



An ecological restoration assessment integrating multi-criteria decision analysis with landscape sensitivity analysis for a hydroelectric power plant project: the Tokat-Niksar case

Sara Demir · Öner Demirel · Arslan Okatan

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Abstract Due to Turkey's reliance on imported electricity, it has been using hydroelectric power plants (HPPs) to cover some of its electrical energy needs since 2011. However, HPP projects, which do not take landscape sensitivity into account, cause the ecological integrity of the basins and the ecosystem structure to deteriorate. This study presents the Tokat-Niksar HPP project field example in Turkey's Central Black Sea region with its steep slopes, rich forest and creek vegetation, protected endemic plants and wildlife, cultural heritage dating back to 3000 BC agricultural activities, and long-established local culture. The study, in fact, aims to develop a landscape restoration plan that considers the sensitivity of landscapes in the HPP project area. For this purpose, a landscape sensitivity analysis consisting of water, habitat, visibility, erosion functions, and multi-criteria decision analysis (MCDA) determining priority of functions conducted with experts were performed. According to

the results, the water function was found to have the highest, and the visibility the lowest priority in the ranking. Consequently, 1st, 2nd, 3rd, and 4th-degree sensitive areas with very high, high, and moderate landscape sensitivity were determined by weighted sum function by considering the priority of each landscape function, and accordingly, a five-stage landscape restoration model was developed including soil protection, areas to be protected, erosion control, vegetation screening, and creek reclamation. This study presents a framework for sustainable landscape restoration solutions in the town by combining landscape sensitivity analysis via MCDA.

Keywords Environmental restoration suggestions · Quantitative ecological sensitivity analysis · Analytical hierarchy process · Landscape planning · Geographic information system

S. Demir (✉)
Department of Landscape Architecture, Faculty
of Forestry, Bursa Technical University, A-316 Bursa,
Turkey
e-mail: sara.demir@btu.edu.tr

Ö. Demirel
Department of Landscape Architecture, Faculty of Fine
Arts, Kırıkkale University, Kırıkkale, Turkey

A. Okatan
Department of Forest Engineering, Faculty of Forestry,
Karadeniz Technical University, Trabzon, Turkey

Introduction

As a result of rapid population growth, urban growth, industrialization, tourism, and technological developments, the need for energy is increasing day by day. This situation accelerates the destruction and deterioration of natural and cultural landscapes. In fact, most of the solutions that are sought for these environmental damages are largely ignored with the justification of energy production (Demir et al., 2017; Yaman & Hasil, 2018). This state has led to an increase in the

need for sustainable energy resources with the least negative impact on the environment. In this context, one of the most important energy sources to meet energy needs is hydroelectric energy that works with water power. Investments in hydroelectric power plants (HPPs) have, then, increased considerably in recent years (Turhan et al., 2015).

HPP projects include regulators, water delivery lines, forebay, penstocks, and power plant units. It also includes sections such as the concrete plant established during the construction phase, stone crusher plant, construction site, and warehouse area. Hydroelectric energy is among the renewable energy sources, including but not limited to, solar, wind, geothermal, hydrogen, and wave energy due to low carbon emissions (Aslan & Soguksulu, 2017; Bobat, 2017). Turhan et al. (2015) state that despite their lower carbon emission compared to fossil fuels, HPP projects do not have as clean and sustainable energy management as it seems because many studies have indicated that such projects lead to the deterioration of the ecological balance in their study areas, destruction of vegetation, fragmentation of habitats, change of the natural water flow system, decrease in air and water quality, noise pollution, waste problem, damage caused by explosions and socio-economic and cultural problems for the local people living close to water resources (Aslan & Soguksulu, 2017; MEUT, 2020; Turhan et al., 2015; Yaman & Hasil, 2018).

The study determined that the environmental damage risk in HPPs mostly occurs during the excavations of penstocks, roads and channels, and uncontrolled pouring of the diggings. The study also established that this destruction is directly related to the amount of excavation and land slope (Aslan & Soguksulu, 2017; Kurdoglu & Ozalp, 2010; Zhao et al., 2020). To prevent these problems, an Environmental Impact Assessment (EIA) Report is prepared for HPP projects. This report, in fact highlights the damages emanated from a project. However, electricity transmission lines within the scope of HPP have not been included in the Turkey EIA process. According to Kurdoglu and Ozalp (2010), excluding these electrical transmission lines from the EIA process, which causes fragmentation of habitat and destruction of fauna and flora, shows fewer environmental problems for HPP projects which, in turn, facilitates the approval of project implementation. However, aside from the electrical transmission line, Aslan and

Soguksulu (2017) stated that as the length of the penstock increases, the effects of destruction and erosion on the landscape also increase. Furthermore, the lack of a restoration plan that needs to be prepared according to the topographic structure-slope and landscape sensitivity also affects the destruction rate.

HPPs cannot be used after the end of their economic life, and as a result of this, they become unsustainable sources of ecological, physical, and visual pollution. It is an internationally accepted approach to determine and evaluate the technical and economic benefits of HPP projects, and the environmental problems they create in the triangle of energy, economy, and ecology (Andolina et al., 2020; Bobat, 2017). In this context, according to the European Landscape Convention (ELC), which is of international importance, landscapes have an important resource value in terms of natural, cultural, economic, ecological, and social aspects and also have public interest. For this reason, ELC has shed light on the necessity of a landscape restoration plan by stating that pressures can cause changes in the landscape and also the important role of destroyed landscapes have in life cycle (Demir, 2019a; Zhao et al., 2020). Therefore, a landscape restoration plan is needed to ensure the sustainability of the area where the project is applied and to present it to nature again (Yaman & Hasil, 2018).

A landscape restoration plan includes all works of restoration, rehabilitation, or reclamation in landscapes of which functional features have changed as a result of disasters or human intervention (Chazdon et al., 2021; Rahman et al., 2014; Sahin et al., 2014). With the restoration works, it is necessary to make water, soil, erosion, biodiversity, visibility, and habitat analyses, and determine the landscape sensitivity values they have in the area where the project will take place, and according to these values, the environmental damage that occurs during the construction and operation phases should be restored, managed, and monitored (LUC, 2017; MEUT, 2020). In this context, Rahman et al. (2014), Sahin et al. (2014), Akayezu et al. (2020), and Chazdon et al. (2021) used landscape restoration techniques such as soil management-improvement, area to be preserved, erosion control, vegetation screening, and coastal arrangement within the scope of the landscape restoration process.

Under the national development policies, new energy policies have been developed to meet the

growing energy needs of Turkey. Turkey, which is foreign-dependent in electrical power production, has recently inclined to using renewable energy sources in addition to utilizing previous fossil resources. Within this scope, 23% of the electrical energy needs of Turkey have been met by HPP applications after 2011 (Turhan et al., 2015). HPP applications have come to the fore to meet this energy need. Therefore, 714 HPPs completed in many basin valleys have been established (GDHW, 2020). However, taking into account the Turkey's morphological and hydrological structure, Turkey manages this potential in an unplanned way and destroys it even though it has a large hydroelectric power potential (Turhan et al., 2015).

Landscape restoration plans are made, and reports are prepared with the aim of getting the EIA approval by the public or private institutions for a portion of the HPP projects in Turkey (Sahin et al., 2014; GEZI, 2020; Demir et al., 2017). However, the landscape restoration of the destructions in the project area during the construction and operation phases has not been completed yet because currently in Turkey, there is no integrated water policy and "Water Framework Law" associated with water management. This condition causes a lot of problems and confusion of authority in policies for water management (Aslan & Soguksulu, 2017; Bobat, 2017). Thus, the technical faults in the construction phase of the HPP projects in Turkey, reduction of the area's tourism potential, applications made without attention to the landscape sensitivity, deficiency in the restoration plans, and the EIA process impair the ecological integrity and ecosystem structure of the project area (Aslan & Soguksulu, 2017; Yaman & Hasil, 2018). To avoid these problems and insufficient planning decisions in Turkey, this research examined the HPP project area and basin with 2.27 MW capacity in the Niksar district of the province of Tokat. The EIA process of the HPP project started in 2014, and the project is in the construction phase. The research aims to develop an applicable landscape restoration plan model based on the function and sensitivity analysis of the landscape and multi-criteria decision-making method to improve the natural and cultural landscapes that have deteriorated as a result of HPP applications. The study also presents a methodology for developing a landscape restoration plan in ecologically sensitive areas. In this context, the fragile and sensitive

areas were determined with the landscape sensitivity based on the landscape function of the study area. As a result, in this research, a landscape restoration plan was developed to provide sustainability and restore the existing degradation of landscape values.

Qualitative landscape restoration proposals have been developed to address problems in HPP projects completed in previous years. More specifically, unlike other studies, in this study, an innovative method was used as it integrated multi-criteria decision-making analysis and landscape sensitivity analysis quantitatively in a GIS environment. This study is then original in terms of the quantitative spatial solutions it uses. Therefore, this study can set an example for creating a framework for landscape restoration plans in ecologically sensitive areas of Turkey and other developing countries.

Study area

The study area included the Kaynar regulator and HPP project built on the Canakci creek rainfall basin in Niksar district of Tokat is 324 ha (Fig. 1). The drainage area was determined as 30.70 km² and the average flow rate as 0.43 m³/s (Okatan & Demirel, 2014). It is in a rainfall basin with narrow valleys and steep slopes. It is between the elevations around 850–1350 m. The geological structure of the study area consists of alluvium and basaltic-andesite tuff. In the project area with plant species belonging to Europe-Siberia, Mediterranean, Black Sea, Iran-Turan phytogeographical regions, there are 8 endemic plant species, which are endangered and protected according to IUCN criteria, 6 amphibians (*Amphibia*), and 11 reptiles (*Reptilia*) species (Okatan & Demirel, 2014). The area soil is included in 6th class of brown forest soil in terms of quality that is not suitable for agriculture. It has a transitional climate between the Central Black Sea climate and the Central Anatolian climate. Winters are generally warm and rainy, and summers are hot. The average rainfall of the district, which receives rain every month, is 443.1 mm (Okatan & Demirel, 2014). Gulbayir Village and Alan Village are located 500 m north and 1500 m west of the study area. Its economy is largely based on industrial establishments including agriculture and forestry products. It has a history that dates back to 3000

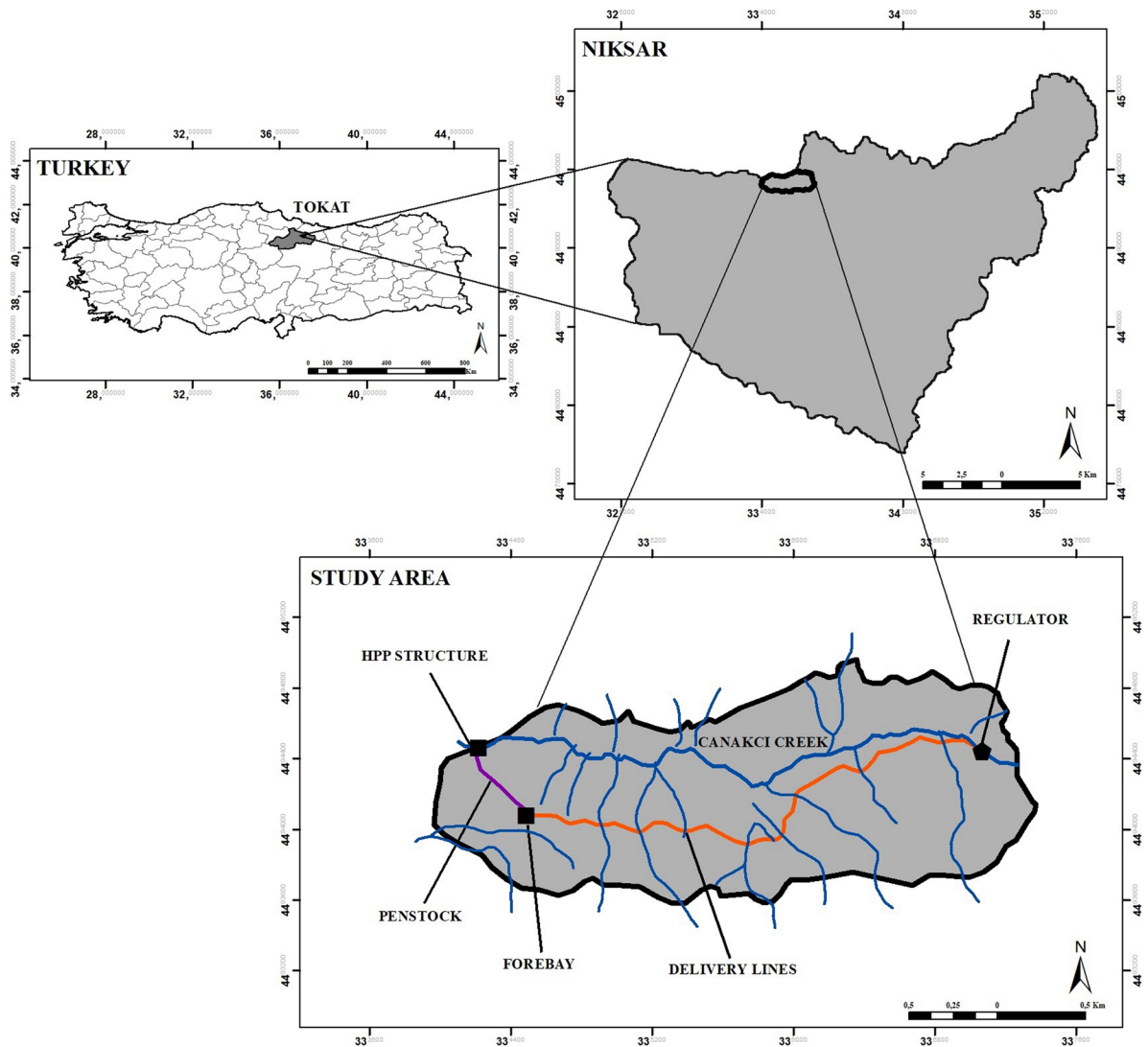


Fig. 1 Location map of the study area

B.C. It has a Roman and Byzantine castle, bridges, fountains, inns and baths, graves and tombs, Ayvaz water, Çamiçi plateau, and lush nature. According to the CORINE (Coordination of Information on the Environment) map, the area has broad-leaved forest, transitional woodland-scrub, sparsely vegetated area, natural grassland, and non-irrigated complex cultivation patterns. After the examination of the HPP project line, the slope revealed land that is steep and very steep, and there are no fields suitable for agriculture. Within the scope of HPP

applications that cause environmental change, it is necessary to ensure the sustainable use of these natural, cultural, and historical landscape values and water resources of national and international importance in the study area. For this purpose, the development of a sustainable landscape restoration plan that takes into account the unique sensitivity of each landscape is very important in terms of protecting these sensitive and fragile landscape values and thus ensuring the continuity of ecological integrity.

Material and method

The main material of this research is the natural and cultural landscape values of the HPP project area in Tokat-Niksar. To reach general information of the study area about the land use/cover, Kaynar regulator, HPP structure, the forebay, penstock, and delivery channel, the point data were collected primarily using global positioning system (GPS) through the field study. Especially some of these points were used to create a visibility function map as observer points in viewshed analysis. Besides, the sample points from all function maps were chosen for each landscape function in the GIS environment, and those points were confirmed in the field study using GPS. Also, 1/25000 scaled topographic map (2014), geology map (2000), soil map (2000),

forest management plan (2010), and CORINE map (2012) were utilized for this study (MAFT, 2014). Querying of existing maps was carried out within the scope of geographical information systems (GIS) with ArcGIS 10.3 program, and the landscape metrics were calculated with Fragstat4 programs (McGarigal & Marks, 1994). In the calculation of the total sensitivities of the landscapes, the 2010 Microsoft Office Excel program and Expert Choice 11 software were used to obtain the results of the paired comparison made in the analytical hierarchy process (AHP). This landscape restoration work, which offers suggestions for the restoration of the HPP project’s damage that is planned to be realized in Tokat province-Niksar district to the ecosystem, consists of 4 analytical processes that are elaborated in the following sections (Fig. 2).

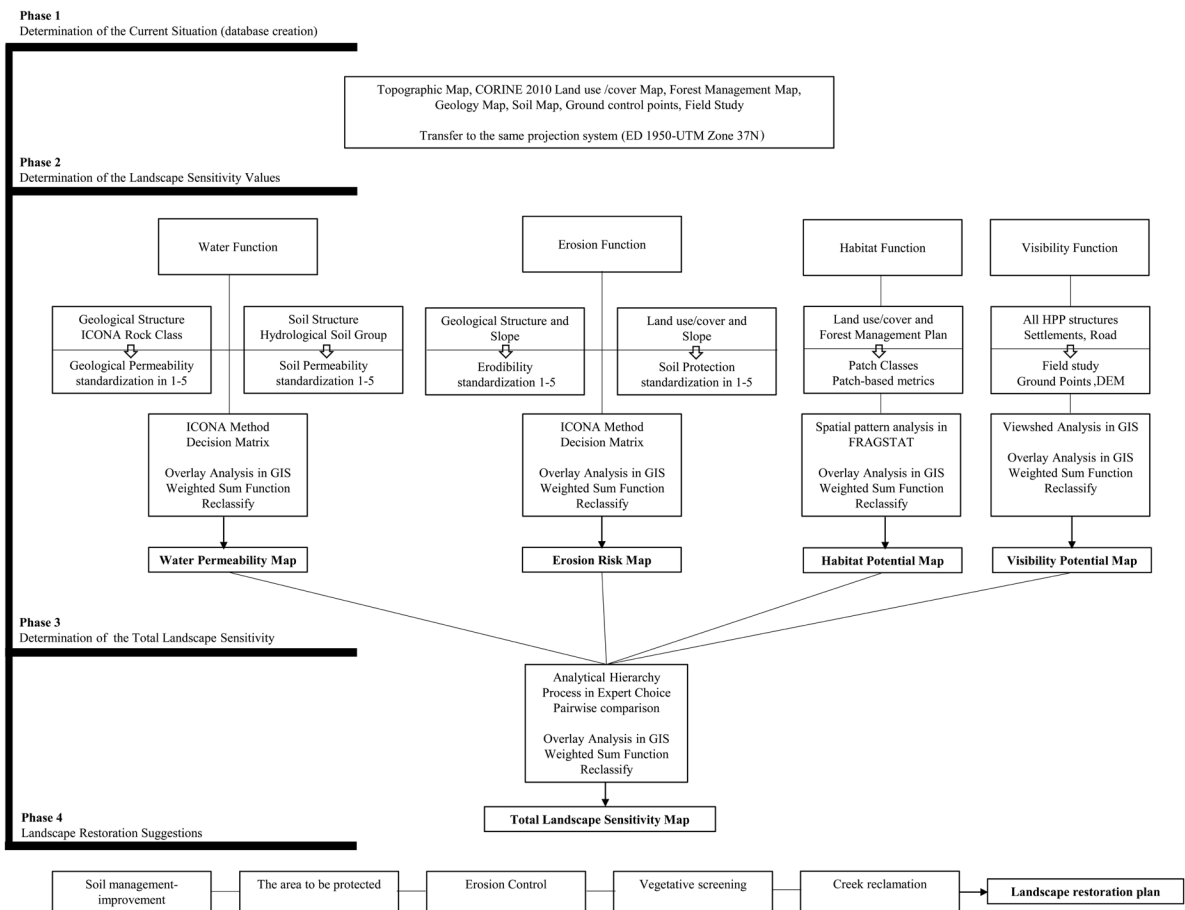


Fig. 2 Flowchart showing the analytical phases of the research process

Determination of current situation (database creation)

Within the scope of the research, geology and soil maps were used to determine the water function of the study area. Furthermore, land use/cover, forest management, topographic and geology maps were utilized to determine the erosion risk, classes of land use/cover map were used to determine the habitat function, and topographic map and point data that were taken from the ground were used to determine the visibility function (Figs. 3 and 4). In this context, the data related to the current situation were digitized in the GIS environment, transferred to the same projection system (ED 1950-UTM Zone 37 N), and made ready to be analyzed in a common database.

Determining landscape sensitivity

Landscape sensitivity is considered as the landscape's ability to resist change in response to natural and anthropogenic external influences (LUC, 2017;

Manolaki et al., 2020; SLA, 2015). Landscape sensitivity values are used to guide landscape planning and restoration practices and to evaluate alternatives (LUC, 2017; SLA, 2015). Landscape sensitivity determines the capacity and degree of change of landscape functions within the scope of ELC (LUC, 2017; Uzun et al., 2018). The potential value and risk of the landscape are evaluated to determine landscape sensitivity using the water, erosion, habitat, biodiversity, biotope, and visual functions of the landscape. Landscape function analysis (LFA) is a monitoring procedure that examines the existence, use, cycle, and disappearance of physical and biological resources from a landscape (Ozhanci & Yılmaz, 2018; Demir, 2019a; Manolaki et al., 2020). In the functioning of this process, the overlay technique developed by McHarg (1969) is applied through geographic information systems (GIS) (Mohamed et al., 2019). LFA, of which the evaluation process is simple, fast, and applicable and offers the opportunity to evaluate many data together, is used in the evaluation and monitoring of landscape planning, management, and landscape restoration studies. These analyses can identify sensitive

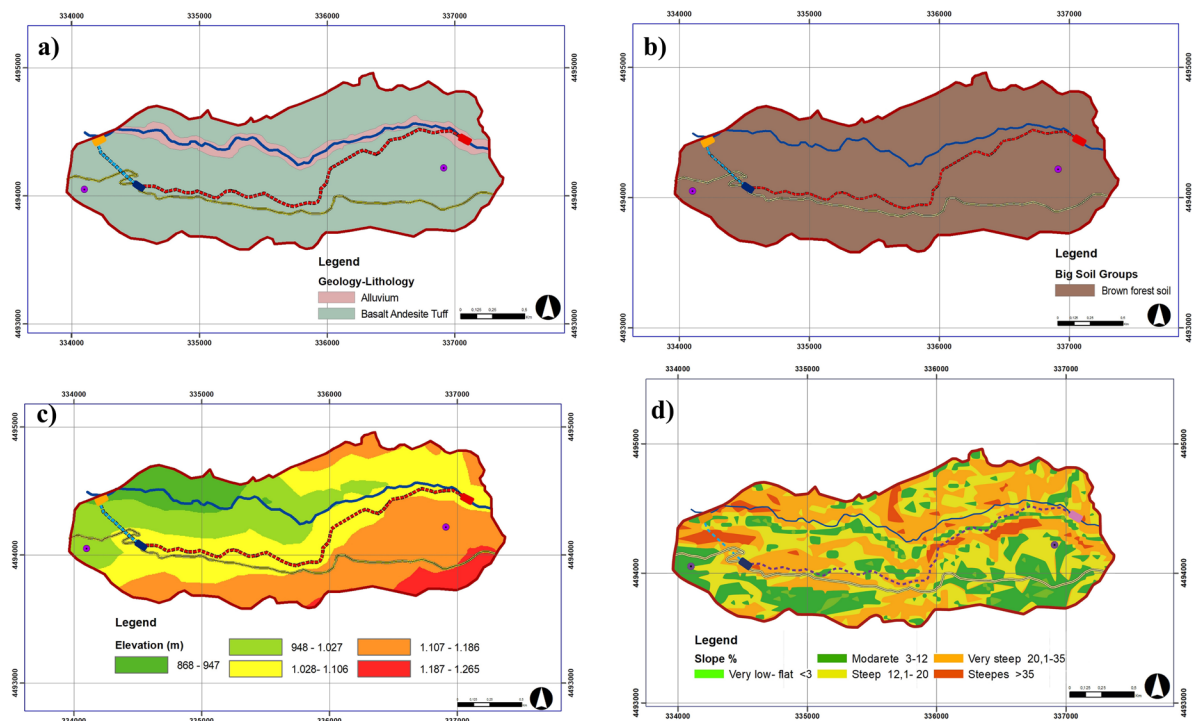


Fig. 3 Spatial distribution of **a** geology map, **b** soil map, **c** DEM map, **d** slope map

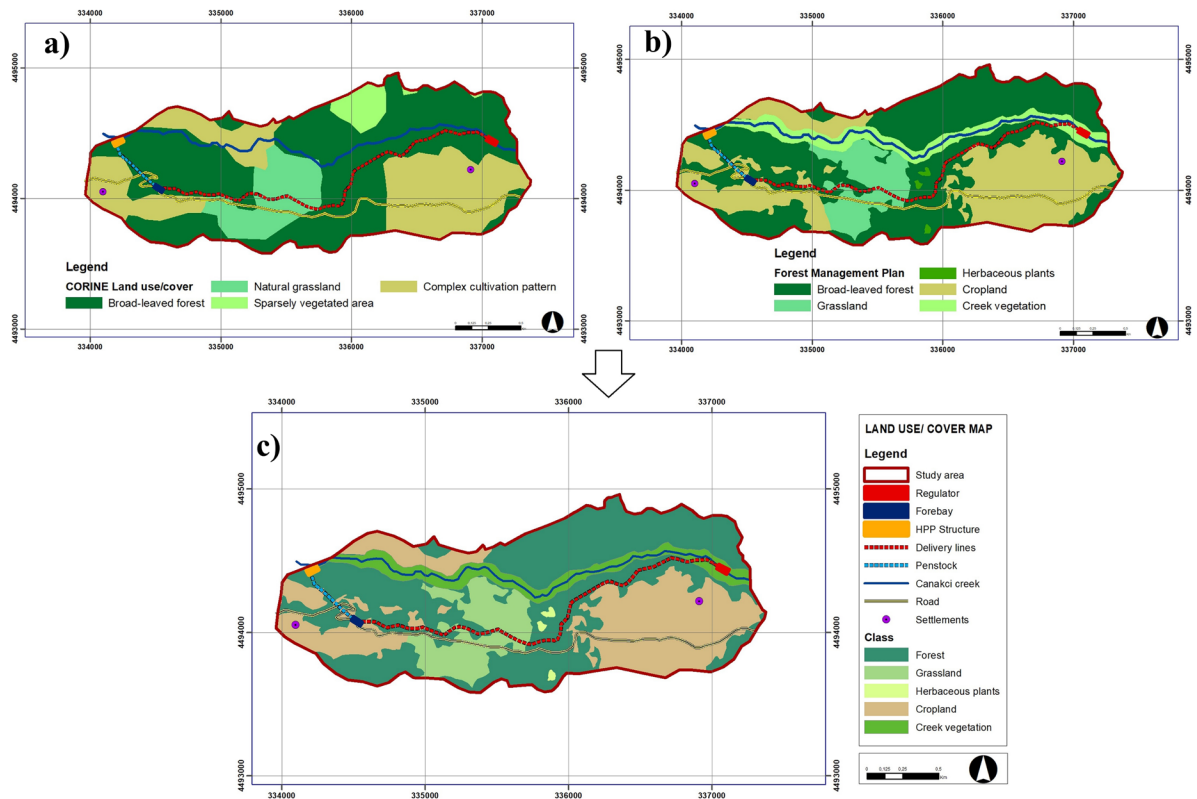


Fig. 4 Spatial distribution of **a** CORINE land use/cover map, **b** forest management plan, **c** updated land use/cover map

areas (Sahin et al., 2014; LUC, 2017; Safaei et al., 2019; Manolaki et al., 2020). Within the scope of this research, geology, soil, topography, slope, land use/land cover, and forest data were analyzed to determine the water, erosion, habitat, and visual functions of the landscape in the GIS environment. According to the studies of Ozhanci and Yılmaz (2018) and Sahin et al. (2014), each function map depending on its importance was classified into five different categories from very low (1) to very high (5) to observe the sensitivity of landscape. Therefore, all function values were assigned in the range of 1 to 5 for each to ensure standardization in this research.

Water function of the landscape

Within the scope of the project, the water sources of this study are the Canakci Creek and its tributaries. At this stage, analyses were made to determine the water function. In this research, the MAPA/ICONA

(National Institute for the Conservation of Nature) water permeability method, which was developed by Buuren (1994), Sahin et al. (2014), and Uzun et al. (2018), was utilized to ensure the sustainability of the ecological functions of regions containing water resources that need to be protected. This method provides information about the water permeability degrees of the study area (Zotou et al., 2019). Potential ground and surface water resources should be taken as a base in determining the water function of the landscape. In this context, the geological and soil structure permeability of the research area and its immediate surroundings were taken into consideration. Thus, the rock structure of the area was evaluated in determining the geological permeability (1) and for soil permeability (2), the hydrologic soil group (HSG) was formed based on the big soil group of the area (Fig. 3).

The geological permeability and groundwater feeding status of the rocks in the study area were evaluated based on ICONA rock classes (Sahin et al., 2014;

Ozhanci & Yılmaz, 2018; Uzun et al., 2018) (1). The big soil group was examined to determine the soil permeability and the hydrological soil group classes (the infiltration degree decreases in the order of A, B, C, D) were taken as basis in the determination of the water holding capacity of the soil (Ozdemir, 2007). Accordingly, this study area, which only has brown forest soil, was determined to be in the class D hydrological soil group with high flow potential and low infiltration degree (2). As a result, the water permeability map of the study area was obtained in the GIS environment by overlapping the weights of geological permeability and soil permeability with a weighted sum function and reclassified according to the water permeability decision matrix (Fig. 2).

Erosion risk of the landscape

The study aims to determine the ecologically sensitive areas in terms of erosion risk. With the MAPA/ICONA erosion modeling method used in this context, erosion risk status was evaluated with four main variables which are the land use/cover, vegetation, slope, and geological structure of the area (Akayezu et al., 2020; Lu et al., 2019; Safaei et al., 2019). Using the land use and slope data of the area, soil protection level was created (1), and using the slope and geological structure data, the erodibility status was determined (2). Finally, the erosion risk areas were determined with these two maps. In the first two stages, soil groups, slope, and geological structure were reclassified according to erosion status (Fig. 2). Each variable was weighted using the ICONA decision matrix (Ozhanci & Yılmaz, 2018; Uzun et al., 2018) and reclassified in the range of 1 (low) to 5 (high). As a result, the values of both variables were evaluated using the weighted sum function, and the erosion risk map was obtained in the GIS environment. It was rated into five categories from very weak to very severe based on erosion severity levels of ICONA.

Habitat function of the landscape

To determine the habitat function of the landscape, the patch-corridor-matrix model, which is used in landscape ecology studies and determines the landscape structure, was used (Demir, 2019a; da Silva

et al., 2021). This model considers the landscape as a mosaic and evaluates all spatial elements under these three classes. It reflects the biological richness and diversity of the landscape. This way of modeling and defining the landscape has paved the way for methodological studies based on spatial pattern analysis and comparison (Leitão & Ahern, 2002; Zhu et al., 2020). The landscape metrics that are used can quantitatively reveal the spatial characteristics of the landscape pattern, and the calculated four main landscape metrics are patch size, patch shape, edge density, and core area (da Silva et al., 2021; Leitão & Ahern, 2002). Environmental pressures caused by interventions such as HPP cause patches to break into fragments and become smaller. This reduces the habitat value (Leitão & Ahern, 2002; Banks-Leite et al., 2020; Zhu et al., 2020). However, large patches are more resistant to external influences and have more internal types. Also, the patches with a high number of edges are more affected by the neighboring environmental patches, and the indoor habitat type is damaged. As the number of core areas increases and the total core area expands, the habitat value of the patches increases due to the internal habitat types (Leitão & Ahern, 2002; Demir, 2019a; da Silva et al., 2021).

While working with landscape metrics, the land cover of the study area is considered as a patch (Leitão & Ahern, 2002; Banks-Leite et al., 2020; da Silva et al., 2021). According to the CORINE land use/cover, the study area consists of broad-leaved forest, transitional woodland-scrub, sparsely vegetated area, natural grassland, and non-irrigated complex cultivation patterns. Within this scope, a newly updated land cover map was obtained by evaluating the CORINE land use/cover and forest management plans together in determining habitat landscape sensitivity consisting of more detailed patches in the study area (Fig. 4). As a result, an updated land use/cover consisting of forest, grassland, croplands, herbaceous plants, and creek vegetation was obtained for evaluating patches. Each class was determined as a separate patch, and each patch was measured with 17 sub-metrics under the area, shape, edge, and core area metrics (6,5,3,3 sub-metrics respectively) using the FRAGSTAT program. Finally, when examined in terms of animal and plant presence, these metrics for each land cover patch were classified into five classes (very low to very high) for standardization according to their function and importance. Accordingly, patch classes with a high number

of patches, patch size, number of core areas, and total core values, and also classes with low total edge, edge density and, mean perimeter-area ratio values had high values in terms of habitat function. Land use/cover layers scoring according to 17 metrics were overlaid using the weighted sum function in the GIS environment. The total habitat function of the study area was qualitatively reclassified from very low to very high.

Visual function of landscape

To determine the visual function of the landscape, it is necessary to reveal the characteristics of the research area and its immediate surroundings that define a landscape visually and aesthetically (Demir, 2019b; Andolina et al., 2020). The aim at this point is to determine the visibility of areas that can be easily seen from roads and settlements. In this way, it is possible to ensure that the activities that will take place during the planning process do not cause visual loss of value in the landscape and do not harm resource values (Demir, 2019b; Andolina et al., 2020; GDF, 2020). In the research area, topographic modeling created with the digital elevation model (DEM) generating with a 5-m contour interval, and ground points of Kaynar regulator, HPP structure, the forebay, penstock, delivery channel, existing settlements, and the road collected with GPS during the field study, were evaluated as observer points with raster-based viewshed analysis under the visibility toolset in GIS option. Visibility states of each observer point were determined only as visible and non-visible. To determine the total visibility of the study area, the degrees of visibility of each point were overlaid using the weighted sum function in the GIS environment and then qualitatively reclassified into three categories.

Determination of total landscape sensitivity with analytical hierarchical process

To determine the total landscape sensitivity, the water, erosion, habitat, and visual functions of the landscape, which were determined to be the potential value and risk in the area, were evaluated together firstly. To determine the importance of each function,

the opinions of 247 experts (landscape architect, forest engineer, agricultural engineer, civil engineer, topographical engineer, geologist, meteorologist, ecologist) were received in the interdisciplinary survey study. With this questionnaire, consisting of 6 questions, all the functions were compared with the analytical hierarchy process (AHP) technique in pairs and weighted according to their importance. AHP is one of the well-known multi-criteria decision-making methods and has a simple, flexible, and quantitative nature (Demir & Atanur, 2019; Rahman et al., 2014; Saaty, 2008). This method supports the participatory approach and lists the priorities objectively in the decision-making process (Mohamed et al., 2019). The fact that the consistency ratio of the obtained result is less than 0.1 increases the acceptability of the analysis (Demir & Atanur, 2019; Rahman et al., 2014). To calculate the total landscape sensitivity of the study area, the weighted sum function was applied according to the weight values of each landscape function by using pairwise comparison in AHP. As a result, the sensitive areas were reclassified as five classes from very low to very high landscape sensitivity.

Landscape restoration suggestions

For the sustainable restoration goal, the sensitivity values of landscapes should be determined and protected in impaired areas (LUC, 2017; Okatan & Demirel, 2014). It is known that the area and its immediate surroundings are damaged during the HPP works (Aslan & Soguksulu, 2017; Banks-Leite et al., 2020). Effects arising from these damages take place during the construction and operation phases. At the stage of this study, the landscape restoration plan was formed by interpreting the landscape function maps (water, erosion, habitat, and visual functions) as well as the total sensitivity maps of landscape and soil conservation. In the implementation of the restoration plan decisions of the research, five alternative restoration suggestions were developed: soil management/improvement, areas to be protected, erosion control, vegetative screening (visual landscape management), and river reclamation. Thus, the study aimed to prevent the potential damages and improve the existing ones.

Results

Determination of the water permeability of the landscape

In determining the water permeability of the study area, the rock structure and soil properties were analyzed. According to the ICONA rock classes, the geological structure of the study area was reclassified into 2 categories as highly permeable rock consisting of alluvium and slightly permeable rock consisting of basalt, andesite, and tuff (Table 1). The big soil group of the area was reclassified as a hydrological soil group to reveal the soil permeability condition. In this context, the study area with brown forest soil with the minimum infiltration and high surface flow potential was reclassified to be in the D class hydrological soil group (Table 1). As a result of ICONA decision matrix (Table 2), the water permeability map created by geological and soil permeability was reclassified into 2 categories as very low (1) and low (2) water permeability (Fig. 5). According to this map, the creek bank of the project area has a low degree of water permeability (29 ha), and the majority of the area has a very low degree of water permeability (295 ha).

Determination of the erosion risk of the landscape

In determining the erosion function, the erodibility and soil protection level characteristics of the land were analyzed. The erodibility map was obtained by

Table 1 The permeability value of geological rock structure and big soil group (Buuren, 1994; Ozdemir, 2007; Ozhanci & Yilmaz, 2018; Uzun et al., 2018)

Geological rock structure	Infiltration rate, permeability
Andesite, basalt, tuff (hard rock formation)	1
Alluvium (soft rock formation)	4
1: very low, 2: low, 3: moderate, 4: high, 5: very high	
Big soil group (BSG)	Hydrological soil group
Brown forest soil	D
D: high flow potential with very low infiltration	

Table 2 ICONA decision matrix of rock and soil permeability in determining water permeability (Buuren, 1994; Ozhanci & Yilmaz, 2018; Uzun et al., 2018)

Water permeability	Hydrological soil group (HSG)			
	A	B	C	D
Geological permeability				
Very high	5	4	3	2
High	5	4	3	2
Moderate	4	3	3	2
Low	3	3	2	2
Very low	3	3	2	1

1: very low, 2: low, 3: moderate, 4: high, 5: very high

overlaying the slope map and rock structure (geology) maps classified according to ICONA erosion degrees (Fig. 2). Accordingly, the study area has moderate, severe, and very severe erodibility conditions (Table 3). In the study area, moderate erosion prevails, the lands where the slope is 20–35% have a severe erosion degree, and very severe erosion is observed around the Canakci creek.

Vegetation has been considered as a natural landscape component that keeps the soil against erosion. In the study area, where sparse vegetation is dominant, there are forest, grassland, and herbaceous plants, and creek vegetation. Soil protection degrees were determined by overlaying the land cover map with the slope map, which is also classified according to ICONA erosion degrees. Accordingly, in the study area where a very high soil protection level is dominant, there are moderate, low, and high soil protection levels respectively (Table 4). As a result of ICONA decision matrix (Table 5), the erosion risk map was created by overlaying the data of erodibility and soil protection level maps obtained (Fig. 6). Accordingly, in the study area, where very weak erosion risk (180 ha) is dominant, there is ineffective (103 ha) and moderate (14 ha) erosion risk, respectively, while very severe (18 ha) and severe (9 ha) erosion risk was determined along the creek bank.

Determination of the habitat potential of the landscape

The habitat function of the study area was determined based on the area, shape, edge, and core metrics of the land cover types. According to the patch area

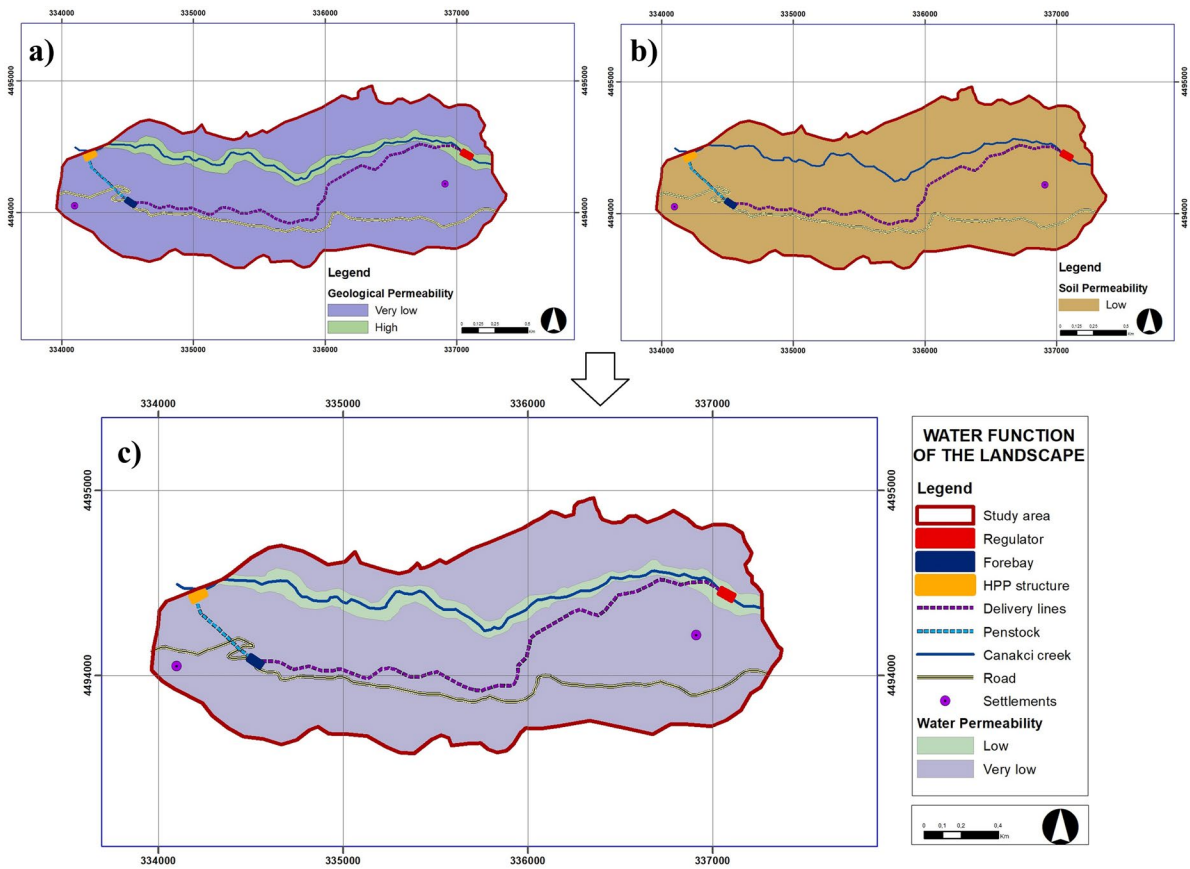


Fig. 5 Spatial distribution of **a** geological permeability, **b** soil permeability, **c** water permeability of the study area

metrics, the creek vegetation and grassland patch classes have the highest habitat function with the high number and the big size of the patches, and herbaceous plant class has the lowest habitat function due to the small number and the small size of patches. According to the patch shape metrics, since the mean patch fractal dimension (MPFD) value approaches 1

and the mean perimeter-area ratio (MPAR) value is small, creek vegetation, and grassland patch classes have the highest habitat function, while the cropland class has the lowest habitat function. According to the patch edge metrics, the herbaceous plant patch class with low edge density has the highest habitat function, while the forest patch class has the lowest

Table 3 ICONA decision matrix of geological rock structure and slope in determining erodibility (Sahin et al., 2014; Ozhançı & Yılmaz, 2018; Uzun et al., 2018)

Erodibility	Slope (%)				
	< 3	3–12	112–20	20–35	> 35
Geological rock structure	Very low	Moderate	Steep	Very steep	Steepest
Andesite, basalt, tuff (hard rock formation)	1	1	1	1	1
Alluvium (soft rock formation)	2	3	4	5	5

1: very low, 2: low, 3: moderate, 4: severe, 5: very severe

Table 4 ICONA decision matrix of land use/cover type and slope in determining soil protection (Sahin et al., 2014; Ozhanci & Yilmaz, 2018; Uzun et al., 2018)

Soil protection CORINE land use/cover	Slope (%)				
	< 3	3–12	12–20	20–35	> 35
	Very low	Moderate	Steep	Very steep	Steepest
Broad-leaved forest	5	5	5	5	5
Sparsely vegetated area	5	5	5	5	5
Natural grassland	4	3	3	3	1
Complex cultivation pattern	5	5	5	5	2
Transitional woodland-scrub	4	2	2	2	1

1: very low, 2: low, 3: moderate, 4: high, 5: very high

habitat function because the edge density is in direct relation with the number of patch edges but inversely proportional to the number of internal species. Patch core area metrics in the inner parts of all patch classes of the study area away from external effects were calculated. Based on these determinations, the forest patch class with a great number of core areas and a high total core area has the highest habitat function, while the herbaceous plant patch class has the lowest habitat function (Table 6).

After the habitat functions of all metrics were determined separately, the scores of the patch classes were added by overlaying all of them and a total habitat function map was created. The total habitat function of the study area, with maximum and minimum scores ranging from 9 to 17, was reclassified under four classes as low, moderate, high, and very high (Table 7). Since the study area does not have a score between 1 and 8 in terms of habitat value, very low habitat classes could not be determined. Accordingly, most of the project area was determined to have a moderate habitat value (159 ha), then low (102 ha),

high (34 ha), and very high (29 ha) habitat value, respectively. Creek vegetation and grassland areas with very high and high habitat values are located in the middle and south parts of the study area. Due to fragmentation, the forest has moderate habitat value. Cropland and herbaceous plants areas with low habitat value, which has less internal habitat type due to the most destructions and impairment, and also grassland with high habitat values, were identified around the delivery line and penstock (Fig. 7).

Determination of the visibility of the landscape

Visibility analysis of all structures was evaluated together with topographic modeling created with the DEM (digital elevation model) image and observer points of the study area. Together with areas that were visible and not visible at all, the visibility function of the study area, which received maximum and minimum scores ranging from 0 to 24 values, was reclassified into three classes as moderate (1–12), high (13–24), and non-visible (0) areas. Thus, the study determined that there are areas of moderate visibility (101 ha) and high visibility (31 ha) in the project area together with non-visible (192 ha) areas. In the study area (30 ha) where the HPP structures are not visible, the Kaynar regulator and the perimeter of the forebay, and the delivery line, road, and creek can be seen moderately from long distances due to the land topography. The northern slopes are seen more than other regions (Fig. 8).

Priority rankings of total landscape sensitivity with integrated LFA and AHP analysis

Water permeability, habitat potential, visibility, and erosion risk criteria, which are effective in the study

Table 5 ICONA decision matrix of erodibility and soil protection in determining erosion risk (Sahin et al., 2014; Ozhanci & Yilmaz, 2018; Uzun et al., 2018)

Erosion risk Erodibility	Soil protection				
	Very low	Low	Moderate	High	Very high
Very severe	5	5	5	4	4
Severe	5	5	4	3	2
Moderate	5	4	3	2	2
Low	4	3	3	1	1
Very low	4	3	2	1	1

1: ineffective, 2: very weak, 3: moderate, 4: severe, 5: very severe

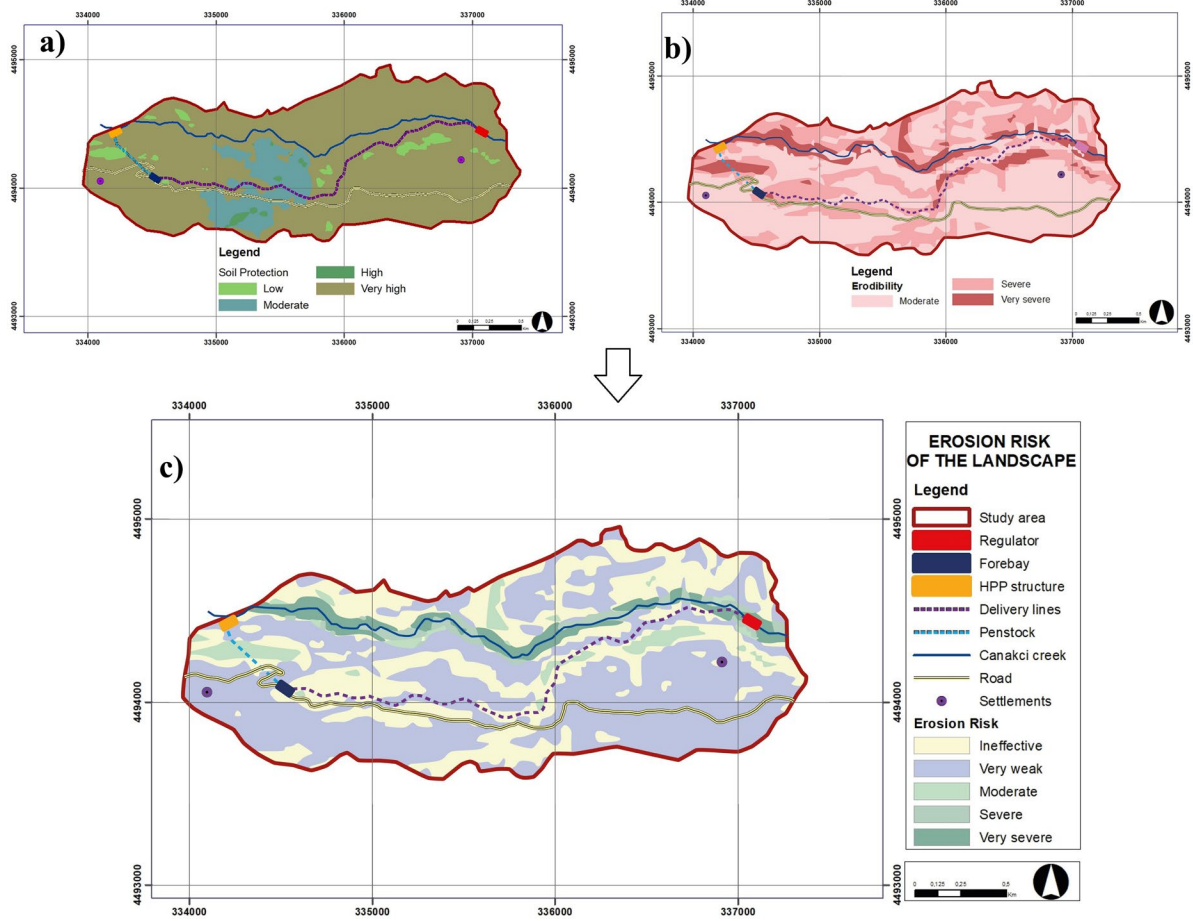


Fig. 6 Spatial distribution of **a** soil protection, **b** erodibility, **c** erosion risk of the study area

area with the integrated functional analysis with AHP, were evaluated by the experts using the paired comparison method. It was determined to have an acceptable consistency of 0.07. The potential and risk criteria of this landscape were selected as water function (0.43), erosion function (0.28), habitat function (0.18), and visibility function (0.11), respectively (Fig. 9). The water function was chosen as the most important criterion among all functions. It appears that the water function is followed by other functions with a sharp decrease of about 50%. The visibility function was chosen as the least important criterion.

While determining the total landscape habitat, each function was overlaid according to the coefficient taken with AHP. The total landscape sensitivity of the study area, of which maximum and minimum values ranged from 7 to 33, was determined. To classify

the resulting map, these points were divided equally by the total number of weights (Fig. 10). Since there is no score between 0 and 6 in the study area, very low landscape sensitivity could not be determined. First-degree sensitive areas (27 ha) with the highest landscape sensitivity cover the creek bank passing through the middle of the project area. Second-degree sensitive areas (114 ha) with high sensitivity include forest areas near the creek. In these areas, where priority restorations and minimum intervention should be made against deterioration, it is necessary to take necessary erosion-reducing measures and protect the creek vegetation. The remaining Kaynar regulator and HPP project area of the basin were determined as 3rd (182 ha) and 4th-degree (1 ha) sensitive landscape areas. The delivery line and penstock of the HPP project pass through these areas.

Table 6 The results of the area, shape, edge and core areas metrics

Land use-land cover	Area metrics ^a			Shape metrics ^b							Edge metrics ^c					Core area metrics ^d		
	MPS	NumP	MedPS	PSCoV	PSSD	CA	AWMSI	MSI	MPAR	MPFD	AWMPFD	TE	ED	MPE	NCA	TCCA	CAI	
Herbaceous plants	0.336	3	0.300	16,509	0.055	1007	1222	1207	741,000	1358	1360	746,032	2302	248,677	1	54,280	36,240	
Forest	14,436	11	1696	140,910	20,342	158,799	2853	2440	3,347,500	1488	1350	28,090,464	86,689	2,553,679	8	3,554,690	83,960	
Cropland	12,596	8	2691	161,838	20,385	100,770	2120	1725	7,079,075	1423	1317	14,472,183	44,662	1,809,023	6	2,018,380	91,480	
Grassland	34,333	1	34,333	0.000	0.000	34,333	2672	2672	161,600	1353	1353	5,549,296	17,125	5,549,296	4	894,270	76,140	
Creek vegetation	29,129	1	29,129	0.000	0.000	29,129	3721	3721	244,400	1410	1410	7,119,844	21,972	7,119,844	3	689,750	58,720	

^aArea metrics: CA class area, NumP number of parch, MPS mean patch size, MedPS median patch size, PSSD patch size standard deviation

^bShape metrics: MSI mean shape index, AWMSI area-weighted mean shape index, MPAR mean perimeter-area ratio, MPFD mean patch fractal dimension, AWMPFD area-weighted mean patch fractal dimension

^cEdge metrics: TE total edge, ED edge density, MPE mean parch edge

^dCore area metrics: NCA number of core area, TCA total core areas, CAI core area index

Table 7 Total habitat function of four main metrics

Patch classes	Area metrics	Shape metrics	Edge metrics	Core metrics	Total habitat function
Forest	2	2	1	5	10
Herbaceous plants	1	2	5	1	9
Grassland	5	5	3	3	16
Cropland	2	1	2	4	9
Creek vegetation	5	5	4	3	17

1: very low, 2: low, 3: moderate, 4: high; 5: very high

Landscape restoration suggestions

The intervention types that should be applied to reach the landscape restoration objectives of the project are presented with the restoration plan map in Fig. 11. Accordingly, the interventions in the area were collected under five groups: soil management-improvement, areas of which nature will be protected, erosion control, vegetative screening, and creek reclamation (Table 8). Also, the suitable plant species to be used for each landscape restoration suggestion in this study area were listed in Table 9.

Soil management-improvement

Topsoil should be stripped, stored, and maintained to be used in post-project landscape restoration works in all landscapes to be intervened. The most important step to be considered during the construction period is good topsoil management. In this context, according to the erosion risk analysis of the landscape, areas at risk for severe and very severe erosion were primarily evaluated. Within the scope of Kaynar regulator and HPP project (Tokat-Niksar), the purpose should be to strip the topsoil in the areas where construction work will be done (including steep and side sloping areas) and protect it by taking necessary precautions so that it does not mix with the subsoil during construction. Topsoil should be stripped to a minimum of 15 cm and a maximum of 30-cm depth. Topsoil should be stored in a way to be drained in cutoffs that are not higher than 2 m and have slopes of less than 45° (Dirik, 1990). At this stage, it should be slightly compacted to reduce the penetration of rainfall. After the slope of the impaired areas is re-given, and the landform is made compatible with the environment, the topsoil should be spread over all impaired surfaces. Subsequently, a slightly rough, loosely pressed structure should be provided to facilitate plant growth.

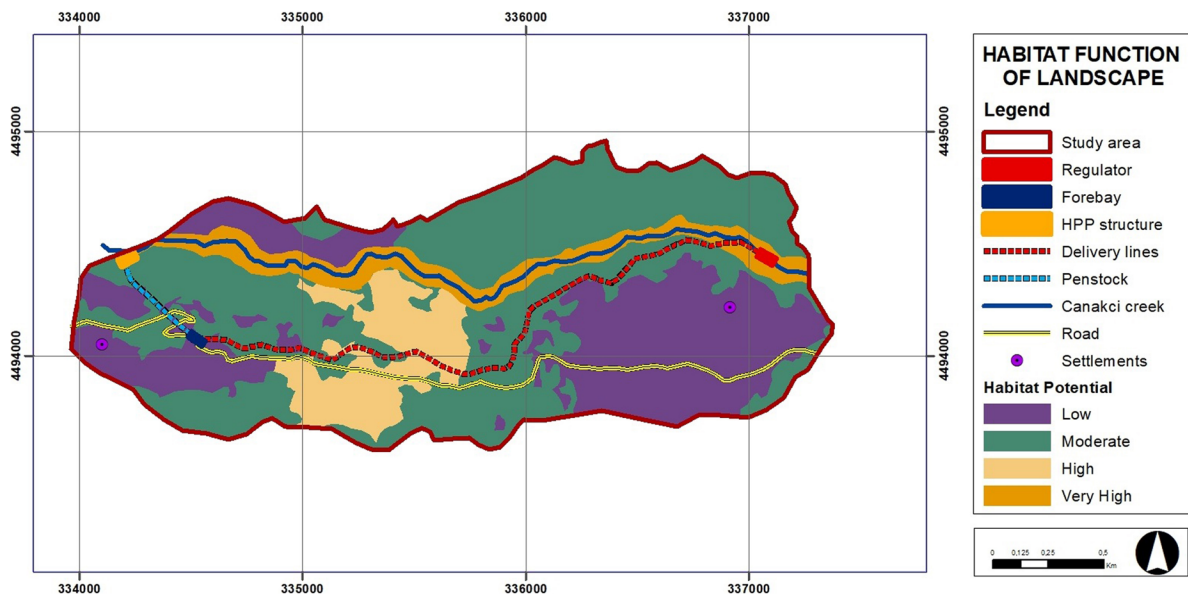


Fig. 7 Habitat potential of the study area

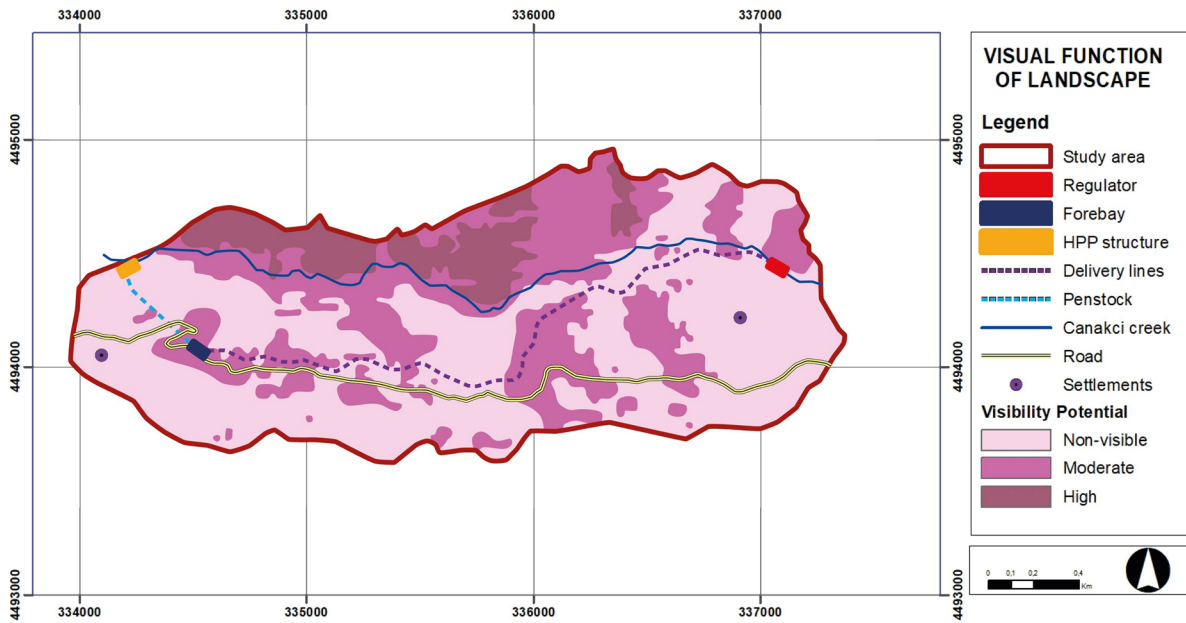


Fig. 8 Visibility of the study area

Also, the top and subsoil in the area where the delivery line passes should be kept separately. After construction, the two types of soil will be laid on the delivery line in the same way. Thus, due to the seed richness of the topsoil, the restoration should occur naturally.

The area to be protected

As a result of the habitat function analysis and landscape sensitivity analysis, the areas of nature that should be protected were very high and high habitat function areas, and very high, high, and moderate sensitive landscape areas (1st, 2nd, and 3rd-degree sensitive areas, respectively). They are located in the middle, north, east, and southeast sensitive landscape

areas parts of the study area. Important wildlife and vegetation must be protected to guarantee the continuity of the species in these areas. In this context, human intervention should be minimized and vegetation (tree, bush, herbaceous) should not be destroyed.

Erosion control

To control erosion, areas with weak vegetation, areas with high slope, and areas at risk of severe and very severe erosion were prioritized for evaluation. In line with this, tubular plants that are at least 1–3 years old should be used and should be advanced together with structural measures (Dirik, 1990). Planting success increases significantly with these plants that show easy adaptation, rapid root development, and rapid

Fig. 9 Priority rankings of the integrated landscape sensitivity values and AHP results



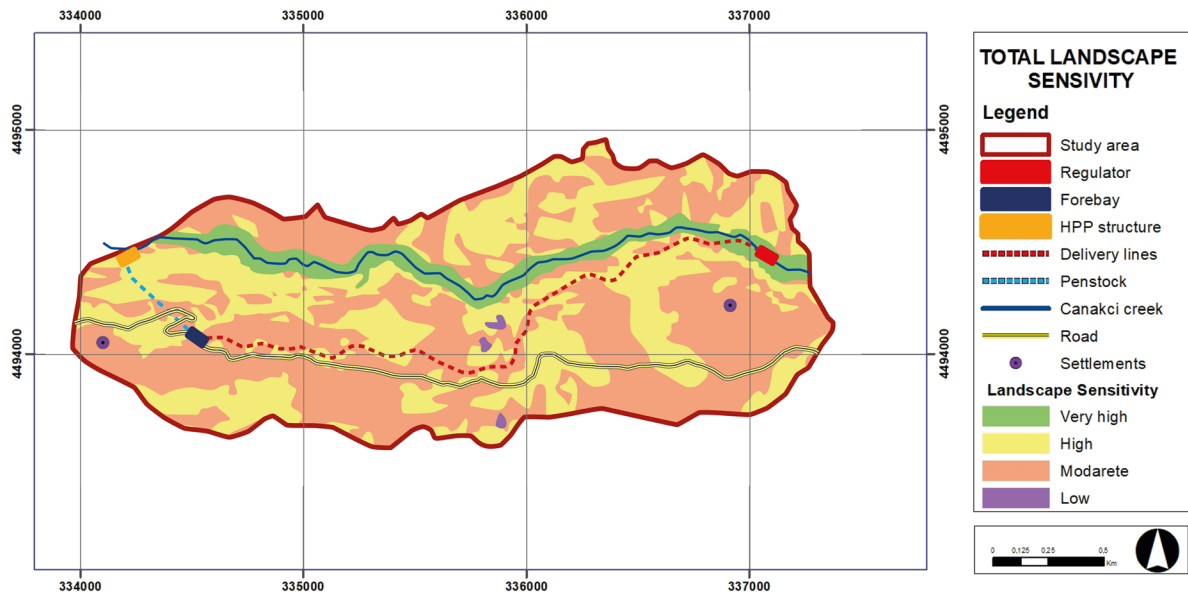


Fig. 10 Total landscape sensitivity of the study area

growth (Dirik, 1990). This allows the plants to hold the soil quickly with their roots and reduces the risk of erosion, especially in areas where the top cover has been destroyed during the construction of the HPP and in the very high and highly sensitive landscape

areas. Where necessary, water breakers, discharge channels, pocket terraces, and silt holders should be built. Areas with high erosion risk are seen on the northern border of the project area. Accordingly, cut tree roots should be left in place as much as possible

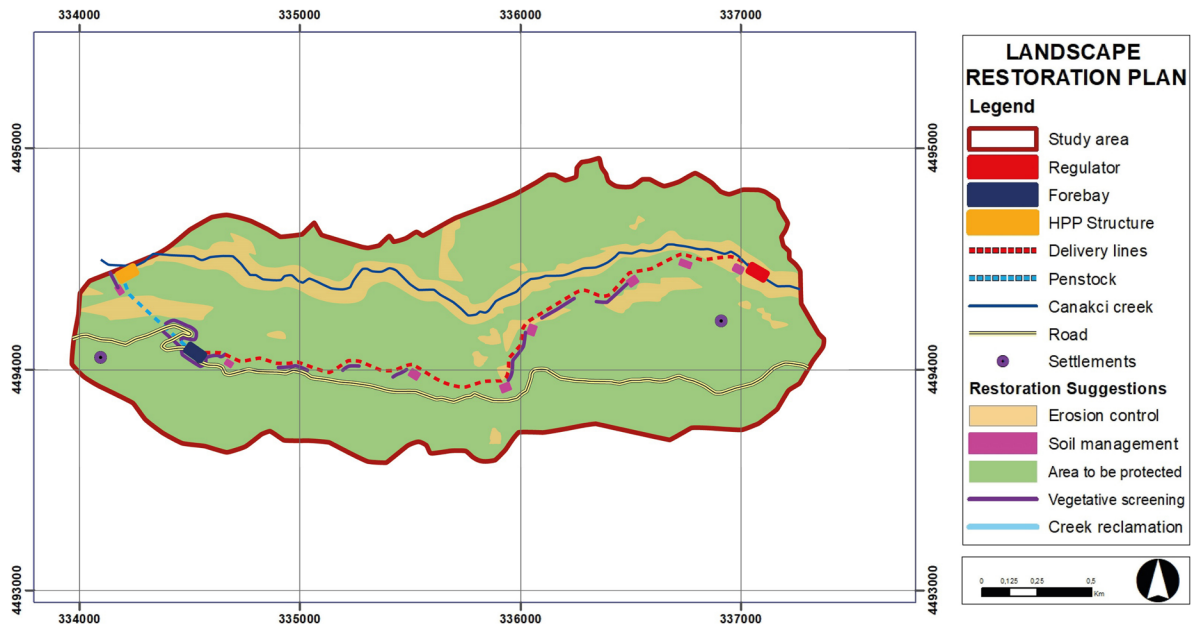


Fig. 11 Landscape restoration plan of the study area

Table 8 The landscape restoration suggestions and their details

LANDSCAPE RESTORATION SUGGESTIONS	Soil management-improvement	In all landscapes to be intervened, topsoil should be stripped, stored, and maintained to be used in post-project landscape restoration studies (Dirik, 1990; Lu et al., 2019; Safaei et al., 2019). For this purpose, recommendations have been developed to protect the soil cover in the study area. Within this framework, total landscape sensitivity, soil permeability, erosion-risk areas, and land cover data were utilized
	The area to be protected	It is very important to protect areas with high habitat sensitivity in terms of the continuity of species (Demir, 2019a). According to the habitat function and total landscape sensitivity, the areas of which the quality should be protected were determined. In this context, natural solutions are proposed for areas of which the quality should be protected
	Erosion control	In areas under the threat of erosion, natural and structural solutions such as using vegetation or improving existing vegetation are used to stop erosion (Akayezu, et al., 2020; Lu et al., 2019). Accordingly, areas that have erosion risk were evaluated. For this purpose, suggestions were developed to reduce the erosion effect
	Vegetative screening (Visual landscape management)	Unwanted images and permanent damages that will occur during the construction and operation phases must be screened (Demir, 2019b). In this context, natural and artificial solutions for screening are proposed. Accordingly, the findings of visibility analysis and areas that have erosion risk were evaluated. Plants to be used in the herbal restoration are expected to be the existing vegetation, be species that are easy to produce and maintain, show rapid development, have high water holding capacity, have noise and wind barrier properties, have the endurance to bad conditions, and climatic conditions, be resistant to shallow grounds and areas open to erosion, have economic convenience, and be complementary with other species such as leaves and tissues with their physiological characteristics (Chazdon et al., 2021)
	Creek reclamation	Within the scope of the HPP project, it is necessary to determine the afforestation strategies to be applied during the creek reclamation works (Demir et al., 2017; Zotou et al., 2019). In this context, the plant condition before the HPP construction was determined in the study area, and suggestions were developed to restore it during the restoration phase. For this purpose, areas that should be protected according to their habitat function and total landscape sensitivity and erosion-risk areas were evaluated. Also, visual solutions were proposed to reduce the impact of the erosion and excavation residues that will occur due to the low water level of rivers

Table 9 The suitable plant species to be used for each landscape restoration suggestions

Landscape restoration suggestions	Plant species suggestions
Soil management-improvement	<i>Juniperus oxycedrus</i> , <i>Crataegus orientalis</i> , <i>Onobrychis cornuta</i> , <i>Festuca ovina</i> , <i>Juniperus oxycedrus</i> L. subsp. <i>Oxycedrus</i> L., <i>Lotus corniculatus</i> , <i>Medicago lupulina</i> , <i>Trifolium repens</i> , <i>Trifolium pratense</i> , <i>Quercus ilex</i> , <i>Quercus pubescens</i> WILLD., <i>Quercus coccifera</i> L., <i>Quercus petraea</i> (MATTUSCHKA) LIEBL. subsp. <i>iberica</i> (STEVEN EX BIEB.) KRASSILN
The area to be protected	<i>Acer campestre</i> , <i>Carpinus orientalis</i> MILLER., <i>Carpinus betulus</i> L., <i>Cerris</i> , <i>Juniperus oxycedrus</i> <i>Fagus orientalis</i> , <i>Elaeagnus angustifolia</i> , <i>Platanus orientalis</i> , <i>Laurus nobilis</i> , <i>Quercus cerris</i> var., <i>Quercus ilex</i> , <i>Quercus pubescens</i> WILLD., <i>Quercus coccifera</i> L., <i>Populus tremula</i>
Erosion control	<i>Juniperus horizontalis</i> , <i>Cotoneaster horizontalis</i> , <i>Ligustrum vulgare</i> , <i>Salix rosmarinifolia</i> , <i>Phillyrea latifolia</i> L., <i>Juniperus oxycedrus</i> L. subsp. <i>Oxycedrus</i> L., <i>Lotus corniculatus</i> , <i>Medicago lupulina</i> , <i>Trifolium repens</i> , <i>Trifolium pratense</i> , <i>Quercus ilex</i> , <i>Quercus pubescens</i> WILLD., <i>Quercus coccifera</i> L., <i>Quercus petraea</i> (MATTUSCHKA) LIEBL. subsp. <i>iberica</i> (STEVEN EX BIEB.) KRASSILN., <i>Ostrya carpinifolia</i> SCOP., <i>Colutea cilicica</i> BOISS. ET BAL., <i>Clematis vitalba</i> L
Vegetative screening (Visual landscape management)	<i>Acer campestre</i> , <i>Carpinus orientalis</i> MILLER., <i>Carpinus betulus</i> L., <i>Fagus orientalis</i> , <i>Elaeagnus angustifolia</i> , <i>Platanus orientalis</i> , <i>Laurus nobilis</i> , <i>Quercus cerris</i> var. <i>Cerris</i> , <i>Juniperus oxycedrus</i> , <i>Salix babylonica</i> , <i>Populus tremula</i> , <i>Pistacia terebinthus</i> L. subsp. <i>Palaestina</i> (BOISS.) ENGLER
Creek reclamation	<i>Arundo donax</i> , <i>Juncus acutus</i> , <i>Carex pendula</i> , <i>Arhenatherum elatius</i> , <i>Carex morrowii variegata</i> , <i>Deschampsia caespitosa</i> , <i>Phragmites australis variegata</i> , <i>Alnus glutinosa</i> (L.) GAERTNER subsp. <i>glutinosa</i> , <i>Salix caprea</i> L., <i>Platanus orientalis</i> L., <i>Carpinus orientalis</i> MILLER., <i>Celtis caucasica</i> WILLD., <i>Mentha longifolia</i> (L.) HUDSON subsp. <i>longifolia</i> (L.) HUDSON, <i>Mentha spicata</i> L. subsp. <i>spicata</i> L., <i>Carex hordeistichos</i> VILL., <i>Plantago major</i> L. subsp. <i>major</i> L., <i>Plantago lanceolata</i> L., <i>Polygonum persicaria</i> L., <i>Foeniculum vulgare</i> Mill., <i>Hieracium umbellatum</i> L., <i>Lotus corniculatus</i> L. var. <i>corniculatus</i> . (BIEB.) ARC., <i>Teucrium scordium</i> L. subsp. <i>Scordioides</i> (SCHREBER) MAIRE ET PETITMENGIN, <i>Rumex acetosella</i> L., <i>Potentilla erecta</i> (L.) RAUSCHEL, <i>Ranunculus sericeus</i> BANKS ET SOL., <i>Galium rivale</i> (SM.) GRISEB., <i>Alopecurus arundinaceus</i> POIRET, <i>Epilobium parviflorum</i> SCHREBER, <i>Glyceria plicata</i> (FRIES) FRIES. <i>Lamium purpureum</i> L. var. <i>purpureum</i> L

to stabilize the soil. Collapses and soil movements that may occur during excavation and filling operations should be prevented.

Vegetative screening (visual landscape management)

The forest cover around the permanent structures to be built for the HPP project creates a partial screening effect in the study area. For this reason, according to the visibility analysis of the landscape, the Kaynar regulator and HPP structure, forebay, penstock, delivery channel, existing settlements, and the visibility degrees of the road were taken into consideration. Within this scope, planting was suggested for screening around the existing roads that connect Gulbayir Village and Alan Village and pass through the project area (Table 3). On the northern slopes of the study area where the project structures are moderately and

highly visible, existing vegetation needs to be protected and improved, depending on the topography and soil condition.

Creek reclamation

Within the scope of the HPP project, afforestation strategies will be applied during the creek reclamation, and a new tree should be planted in place of each tree that will be submerged in the water reserve area that will reach full-filling after the HPP project (Demir et al., 2017). In this context, the study area is planned to restore to its former conditions after the construction of the HPP, taking into account the existing vegetation because plant species that have adapted to the study area before giving a more successful result (Dirik, 1990). Besides, providing the existence of plants and plant diversity in and around the water

is very important in terms of ensuring the sustainability of habitats (Sahin et al., 2014; Demir, 2019a). Two planting methods should be applied for afforestation in the forebay and its immediate surroundings. Due to their ease of transport, trees shorter than 1 m in the forebay and their immediate surroundings should be removed with their roots by an excavator (Dirik, 1990). These should be planted as soon as possible in areas that are determined to be sensitive in terms of landscape function. Thus, the erosion risk of sensitive areas is reduced by the soil surface enrooting with planting. Planting should be done in accordance with the close environment in terms of composition and density. During planting, attempts to damage the existing vegetation should be avoided. When trees longer than 1 m in the forebay cannot be replanted, 3- to 5-year old plants taken from nurseries should be planted. Tubular or coated plants should be preferred for planting because they are light and easily transportable, can grow quickly, the root structure is simple, can be planted every season, and the damage and losses encountered during planting are low (Dirik, 1990). Besides, within the scope of the Kaynar regulator and HPP project, traces of erosion, rubble, residues of underwater structures, and drying aquatic organic materials will be seen in periods when the water level drops. To prevent this visual pollution, a waste management plan should be made to reduce this effect that is likely to occur in August and October when the flow is the lowest. As a result, creek reclamation aimed to ensure the sustainability of the water for the study area and to protect the ecological integrity of the habitat areas that were determined to have high and very highly sensitivity in terms of flora and fauna.

Discussion

This study analyzes all the processes affecting the natural and cultural landscapes and shape/transform the landscapes to prevent the damage caused by the Kaynar regulator and HPP project, under the name of landscape function. These functions were evaluated objectively with AHP, which is a participatory approach, and the total landscape sensitivity of the landscapes was determined. The landscape restoration plan and suggestions were developed according to the total landscape sensitivities and landscape functions.

In the pertinent literature, the pressures of HPP projects on natural and cultural landscape values are mentioned. For example, Kurdoglu and Ozalp (2010), Turhan et al. (2015), and Yaman and Hasil (2018) addressed environmental issues of the existing HPP projects in Turkey but did not develop any landscaping restoration work for the solution of these problems. On the contrary, unlike other HPP projects for which landscape restoration plans were completed (Sahin et al., 2014; GEZI, 2020; Demir et al., 2017), within the scope of this research, landscape restoration decisions were taken with AHP, which has a participatory method in a holistic framework, following the landscape sensitivity. The 6-question paired comparison surveys were applied randomly to experts conducting studies on HPP, landscape restoration, hydrology, geology, erosion, landscape ecology, landscape planning, visual quality, and/or Tokat-Niksar, relevant public institutions, and the private sector. The results of the questionnaire analyzed by the AHP method were found to have an acceptable consistency (0.07). However, there was no return about the survey from other public and private institutions except experts. Increasing the number of respondents to the survey, which was answered only by 247 experts, with the participation of local people and other institutions is very important in terms of increasing the precision of the study. In future surveys, different participation techniques (online conferencing, face-to-face meetings, workshops, social media platforms, etc.) should be used to increase the number of participants.

Landscape restoration models and suggestions have been developed in the study area to prevent damage to ecological and cultural values. In this context, the landscape functions were evaluated by the pairwise comparisons technique. The water permeability, habitat potential, visibility, and erosion risk of the landscape were ranked respectively based on their priorities by AHP. The study indicated that water function is the most important potential for the study area, while erosion is the most important risk. This implies that water and erosion play an important role in determining landscape sensitivity. The landscape sensitivity analysis was determined to prioritize these landscape functions and very high, high and moderate, and low landscape sensitive areas were determined in the study area. Canakci creek and its surroundings, which has a high permeability rock structure, soft

formation alluvial soil, and has a steep and very steep slope, has very high and high sensitive areas that are very important especially in terms of areas that need protection. However, the study also determined that the erosion risk of this area, which has a very high habitat value, is very severe. For this reason, landscape restoration strategies have been introduced for erosion control, areas to be protected, and river regulation in Canakci creek, and its surroundings. In this context, the study suggests preserving the existing vegetation for the stabilization of the soil, leaving the roots of the previously cut ones, using plant species with rapid root development and growth, and limiting human interventions. Thus, the ecological integrity and habitat value of this area, which has creek vegetation, were aimed to protect by reducing the erosion risk. At the same time, with these restoration decisions, the continuity of the species can be guaranteed in these areas with very high and high habitat value. Thus, absolute protection of important wildlife and vegetation can be achieved. Soil management, vegetation screening, and landscape restoration strategies for erosion control were developed to minimize the deterioration that may occur in moderate sensitive areas covering the Kaynar regulator and HPP project area.

The delivery line and penstock, which has a very poorly permeable rock structure, the geological features of basalt, andesite, and tuff, with moderate and very severe slope and with weak and moderate erosion risk were determined as moderate sensitive areas. The length of the penstock and the delivery line affects the destruction and erosion risk on the landscape negatively. Therefore, a lack of a restoration plan causes an increase in this destruction rate (Aslan & Soguksulu, 2017; Bobat, 2017). In this context, restoration decisions for erosion control, soil management, and areas to be protected were taken for this area. Also, this landscape restoration was developed to reduce the impairment caused by the excavations along the HPP line, which has a high and very high habitat value, during the construction phase. For this purpose, the topsoil stored with the seeds inside before construction was offered to be used after construction to speed up the landscape restoration. Also, due to its height and inclination, the HPP structure, regulator structure, and the areas where the HPP line passes have moderate visibility. Hence, to mask the appearance of the HPP structure and the regulator

structure in the study area, landscape restoration was developed for vegetative screening at the places where the road approaches the delivery line. For this purpose, visibility analyses were considered. This planting is also important in terms of erosion control. These landscape restoration decisions are taken for the areas where the HPP line passes can be used as an opportunity to reduce and improve the natural and cultural landscape values.

Turkey has no water management framework law which causes problems and confusion for authority in determining policies for water management (Demir et al., 2017; Turhan et al., 2015). Within the scope of this research, the water function of the landscape, selected as in the first rank, was taken into consideration for the healthy water management and the landscape restoration plan, and the water sensitivity against pressures was revealed. In the restoration plan developed as a result, creek arrangement decisions were taken. However, when determining the water function of the landscape, rainfall data leaking into the soil and evaporating are also needed (Lu et al., 2019; Sahin et al., 2014; Uzun et al., 2018; Zotou et al., 2019). Despite this fact, these data could not be obtained from the relevant institutions in this study. Therefore, it will be useful to calculate the precipitation data that leaks into the soil and evaporates with the experts of the field in future studies.

In HPP projects where the EIA process is mandatory, electrical transmission lines were not included in this process (Aslan & Soguksulu, 2017; Bobat, 2017; Kurdoglu & Ozalp, 2010). The analysis in this study revealed that the electricity transmission line passes through areas with medium habitat value, very low and medium erosion value, very poor soil permeability, and medium and high landscape sensitivity value. Thus, the restoration decisions of the erosion control and area to be protected in this direction were developed in this study. In this context, the inclusion and legalization of electricity transmission lines in the EIA process in future studies are very important in terms of the sustainability of the natural and cultural landscapes in the study area. Besides, Aslan and Soguksulu (2017), Yaman and Hasil, (2018), Akayezu et al. (2020), Manolaki et al. (2020), and Zhao et al. (2020) emphasized the necessity of ensuring the compliance of the landscaping studies, within the scope of the EIA reports, with ELC. Thus, within the scope of ELC, landscapes that have

changed under pressure must be restored and ecological integrity must be ensured. In this context, the results of this research can be a base for EIA reports, unlike other HPP project studies of Turkey. Within this framework, a landscape restoration plan model was developed in which the analyses of the landscape function and sensitivity of the area, where the HPP is applied, were detailed step by step. With this model, landscapes were defined according to their functions and sensitivities as required by ELC, and the specific features of the landscape were determined.

The landscape restoration decisions determined within the scope of this research are not only to protect natural, cultural and, socio-economic values, but also to ensure public health, awareness, and security. Even if hydroelectric energy is classified as a renewable clean and green energy source, HPP projects affect adversely the natural and cultural landscapes and land-use decisions that cause habitat fragmentation (Banks-Leite et al., 2020; Chazdon et al., 2021). For this reason, landscape restoration studies were carried out in this HPP project with the quantitative landscape functions and landscape sensitive analyses in a sustainable way within the scope of ELC. It is then necessary to ensure that land use alternatives are determined, and suitable strategies are set after integrating multi-criteria decision analysis with the evaluation of landscape sensitivity.

The use of the landscape restoration plan model proposal, which was developed using the findings and methods with this research, is very important for the sustainability of landscapes. However, analyzing the land cover/land use changes before the construction of the HPP projects, for which the landscape restoration plan has been completed, with a 10-year interval, in a period of approximately 50 years when the activities will end, is recommended for all prospective HPP and similar applications. Thus, in the following studies, it will be possible to analyze the change of HPP applications to natural and cultural landscape values and to make an inference as to whether ecological integrity can be achieved with the applied landscape restoration plan.

According to the result of the quantitative landscape sensitivity consisting of landscape functions, providing the awareness of ecologically sensitive areas can be significant steps for a landscape restoration plan in the study area. Consequently, unlike other qualitative studies, quantitative spatial solutions and

landscape restoration proposals suitable for these solutions have been introduced to ensure the sustainability of natural and cultural landscape resources in the research area.

Conclusion

This study, which evaluated the HPP project area and basin located in Niksar district of Tokat province and planned in Canakci creek and its branches, aimed to improve, develop, and protect the natural and cultural landscapes destroyed as a result of HPP implementations. In line with this, a landscape restoration plan model and landscape restoration proposals have been developed by using AHP, one of the MCDA methods, which adopts a participatory approach with water, erosion, habitat, and visual landscape functions. According to the AHP comparison result, the priority order of the landscape sensitivity of the study area was selected as water function (0.43), the erosion (0.28), habitat (0.18), and the visibility functions (0.11), respectively. In this area, where the water was preferred as the most significant function, the very high and highly sensitive landscape areas according to the total landscape sensitivity analysis were determined as the creek bank and the forest area around it. It shows the landscape's ability to resist change in response to natural and anthropogenic external influences. A landscape restoration plan was obtained by evaluating all the function maps, total landscape sensitivity map, and soil conservation to reduce landscape deterioration. Within the framework of the landscape restoration plan, five alternative landscape restoration suggestions were developed: soil management-improvement, the area to be protected, erosion control, vegetative screening, and creek reclamation.

In HPP projects, it takes many years to restore the landscapes against the damage to the landscape during construction and operation phases. Even the slightest intervention in areas with natural and cultural landscape values destroys the ecological processes and visual quality of the landscape. Therefore, it is necessary to develop appropriate strategies and method for the landscape restoration of these areas. To determine the negative impacts of the penstock, delivery line and electrical transmission line of the HPP project, all the processes that shape the areas were analyzed in this study. In this context, the functions and sensitivities of

the landscape and all variables that cause a change in the ecosystem were integrated with AHP in GIS environment to bring quantitative spatial solutions. It is an ecological way for the restoration plan and suggestions to be developed about the area to reduce or prevent the pressure of the HPP project.

This study, which demonstrates suitable practices and creates a practicable model to successfully carry out quantitative and integrated landscape restoration study in Turkey, offers an innovative approach for the development of a landscape restoration model. The methods and findings of this research can set an example for other similar projects in terms of restoring natural and cultural landscapes that have been impaired due to anthropogenic interventions such as natural disasters or HPP applications in the ecologically sensitive areas of Turkey and other developing countries.

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Data availability The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request available at sara.demir@btu.edu.tr.

Declarations

Conflict of interest The authors declare no competing interests.

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