Kastamonu Uni., Orman Fakültesi Dergisi, 2023, 23(2): 144-155 Research Article
Kastamonu Univ., Journal of Forestry Faculty
Doi:10.17475/kastorman.1368097

Analysis of Basin Characteristics for Stream Management Using GIS: A Case Study of Gümüşhane Micro-Watershed

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Received Date: 24.01.2023 Accepted Date: 23.08.2023

Abstract

Aim of study: Topography and climatic conditions have effected in determining the processes of the streams of the micro-watershed. Nowadays, the management plans were made for water and soil protection measures in the basins.

Area of study: This study was carried outto characterize and prioritize the streams of the Gümüşhane upper Harşit micro-watershed using a GIS-based spatial approach.

Material and methods: Fundamental watershed characteristics including drainage density, slope, land use types, and stream class were evaluated and interpreted for the Gümüşhane micro-watershed. Calculatea comprehensive value for each parameter, drainage density (Dd), flow frequency (Fs), slope (S), length of land flow (Lg), and land use (Lu) was used.

Main results: The drainage density, stream flow frequency, and form factor of the microwatershed are from -4 to 26. Finally, the weighted rankings were summarized, and all micro-watersheds were categorized to five classes based on the risk index as very low risk, low risk, medium risk, high risk, and very high risk. This risk map overlaid to land use type maps in GIS where risk areas were evaluated in the finalrisk results. The 739 ha productive forest area within very high-risk areas was changed to non-risk parameters.

Highlights: The carrying capacity of streams was calculated using the stream density of streams in the Gümüşhane micro-watershed. The risk values produced by streams that pass through neighborhoods where land use values for preventing erosion are present.

Keywords: Land Use Types, Slope, Drainage Density, Türkiye, DEM

CBS Kullanarak Akarsu Yönetimi İçin Havza Özelliklerinin Analizi: Gümüşhane Mikro Havzası Örneği

Öz

Çalışmanın amacı: Mikro havzadaki akarsuların akış süreçlerinin belirlenmesinde topoğrafya ve iklim koşulları etkili olur. Günümüzde havzalarda su ve toprak koruma önlemleri için yönetim planları yapılmaktadır.

Çalışma alanı: Bu çalışma, CBS tabanlı mekansal bir yaklaşım kullanılarak Gümüşhane Yukaru Harşit mikro havzasındaki akarsuları karakterize etmek ve önceliklendirmek için gerçekleştirilmiştir.

Materyal ve yöntem: Gümüşhane mikro havzası için drenaj yoğunluğu, eğim, arazi kullanım tipleri ve akarsu sınıfı gibi temel havza özellikleri değerlendirilmiş ve yorumlanmıştır. Drenaj yoğunluğu (Dd), akış frekansı (Fs), eğim (S), arazi akışının uzunluğu (Lg) ve arazi kullanımı (Lu) için her parametre için kapsamlı bir değer hesaplanmış ve katmanlar olarak birleştirilmiştir.

Temel sonuçlar: Drenaj yoğunluğu, akarsu akış sıklığı ve mikro havzanın biçim faktörü -4 ile 26 arasındadır. Son olarak, ağırlıklı sıralamalar özetlenmiştir ve tüm mikro havzalar, risk indeksine göre olarak beş sınıfa ayrılmıştır. Risk sınıfları; çok düşük risk, düşük risk, orta risk, yüksek risk ve çok yüksek risk olarak ayrılmıştır. CBS yazılımıyla arazi kullanım türü katmanı üzerine nihai risk katmanı bindirilmiştir. Çok yüksek riskli alanlar içindeki 739 ha verimli orman alanı daha sonra risksiz alanlar olarak değiştirilmiştir.

Araştırma vurguları: Akarsuların taşıma kapasitesi, Gümüşhane mikro havzasındaki akarsuların yoğunlukları kullanılarak hesaplanmıştır. Arazi kullanım değerlerinin bulunduğu mahallerden geçen akarsuların ürettiği risk değerleri belirlenmiştir.

Anahtar Kelimeler: Arazi Kullanım Tipi, Eğim, Drenaj Yoğunluğu, Türkiye, SAM

Citation (Atıf): Cakir, G. (2023). Analysis of Basin Characteristics for Stream Management Using GIS: A Case Study of Gümüşhane Micro-Watershed. *Kastamonu University Journal of Forestry Faculty*, 23 (2), 144-155.

Introduction

One of the primary precaution against drought is land use planning with a stream, which also has a significant impact on worldwide human life. Overusing water resources is caused by the pressure on the few natural habitat opportunities, many of which are on the point of extinction, and the ever-growing population makes the issue worse (Jha et al., 2007; Singh et al., 2013). Different geomorphological features of basins such as drainage networks, catchment divisions, slope, aspect, and upstream flow contributing areas, are extracted using digital elevation models (DEMs) (Mark, 1984; Tarboton, 1997). Hydrological data obtained DEM with GIS to evaluate basins is a quick, low-cost method with good accuracy (Grohmann et al., 2007; Panhalkar, 2014). Understanding the issues and recommending site-specific conservation solutions is made easier by taking into account the physical characteristics of the micro-catchment. One of the basic actions in watershed management plans is the identification and prioritization of basin units (Jaiswal et al., 2014; Javed & Yousuf, 2009). These variables are necessary to comprehend the basin's physical characteristics. Additionally, it helps assessing bedrock characteristics, structural controls, soil erosion, and runoff, as well as stream dispersion. Within the basin, DEM is frequently utilized to suggest soil and water conservancy constructions (Cox, 1994; Randhir et al., 2001; Shi et al., 2004; Pidwirny, 2006; Rao et al., 2010; Nagaraju et al., 2011; Shinde et al., 2011; Kale et al., 2014; Sarita et al., 2015; Vijith et al., 2017). In order to manage forests and land in a sustainable way, watershed dynamics should be determined and taken into account in planning. Before valuable lands are allocated to industrial and commercial regions, forest areas must be conserved. However, in order to prepare for a healthy environment and a clean future, it is essential to provide relevant knowledge regarding both compositional and configurationally changes in watersheds (Çakir et al., 2008; Eroğlu et al., 2010; Keleş et al., 2017).

The study was conducted in the province of Gümüşhane because Harsit Stream has been developed there for many years, putting residential areas there at risk of flooding. According to the land use and basin characteristics, the streams' varying degrees of flooding were identified, and their potential future effects on residential areas were examined. The creation of the risk map is one of the best results of the streams passing through the settlements. A GIS-based study has not been finished for the province of Gümüşhane. It provides data that will stimulate additional scientific research.

Material and Methods

Study Area

The research was carried out in Gümüşhane, north-east part of the Türkiye, which lies between 490000-580000 E longitude 4455000-4519000N latitude UTM WGS 84 zone 37 (Figure 1). The Gümüşhane city was built on the upper Harşit micro-watershed, which covers 288763.3 hectares. The annual average temperature in Gümüşhane 9.8˚C. The annual rainfall is between 400 and 600 mm. The rainy season occurs in March, April, May, October, November, and December. Agricultural activities depend almost entirely on the timing of precipitation.

The study area is organized into three primary land systems: forestry, agricultural land, and range land. The majority of previously deforested regions are now being reforested with tree species including *Pinus sylvestris* and *Oak ssp*. People in Gümüşhane are economically impoverished and rely mostly on forests, agriculture, and water. Animal husbandry, forestry jobs, and agricultural products are common sources of income.

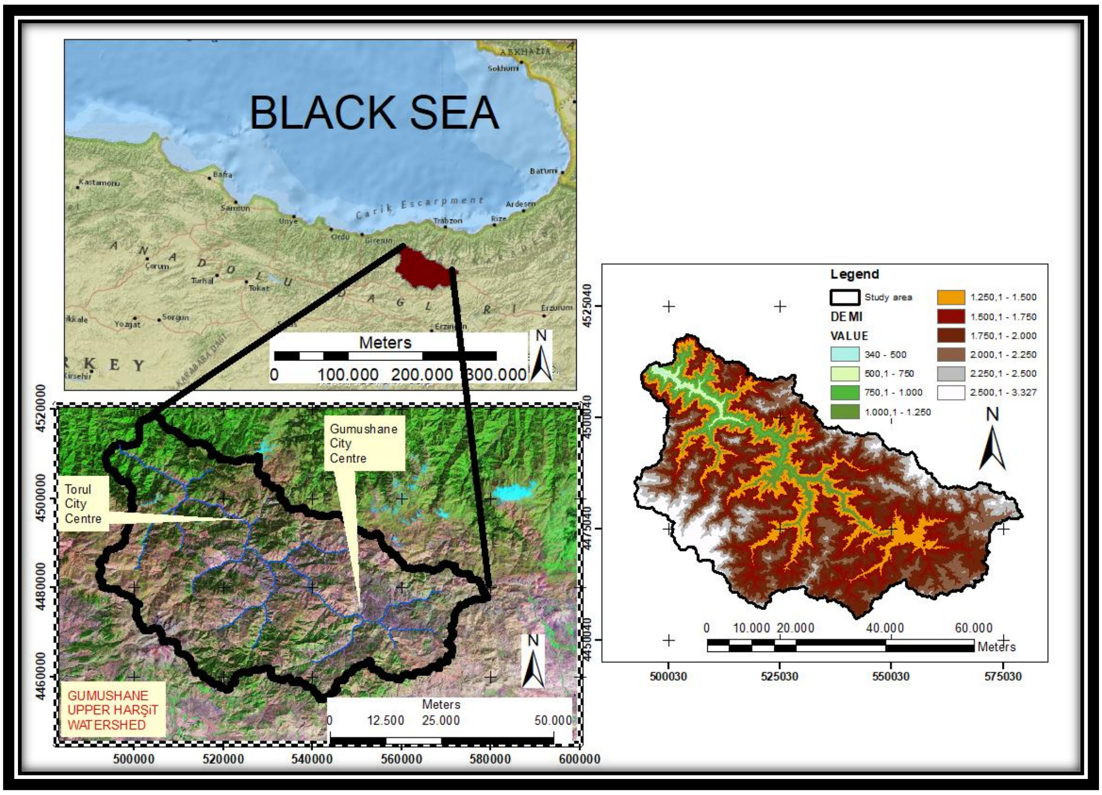


Figure 1. Study area

Database and Methodology

Gümüşhane upper Harşit micro-watershed area was drawn in open-code DEM which was obtained from Sentinel-2 satellite images. These include the creation of a slope, topographic elevation data, the determination of streamlines, and the establishment of micro-watershed with DEM data. Using ArcGIS 10.1 software, the drainage network was digitized, and the number and length of flows of each order, basin size, basin periphery, and total watershed length and width were computed.

Land use, watersheds, and other physical characteristics generated form in a GIS (Table 1 and 2). The land use map was created using the forest management plans. Gümüşhane and Torul settlement areas were situated within the same watershed area. The Harsit stream passes through both residential areas. The study has used drainage density, drainage frequency, stream length, land use class, and elevation ratio in various analyses. Table 2 contains the formulas for the computations used in the study.

Table 1. Land use types

Agr_Settl	Agriculture and Settlement area
DegF	Degraded Forest
ForOp	Forest openings
RangeL	Rangeland
PF_1CC	Productive forest crown closure rate %10-40
PF_2CC	Productive forest crown closure rate %41-70
PF_3CC	Productive forest crown closure rate %71-100
Water	Water body

Table 2. Contains the formulas for the computations some stream characteristics

Stream order (U)	Values rank of streams
Stream length (Lu)	Length of the stream
Stream frequency (Fs)	Fs = Nu/A where, Fs = stream frequency, Nu = total number of streams of all orders, A = area of watershed (Horton, 1945)
Drainage density (Dd)	Dd = Lu/A where, Dd = drainage density, Lu = total stream length of all orders, A = area of watershed (Horton, 1945)

A special algorithm is used to automatically fill depressions in the terrain data, and a bottom-up approach is used to determine the flow direction through flat areas in GIS software. The drainage network was digitized, and the number and length of flows of each order, basin size, basin periphery, and total watershed length and width were computed (Table 3).

The area of the loaded terrain that drains to the selected line's close vicinity (within the specified flow threshold) will be calculated for each feature of the selected line if the option to Create Watershed Areas Showing Drainage to Selected Line(s) is chosen. A separate arrowed line indicating the direction a drop of water placed at each selected point feature will flow in will be generated as a result of the Trace Flow from Selected Point(s) option. An area feature that depicts every area that a specific line feature will drain to will be created by the Trace Flow from Selected Line(s) option. Finding information like the potential location of a pipeline leak using this is helpful. Flow Direction Point Creation, which also enables the layer point style for the quiver plot, creates a point feature with the attributes at each point with the direction (FLOW_ANGLE) and magnitude (FLOW_ACCUM - the number of cells flowing to a given cell) (Figure 2). Each stream segment is ranked using the widely accepted Strahler stream ordering classification for stream networks based on the orders of the incoming upstream segments (Figure 3 a and b) (Karami et al., 2021; Strahler, 1957).

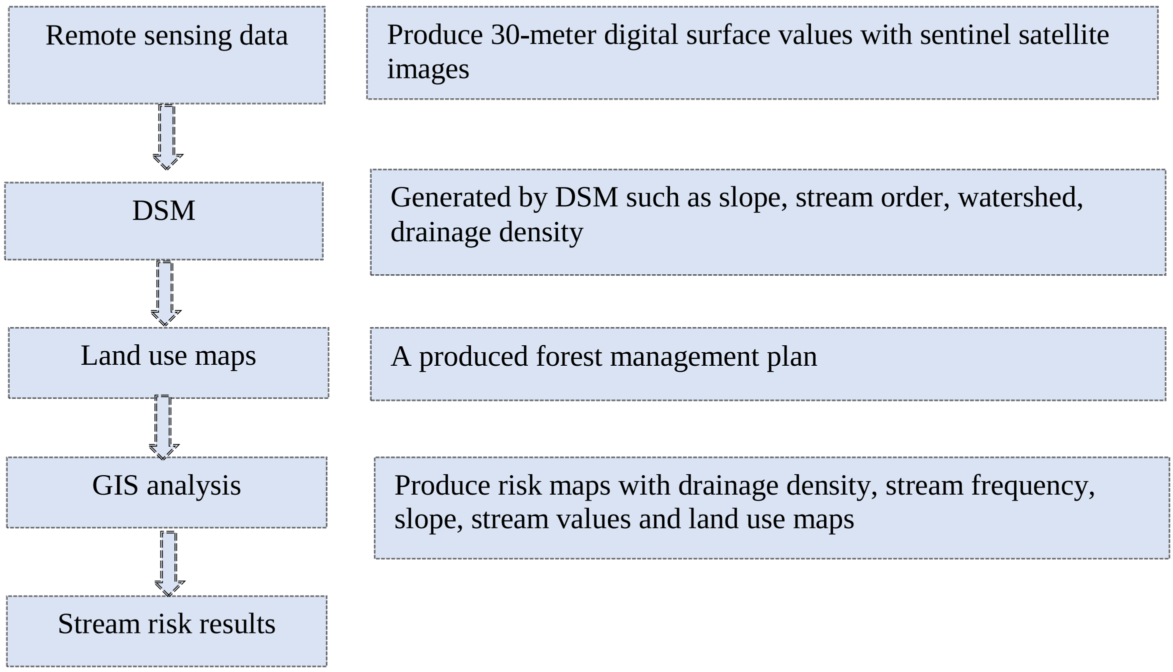
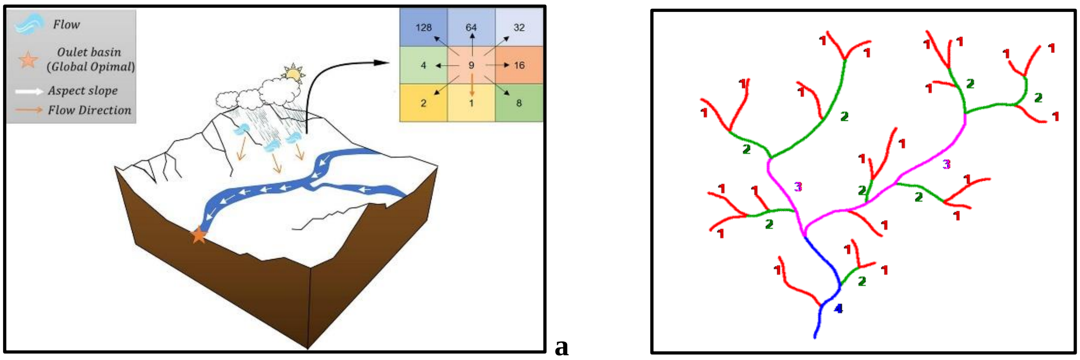


Figure 2. Flow chart stream risk values



a b

Figure 3. a) Flow to outlet of basin to schematic shame (Karami et al., 2021), b) Diagram of the stream order and values procedure used by DEM (Strahler, 1957)

The DEM was used to construct the stream density map. DEM was used to establish basin borders by GIS. The land's stream density, length, stream kinds, and risky zones were determined by assigning grid codes to the relevant stratum. Databases were allocated grid codes 1 through 5. The layers were overlaid to create a new risk layer. The risk map values assigned 1 grid code values to the least risky class, and grid code to the most risk regions. The layers were overlaid to tree maps and create a new risk layer. The risk map values assigned 1 grid code values to the least risky class, and 5 grid code to the most risk regions. (Table 3)

Results

In the study, the drainage density, drainage frequency, flow length, form factor, and land use parameters derived by GIS were assigned GRID codes. The grid codes for each value are shown in Table 3. Grid code values begin at one and increase in value. It was the values of the larger the danger and the greater the value. As the calculated values in each column increase, so does the risk value in the field.

Table 3. Grid values to line density, stream frequency, driver density and risk result in Gümüşhane

Grid Code	Line Density	Stream Frequency	Drainage Density	Risk Results
1	0.03-0.29	-4.50 - -2.51	0-9	VERY LOW
2	0.30-0.49	-2.51- -0.10	10-19	LOW
3	0.50-0.99	0.00 - 2.49	20-29	MEDIUM
4	1.00-1.49	2.50 - 4.99	30-39	HIGH
5	150-1.99	5.00 - 7.49	40-44	VERY HIGH
6	2.00-2.49	7.50 - 9.99		
7	2.50-2.99	10.00 – 12.49		
8	3.00-3.49	12.50 – 14.99		
9	3.50-3.98	15.00 – 17.49		
10		17.50 – 19.99		
11		20.00 – 22.49		
12		22.50 – 24.99		
		25.00 – 26.81		

A risk map was produced by combining the grid values from five different in the GIS environment. The risk map values in Table 4 were obtained based on total grid value. It has very dangerous parts in an area of 347.4 hectares, according to Table 4. The risky regions were 11077.2 hectares. The basin features of the study area's layers were overlaid. The risk values were ranked from low to high by adding the risk grid values on the newly produced layer, and a risk map was obtained.

Table 4. Stream risk values in Gümüşhane watershed

Stream Risk Values	Area hectare	Percentage %
VERY LOW RISK(1)	81744.4	28.6
LOW RISK(2)	136375.2	47.0
MEDIUM RISK(3)	59224.8	20.5
HIGH RISK(4)	11071.5	3.8
VERY HIGH RISK (5)	347.4	0.1
TOTAL	288763.3	100.0

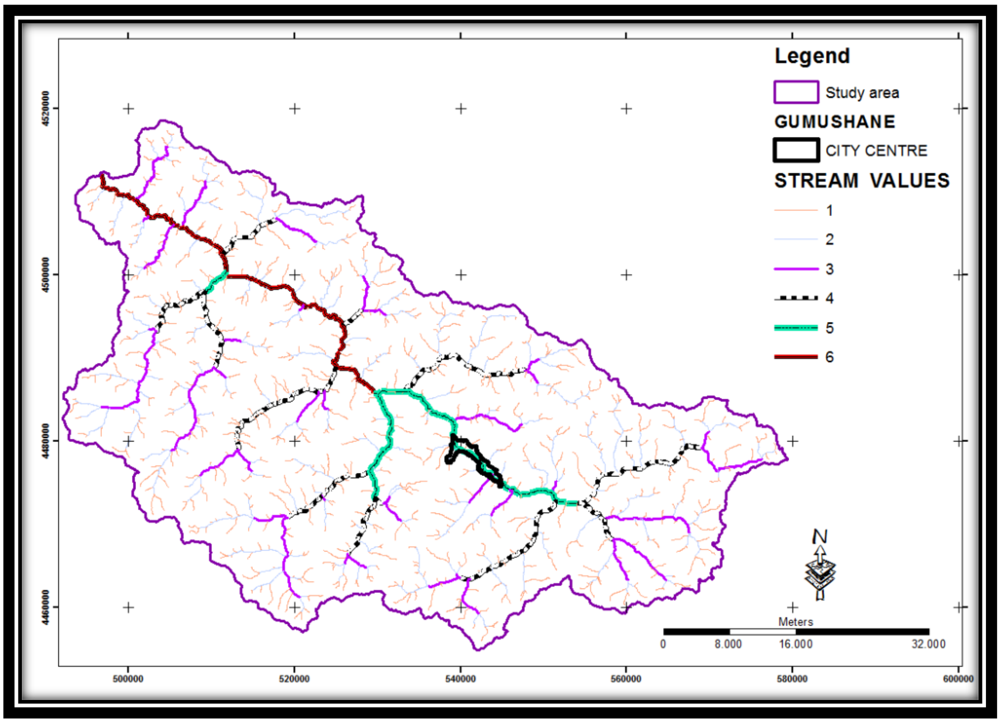


Figure 4. Stream values

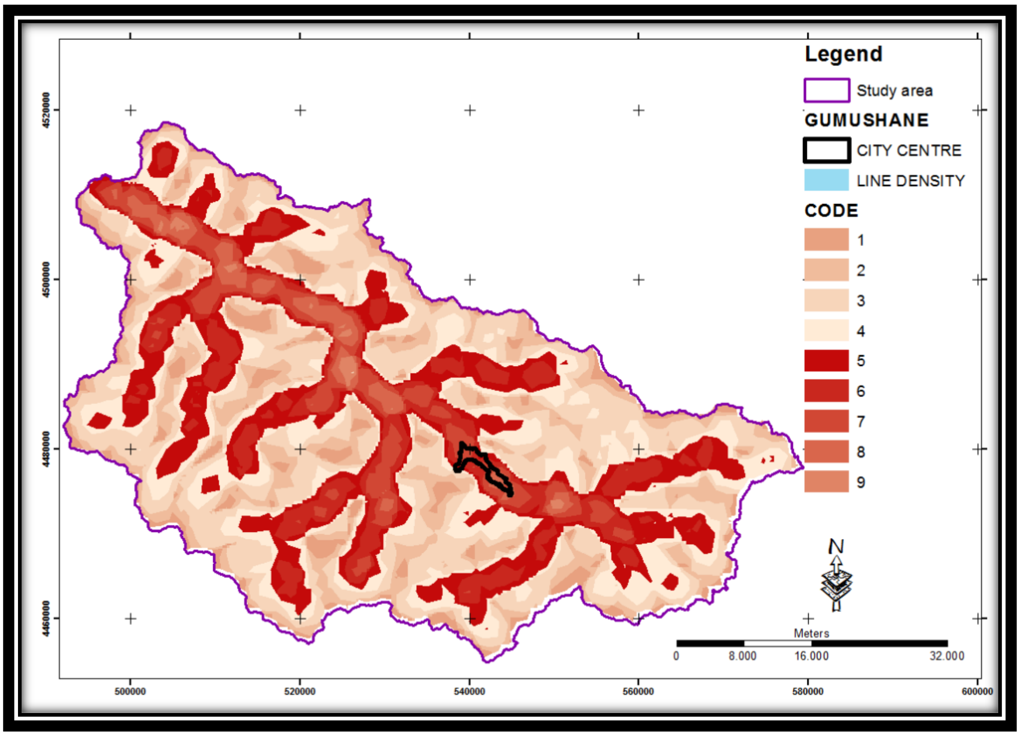


Figure 5. Streamline density

The regions with productive forest areas were identified in studies of the dangerous regions after the land use map was included. These areas have been left out of the category of dangerous areas. The combination of land use patterns and risk maps, as seen in Table 5, to the persistence of some locations within productive forests. However, certain residential and agricultural areas were also included in the risky class. High-risk regions also exist in the region that includes the city center of Gümüşhane and Torul.Table 5 shows that the region with productive woods contains a total of 739 hectares of land in very high risky and high-risk zones. In the area with 4 and 5 risk degrees, there are 10533.7 hectares of agriculture, degraded woods, and forest clearings. These regions are dangerous areas for human life. Additionally, it is evident that dangerous regions are concentrated along the Harşit Stream. The center of Torul district and Gümüşhane city center are in risky locations (Figure 6-8). Productive forest areas were removed from the risky area in the research area's land use layer because they impeded the surface flow.

Table 5. Comparison of Drainage density risks and land use types values

		Land use types								Area
		Agr_Settl	DegF	ForOp	RangeL	PF_1CC	PF_2CC	PF_3CC	Water	Total
Risk class	1	6580.3	12488.5	32572.8	12726.5	2920.9	6104.8	8344.4	6.2	81744.4
	2	17915.8	31090.6	50753.8	9239.0	4890.7	10239.8	12243.6	1.8	136375.2
	3	10595.3*	20494.9*	20231.9*	291.6	1317.1^{+}	2721.1^{+}	3572.3^{+}	0.5	59224.8
	4	2546.4	4600.2	3055.1	-	71.6^{+}	265.6^{+}	397.4^{+}	135.2	11071.5
	5	81.1*	119.7*	131.2*	-	0.2^{+}	5.1^{+}	-	10.2	347.4
Total		37718.8	68793.9	106744,9	22257.1	9200.6	19336.5	24557.7	153.9	288763.3

*Very risk for land use type situation; $^{+}$low risk for land use type situation (forestry area)

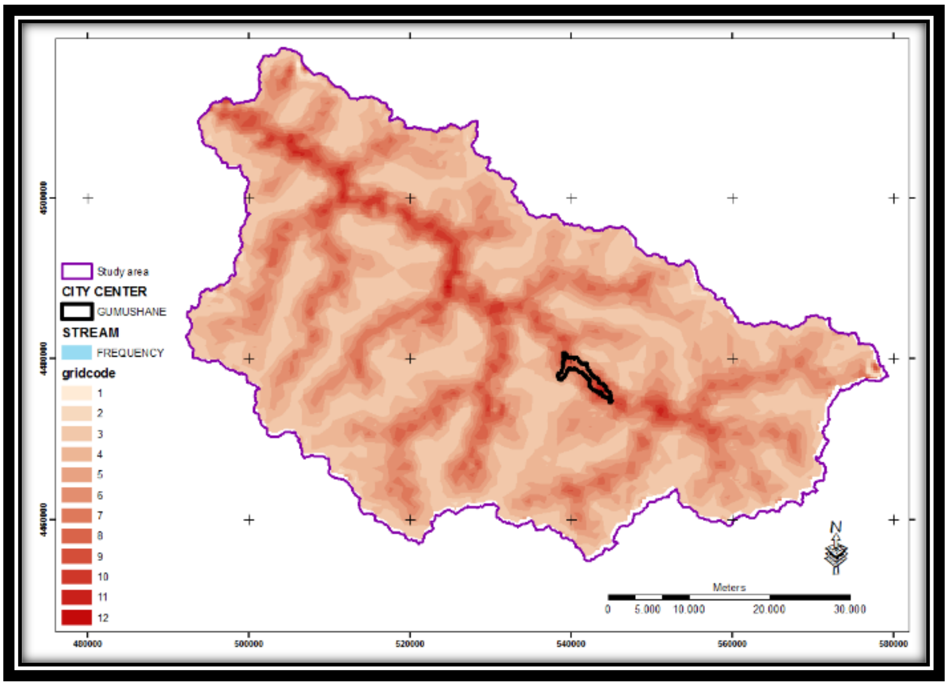


Figure 6. Stream frequency

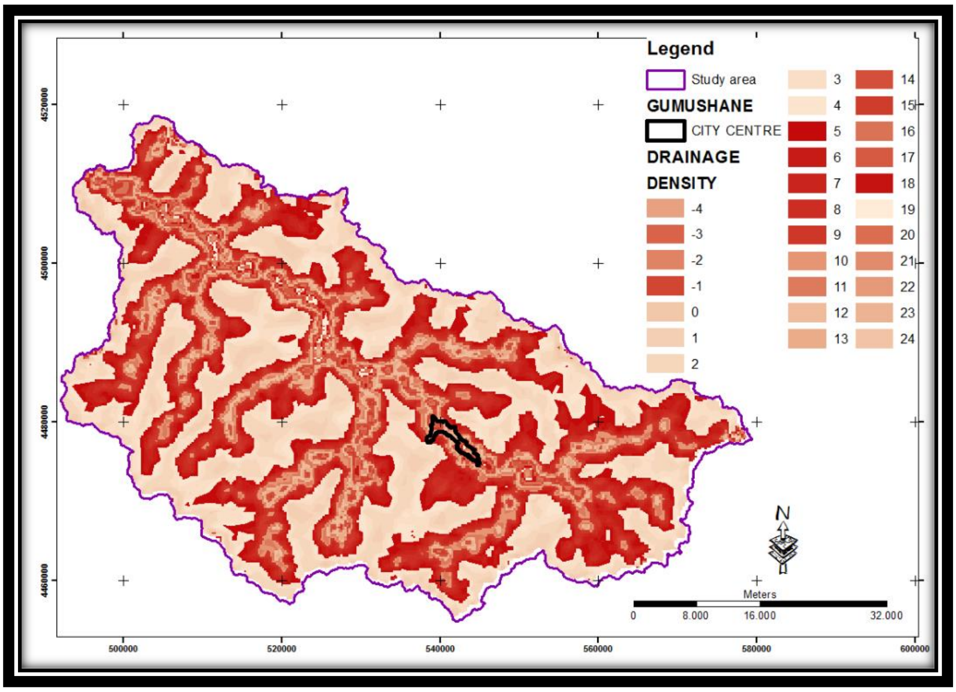


Figure 7. Drainage density map

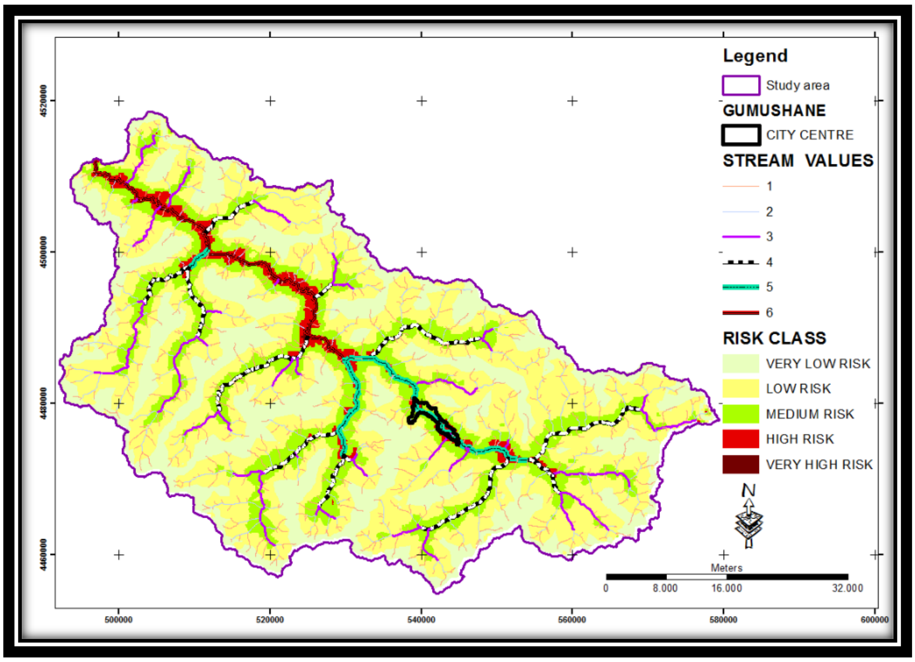


Figure 8. Stream values and risk class maps

Forest management plans of Gümüşhane were used to create a land use map, which was then overlaid with the risk map (Figure 9). High-risk zones were identified as those having the most grid codes.

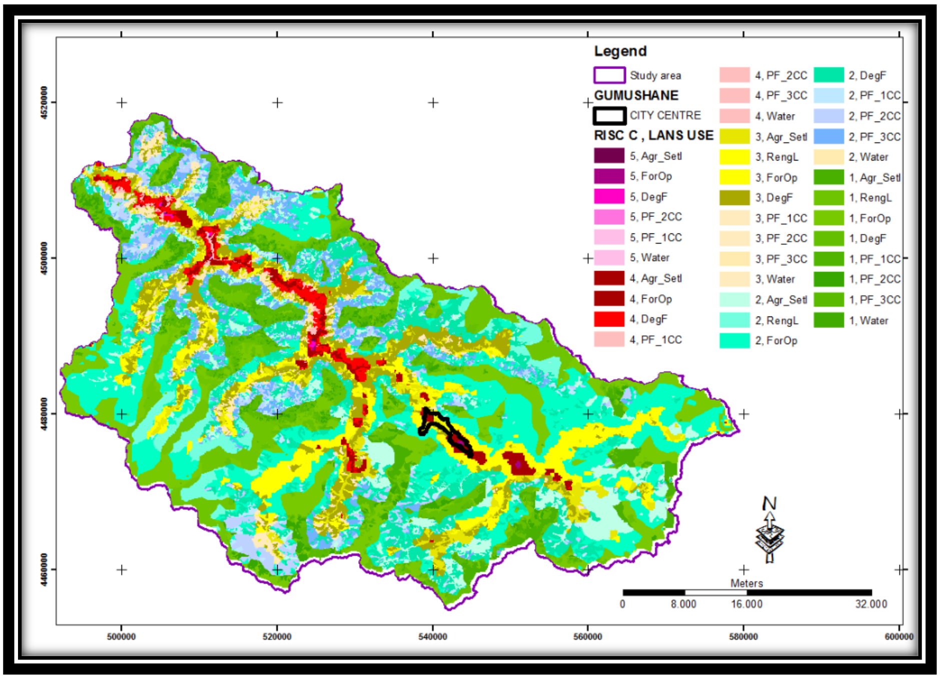


Figure 9. Final results drainage density and land use maps

Conclusion

We provide timely and appropriate access to spatial data for nations wishing to achieve ecosystem-based sustainable development. The social, economic, and ecological components have all been improved (Çakır et al., 2010; Samuwai & Hills, 2018; Brown et al., 2019; Çakır et al., 2019; Chaplin-Kramer et al., 2023; Schulte et al., 2022). Studies on streams are vital in high-sloping and moderately mountainous terrain, as well as geographical basins. Protecting natural ecosystems is the best approach to ward off natural calamities. Therefore, it is important to examine stream density, creek length, drainage density, and vegetation kinds all at once. A crucial step toward enabling managers to make decisions that benefit both nature and people is this method of identifying significant stream flows and stream beds.

Flood risk maps should be developed for all risky zones, at least at the minimal level of accuracy, without waiting for the eradication of many existing inadequacies. Flood risk management and the evaluation and elimination of hazards are highly thorough and very challenging tasks. Due to the high frequency of these natural catastrophes, disaster management procedures should be improved, and residents should be educated about and trained in this subject (Zeybek & Eraslan, 2018; Singh & Basu, 2022). Planning for cities and forest ecosystemshould take into consideration issues like drainage, land slope, stream density, and stream frequency. Examining land use values is one method to be safe from potential natural disasters. The protection of human life can be improved by avoiding dangerous regions.

A sample study of an area of 6140 hectares inside the boundaries of the province of Gümüşhane has been found to be at extremely high risk of flooding. It is equivalent to 0.9% of the study area. Once more, 67440 hectare of the study area fall into the category of high flood risk, with a rate of 10,01%. These two risk groups have an area of 73580 hectares and a rate of 10,92% in the research region (Zeybek & Eraslan, 2018). The existence of water on earth is necessary for ecosystem function, human and living life, and other key activities (Sarukhan and Whyte, 2005; Milly et al., 2005). Water is simultaneously vulnerable to both natural and human pressures (Barnet et al., 2008; Berghuijs et al., 2014). These needs have grown over the past century as a result of rising industry and population, and the need for drinkable water has grown enormously (Vörösmarty et al., 2000).

In site suitability evaluations to safeguard settlements against erosion and flooding, the findings of this study can be applied. These factors allow for the performance of GIS-based analysis (hydrological data, land use, land cover, landforms, geology, water level, and soil erosion) to identify ideal locations for flood/flood protection structures. A more thorough hydrogeological investigation of the micro-catchment is required for better water management and settlement design.

Acknowledgments

The author is thankful to Gümüşhane Faculty of Engineering ad Natıural Science GIS lab..

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: G.C.; Investigation: G.C.; Material and Methodology: G.C.; Supervision: G.C.; Visualization: G.C.; Writing-Original Draft: G.C.; Writing-review & Editing: G.C.; Other: Author has read and agreed to the published version of manuscript.

Conflict of Interest

The author has no conflicts of interest to declare.

Funding

The author declared that this study has received no financial support.

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