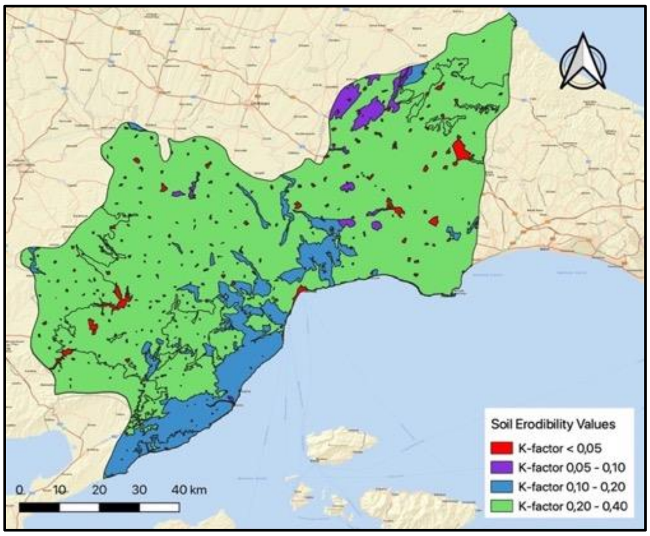

Fig. 6. Soil erodibility values map of Tekirdag region.

C. Factor C

It is known that the base data map prepared with CORINE provides more reliable results since it includes more up-to-date data. However, the rate of areas exposed to erosion was very poor. It should not be ignored that the amount of erosion is greater than that of other fields from sloping lands. In the northern portion of the study region, areas of greater breakup and degradation are at higher risk of erosion. It is important not to forget just how significant the effect of land use and land cover on erosion is. The map with a low level of erosion was found to have higher areas of oak and forest, which reduced the amount of soil loss.

It has been found that the risk of erosion seen in agricultural areas is greater. Farmers should be considered as the target audience in the fight against erosion in agricultural assets and awareness and training should be carried out (Fig. 7). Below are the ratios and isal results for the C values obtained in Tekirdag province (Table 3).

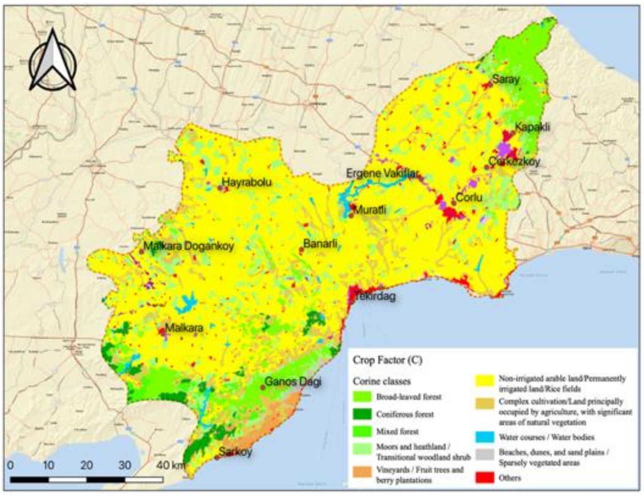

Fig. 7. Reclassifications C factor values

TABLE III. THE AREA AND RATES COMPUTED FOR TEKİRDAĞ COVERED BY THE VALUES OF THE C FACTOR.

CORINE classif. ID	Land cover / Land use classes	C Factor	Area	
			(km²)	*(%)*
311	Broad-leaved forest	0,001	551,928	8,71
312	Coniferous forest	0,010	105,705	1,67
313	Mixed forest	0,050	100,541	1,59
322-324	Moors and heathland/ Transitional woodland shrub	0,038	241,318	3,81
231-321	Pastures Natural grassland	0,090	287,953	4,54
221-222	Vineyards / Fruit trees and berry plantations	0,180	61,603	0,97
211-212-213	Non-irrigated arable land / Permanently irrigated land / Rice fields	0,280	4100,714	64,69
242-243	Complex cultivation / Land principally occupied by agriculture, with significant areas of natural vegetation	0,500	489,286	7,72
511-512	Water courses / Water bodies	0,001	53,546	0,84
331-333	Beaches, dunes, and sand plains / Sparsely vegetated areas	1,000	16,924	0,27
-	Others (Artifical surveys/Wetlands/Marine waters etc.)	-	329,481	5,20
-	TOTAL		6339,000	100,00

C values in the Tekirdag region, scale from zero to 1, can be divided into 10 groups. With a ratio of 64.69

per cent, agriculture occupies the largest region of these classes. Broad-leaved forests take up the most space at 8.71 percent and 7.72 percent of vacant agricultural land.

Cultivated agricultural areas have been identified in the study region where the slope is low. It is worth noting that wide-leaved trees, heathlands, meadows and grazing areas are situated in the higher parts of the Ganos Mountains, where the altitude in the north of the region increases. These areas are places that cannot be opened for various purposes for agriculture and are often used for animal husbandry activities as grazing areas.

D. Factor LS

Below are the results and ratios of the LS values obtained by using the DEM map for the province of Tekirdag (Table 4 and Fig.8).

TABLE IV. COVERED BY THE VALUES OF THE C FACTOR.

LS Class	Covered area and ratio	
	km^2	***Percentage (%)***
0 – 2	5.465,22	87,14
2 – 5	563,84	8,99
5 – 10	221,58	3,53
10 - 125,06	21,03	0,34
Total	6.271,67	100,00

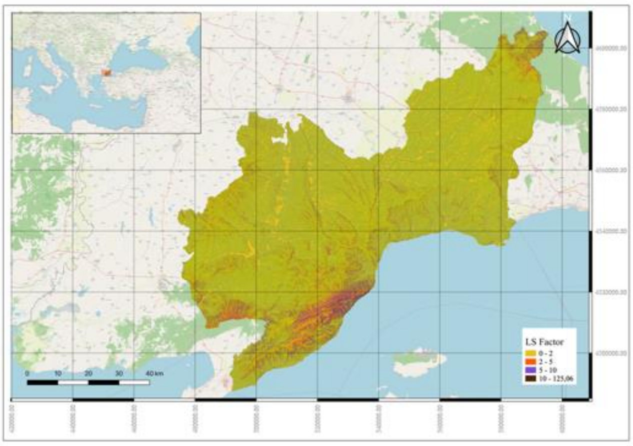

Fig. 8. Soil erodibility values map of Tekirdag region.

The LS values in Tekirdağ province are in 4 classes and range from 0 to 125.06. As can be seen from the table, areas with LS values between 0 - 2 cover most of the area in the research area (5,465.22 km^2 and 87.14%). LS values from 2 to 5 are 8.99% (563.84 km^2), areas with LS values from 5 to 10 are 3.53% (221.58 km^2) and areas with LS values from 10 to 125.06 are 034% (21,03 km^2). When the LS factor distribution map (Figure 6) is examined, low LS values are generally observed in the north and northwest part of the region from the middle part to the south, and high LS values are observed in the mountainous areas near the sea in the south and southwest parts of the region. Figure 6 shows the outcomes of the research area's LS factor map.

E. Factor P

The soil management activities are reflected by Tekirdag Soil Conservation Measures' Element (P). Depending on whether the soil is cultivated in the direction of the slope or perpendicular to the slope or through rotation, erosion processes can be accelerated or slowed down. Within the framework of this analysis, no soil conservation measures were identified in agricultural areas within the Tekirdag boundaries. For this reason, the value of 1.0 for soil protection measures was accepted as constant in the relevant erosion model. This means that Elements P will not be influenced by the erosion calculation process. This value of 1.0 is the P factor value to be taken when the field studied in the RUSLE model has no application for soil safety calculation (Wischmeier and Smith, 1978).

F. Potential Estimation of Soil Loss Distribution (RUSLE-A)

According to the RUSLE model, this was compounded by placing it in the GIS setting to determine the province's potential soil loss and thus estimate the Tekirdag province's potential soil loss.

Spatial and proportional risk classes for the distribution of land losses in Tekirdag province are provided in Table 5. Low soil loss occurs at a rate of 92.31 percent in the province of Tekirdag with 1-5 erosion distribution values in the region of 5969.23 km^2. At the second level, soil loss is 3.68 percent at the light level.

TABLE V. POTENTİAL RATE OF EROSİON İN TEKİRDAG PROVİNCE

Erosion class	Erosion dispersion value	Class of Vulnerable to erosion	Area	
			(km^2)	**Percent age *(%)***
1	1 – 5	Low	59,79	0,92
2	5 – 10	Light	5969,23	92,31
3	10 – 20	Middle	238,18	3,68
4	20 – 50	Strong	102,05	1,58
5	50 -100	Severe	62,87	0,97
6	100>	Extremely Severe	27,69	0,43
	TOTAL		6.466,85	100,00

The Soil Loss Map of the Tekirdag Province obtained by multiplying variables Rusle R, K, LS and C is given in Fig. 9. The loss of soil in Tekirdag province has been found to be 10.25 tons/ha/yr.

When analyzing the distribution chart of potential erosion risk groups, the potential risk of erosion is shown to be minimal. The possible risk of erosion in the plain and near-flat plain components and in the areas around them is seen to be minimal if a generalization is made. On the other hand, in the high portions of the Ganos Mountains in the southwest, where elevation and slope values are high, the potential risk of erosion is seen to be high.

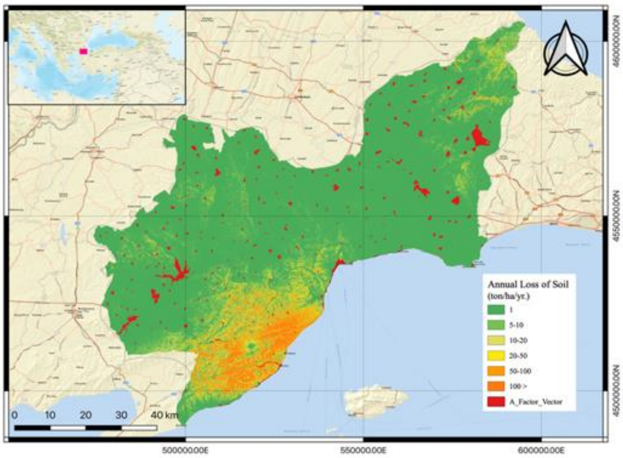

Fig. 9. Potential erosion map of Tekirdag province

In a study conducted in 2014 [7], the soil loss value, which was 10.25 tons/ha/year obtained as a result of research, was found to be 5.26 tons/ha/year. The explanation for this difference can be explained by using various sources to identify the R, K, C and LS factors in the RUSLE equation and to achieve healthier data with the development of the technology used in the interim calculation of these factors.

Potential erosion is a phase where the erosion process is not viewed as an effect of human causes, technologies and cultural traditions. Method models and physically based models give advantages over simple statistical empirical models when describing simply and efficiently individual processes and components causing erosion. The drawbacks of these models, however, are that the mathematical representation of a natural operation can only be approximate, and parameter estimation difficulties remain. RS and GIS techniques are very effective modelling methods for soil erosion and risk assessment for erosion.

In Tekirdag Province, remote sensing and open source GIS software (QGIS) is an approach to soil erosion research methods. RUSLE, which is the most commonly used model, was used in this study to calculate the volume and spatial distribution of erosion and sediment load generated as a result of it. This research also added methods for modeling soil erosion using the RUSLE equation using the data from CORINE 2018 for C-factor interpolation. With this study, potential soil erosion status map for the Tekirdag area was generated with RS and GIS, which was clearly analyzed using RUSLE and QGIS technology in terms of spatial distribution.

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