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Multidimensional Analysis of Potential Cost-to-Cost Risks of Climate Disruption for Energy-Focused Facilities Using Remote Sensing, Drone Photogrammetry, and GIS Methods

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Abstract: One of the changing world climate disorders generally caused by human beings in the long term is abnormal precipitation or droughts. Abnormal rainfalls or droughts experienced in almost every season in Turkey and in the world continue to take a high share of this situation in power plants operating in the energy sector. One of the regions in Turkey affected by the sudden decrease and sudden suppression of rainfall in recent years is the Eastern Anatolia Region. This study was carried out to investigate possible environmental risk factors in a series of HEPP areas built side by side within the borders of Erzincan and Erzurum Provinces. In these power plants, uncontrolled floods caused by excessive rainfall, potential damage to structures such as transmission channels, pools and weirs, or malfunctions in main sections such as main buildings and regulators will be directly affected. Although these structures are built to withstand natural disasters such as earthquakes and excessive rainfall, it may not be foreseeable that climate disturbances will not pose a greater risk. This study was carried out using Geographic Information Systems (GIS)-based Multi-Criteria Decision Analysis (MCDA) by taking into account environmental risk factors such as precipitation risks and landslides that have affected in recent years by evaluating them together with land use. A digital terrain model and orthophoto images were created using drone photogrammetry over the approximately 15 km length and 50 meters wide area where the two power plants are located. An attempt was made to create a risk model with the parameters of land use, elevation, slope, aspect, precipitation, temperature and distance to the streams.

Keywords: Drone photogrammetry, Risk assessment, HEPP, Environmental threats, Remote sensing

Introduction

The increasing global demand for sustainable and renewable energy sources has highlighted the significance of evaluating potential environmental risks associated with energy-focused facilities. Among the renewable energy options, hydroelectric power plants (HEPPs) are pivotal for their contribution to reducing dependency on fossil fuels and supporting cleaner energy production. However, the environmental impacts and the risks posed by climate fluctuations remain critical challenges for energy infrastructure, especially in regions prone to erratic weather patterns. Turkey, a country with diverse topographical and climatic conditions, has experienced notable changes in precipitation and drought patterns in recent years. These alterations have had pronounced effects on energy facilities, particularly in areas such as the Eastern Anatolia Region. Facilities in these areas face challenges from unexpected extreme weather events, which can result in uncontrolled flooding and structural damage. The potential for severe rainfall and climate-induced disturbances to disrupt the operation of HEPPs necessitates comprehensive risk assessment methodologies.

Considering the critical need for efficiency of renewable energy and environmental protection through assessment of environmental sustainability, identification and reduction of potential risks, hydroelectric and solar power plants in Turkey are of utmost importance. Rising concerns about environmental pollution and energy security have increased interest in developing renewable and environmentally friendly energy sources such as wind, solar, hydroelectric, geothermal, hydrogen and biomass to replace fossil fuels (Ahmed, 2024). It is also important that the location selection of all power plants is evaluated with multidisciplinary engineering formation in areas where climatic effects will be minimized.

As decisions increase in complexity and importance, so does the need to formalise them using available information, and to document the rationale. Multi-criteria decision analysis (MCDA) is a decision-making approach that aims to structure complex decisions and evaluate multiple conflicting criteria (Greene et al., 2011). This approach allows decision makers to consider and balance multiple factors such as topography, LULC type, and ecological and social importance values when evaluating different land use options (Mohamadzadeh et al., 2020). It helps to determine environmentally sustainable land use strategies by ensuring that various factors such as elevation, stream structure, slope, geology, and meteorological data are taken into account in the decision-making process, also considering risk factors (Suab et al., 2024).

Geographic Information Systems (GIS) and remote sensing have become indispensable tools in spatial analysis and decision-making processes. GIS provides a robust platform for capturing, storing, analyzing, and visualizing spatial data, while remote sensing enhances data acquisition by enabling the collection of information from satellites, drones, and other aerial systems. These technologies play a critical role in various sectors, including urban planning, environmental management, disaster response, and agriculture.

In recent years, the integration of drones or Unmanned Aerial Vehicles (UAVs) in mapping has revolutionized the field by offering high-resolution, up-to-date imagery at relatively low cost and with significant flexibility. UAVs equipped with advanced sensors allow for detailed, accurate, and efficient data collection over specific areas, bridging gaps between traditional satellite imagery and ground surveys. This capability has expanded the scope of spatial data analysis, making it accessible for more targeted and dynamic projects.

Multi-Criteria Decision Analysis (MCDA) methods complement GIS and remote sensing by providing a systematic framework for evaluating multiple, often conflicting criteria. MCDA aids decision-makers by integrating qualitative and quantitative data to prioritize alternatives or make informed choices in complex scenarios. When combined with GIS, MCDA can be used to solve spatial decision problems, such as site selection, resource allocation, and risk assessment. This integrated approach ensures a comprehensive assessment that accounts for a wide array of spatial and non-spatial variables. By leveraging the combined power of GIS, UAV mapping, and MCDA methods, professionals can gain deeper insights into spatial phenomena and make data-driven decisions with higher precision and reliability.

The integration of Geographic Information Systems (GIS) with Multi-Criteria Decision Analysis (MCDA) represents a significant advancement in spatial decision-making processes. This combined approach leverages the spatial analysis capabilities of GIS and the structured decision-making processes of MCDA, facilitating complex evaluations across multiple criteria. The application of GIS-MCDA has been observed across various fields, such as environmental management, urban planning, and resource allocation (Feizizadeh et al., 2015). Highlight its role in conducting sensitivity and uncertainty analyses for economic vulnerability assessments, emphasizing the robustness that GIS-MCDA can provide in decision-making processes (Feizizadeh & Kamran, 2015).

A comprehensive review by Lokhande et al. (2017) outlines the methodological versatility of GIS integrated with MCDA in landfill site selection, showcasing how different MCDA techniques—such as Analytic Hierarchy Process (AHP) and Weighted Linear Combination (WLC)—can be employed to enhance spatial decisionmaking (Lokhande, 2017). Similarly Abdullah (2014) demonstrates the adaptability of GIS-MCDA for spatial distribution Modeling of settlements, providing insights into the compatibility between environmental elements and criteria (Abdullah, 2014).

The ecological applications of GIS-MCDA are exemplified by Kazemi and Akinci (2018) who used this combination for land use suitability analysis for rainfed farming, showcasing the ability of GIS-MCDA to assess spatial data holistically (Kazemi & Akinci, 2018). In a similar vein, Ozkan et al. (2020) ıntegrated hesitant fuzzy linguistic term sets with GIS-MCDA to evaluate landfill sites, which further confirms the method's applicability in addressing uncertain decision environments (Ozkan et al., 2020).

Cetinkaya et al. (2016) presented a GIS-based fuzzy MCDA approach for refugee camp site selection in southeastern Turkey, highlighting its strategic importance in humanitarian logistics The methodological framework involving fuzzy logic was expanded by Ustaoglu et al. (2021) who employed the TOPSIS method integrated into a GIS environment to optimize agricultural land suitability in peri-urban areas (Ustaoglu et al., 2021). Additionally, the work of Fernandes et al. (2021) on prioritizing water quality interventions demonstrated the effectiveness of GIS-MCDA in environmental monitoring, illustrating how contamination risk and intervention complexity can be analyzed using this hybrid approach (Fernandes et al., 2021).

This integration also extends to public safety and urban planning, as evidenced by Alemdar et al. (2020). Who explored pedestrian crossing evaluations using AHP and VIKOR in a GIS context (Alemdar et al., 2020). Finally, Kavurmaci (2016) applied the GIS-MCDA model for groundwater quality assessment in Aksaray, Turkey, showcasing the adaptability of such systems for hydrological studies (Kavurmaci, 2016).

This study was conducted to assess the environmental sustainability and efficiency of two adjacent Hydroelectric Power Plants (HEPP) between Erzincan and Erzurum Provinces, located in the north-eastern part of Turkey. This study aimed to perform MCDA using remote sensing, drone mapping and Geographic Information Systems for sustainable HEPP and Solar Energy Power Plant (SEPP) management in the Eastern Black Sea region of Turkey. Studies focuses on the environmental risk factors influencing two hydroelectric power plants in Erzincan Province, Turkey. Utilizing Geographic Information Systems (GIS)-based Multi-Criteria Decision Analysis (MCDA), combined with drone photogrammetry and remote sensing techniques (Alkan et al.,2023), the study aims to develop a risk model that accounts for critical factors such as land use, elevation, slope, precipitation, and distance to streams. This multidisciplinary approach offers a framework for assessing and mitigating environmental risks, ensuring sustainable operation and resilience of energy facilities.

Method

Study Area, Methodology and Data Collection

In the first phase of this study, the risks posed by a series of Hydroelectric Power Plants in Erzurum and Erzincan provinces, especially against unpredictable excessive rainfall, were investigated. The selected area spanned approximately 15 km in length and 50 meters in width around the two HEPP sites (Figure 1).

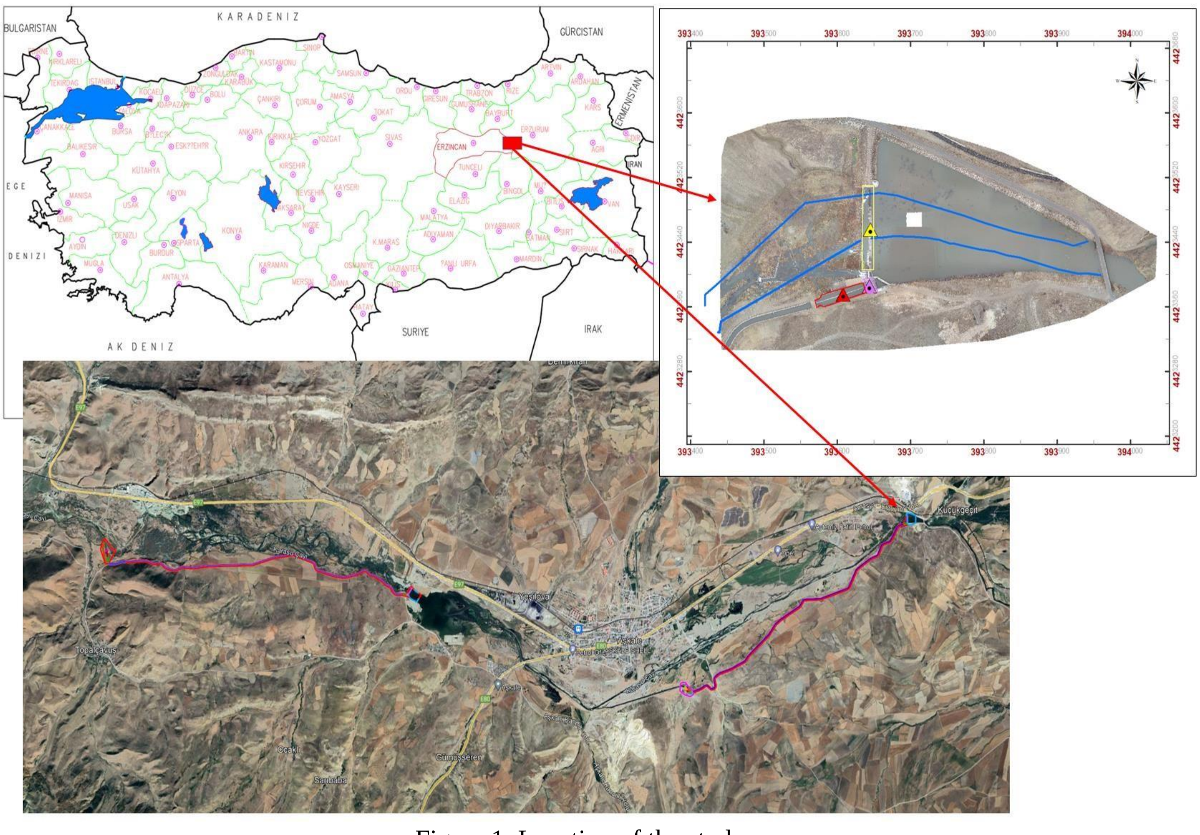

Figure 1. Location of the study area

The GIS-based multi-criteria decision analysis (MCDA) method approaches a correct decision analysis for each criterion. An analytic hierarchy process (AHP) is a well-known technique in the MCDA method due to its flexibility, simplicity, implementation in a GIS environment, and the ability of users to derive the weight of criteria on maps(Malczewski, 2007; Rauf et al., 2023). AHP is based on a pairwise comparison approach that compares criteria with each other according to their importance (Ishizakaand Nemery, 2013). To conduct a comprehensive environmental risk assessment of the two HEPPs in Erzincan Province, a combination of GIS-based MCDA, drone photogrammetry and remote sensing (Alzubade&Alkan,2022) was employed. The work steps were tried to be put into practice with the flow chart summarizing the work (Figure 2).

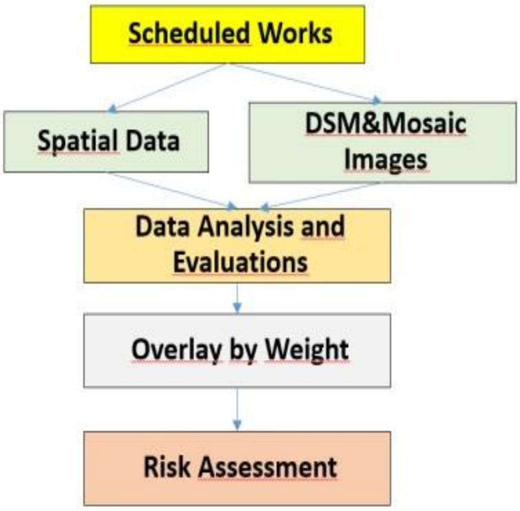

Figure 2. Flow chart of the work

With GPS module drone flights, firstly the images of the approximately 15 km long line including the power plant building-transmission channel-regulator area of the two power plants were obtained. By processing these images, mosaic images of the region were obtained and Digital Surface Model (DSM) and Digital Elevation Model (DEM) were created. Data collection involved capturing high-resolution orthophoto images using drone photogrammetry and integrating these images into a (DSM) and (DEM) (Figure 3).

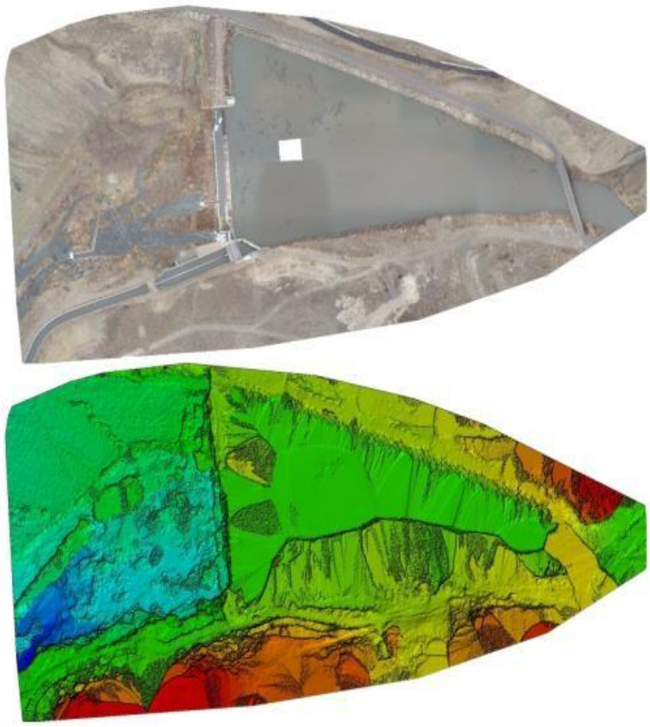

Figure 3. Digital Surface Model (DSM) and Digital Elevation Model (DEM) of the study area

MCDA Framework

MCDA was applied to include various environmental data into the risk model. Parameters affecting risk factors include land use and land cover (LULC) , elevation, slope, aspect, curvature, and distance to water bodies. The decision-making process was structured to evaluate the relative importance of each factor and its contribution to possible risks. GIS analyses were performed by Arcmap software and raster result data were obtained. The risk criteria that are predicted to affects the region were determined as a result of feasibility reports prepared before the construction phase of HEPPs, updated reports, and literature research and studies GIS-based weighted overlay analysis was applied. The weights and scores of the determined criteria were obtained with the help of these environment-specific reports and expert opinions (Table 1). Slope, aspect, distance to water bodies, land use capacity, land use status were accepted as natural criteria.

Table 1. Scores and weights for used criteria

Criteria	Subcriteria	Average Score	Average Weight
Slope	0%-5%	4	20%
	5%-10%	5	
	10%-25%	3	
	25%-40%	1	
	40%-100%	0	
Aspect	S	5	20%
	SE-SW	4	
	E-W	3	
	NE-NW	2	
	N	1	
Land Use	Agriculturel Zone1	1	20%
	Agriculturel Zone2	2	
	Limited Agr.Zone	3	
	Forest	0	
	Grassland	5	
Curvature	I	1	20%
	II	2	
	III	3	
	IV	4	
	V	5	
Hdrology (Distance to Waterbody)	0-20	5	20%
	20-50	4	
	50-70	3	
	70-100	2	
	100+	1	

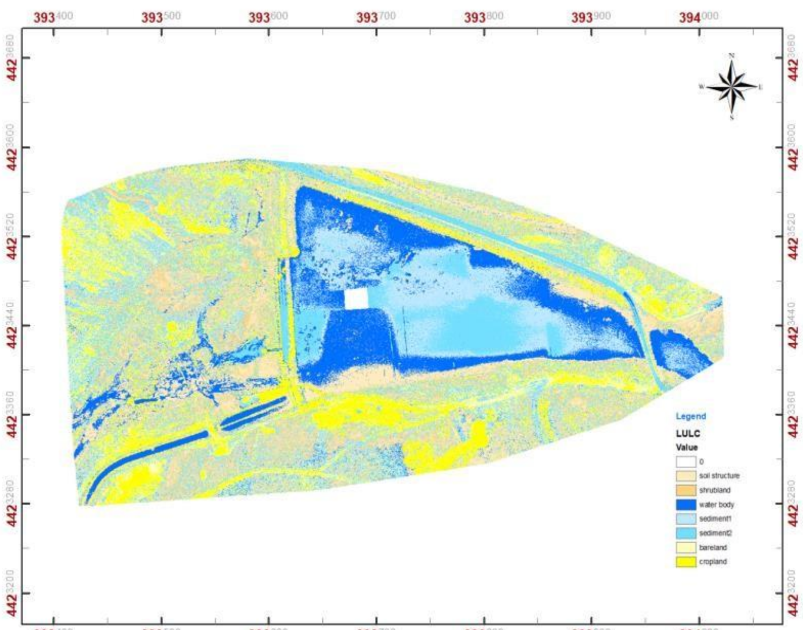

Figure 4. Land Use Land Cover (LULC) image

In the study area, the topography is dominated by the north, north-west and south-west, west orientation. The Karasu River, which HEPP's benefit from, extends in the east-west direction, but forms deep pits when directed south. In the south-west side, where the orientation is risky, the risk of flooding in an unexpectedly excessive rainfall is a negative factor. For Land Use Land Cover (LUCL) Analysis, supervised classification was performed for 7 classes by obtaining high-precision drone images as mosaics using remote sensing techniques (Alkan et al.,2022) with visible and infrared bands. Accuracy analysis was performed by sampling the land structure and usage around the area where the HEPP transmission channel, sedimentation basin and regulator are located. The classified result image in this study, where user accuracy is 87%, is shown in Figure 4. The other data to be used in the overlay analysis stages is the Digital Elevation Model created by processing drone images of the region (Figure 5)

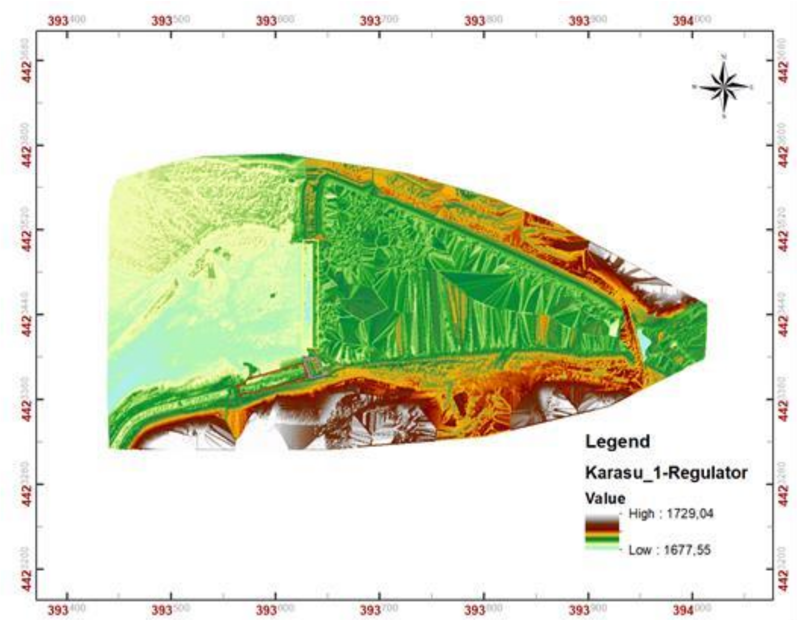

Figure5. DEM ımage of the study area

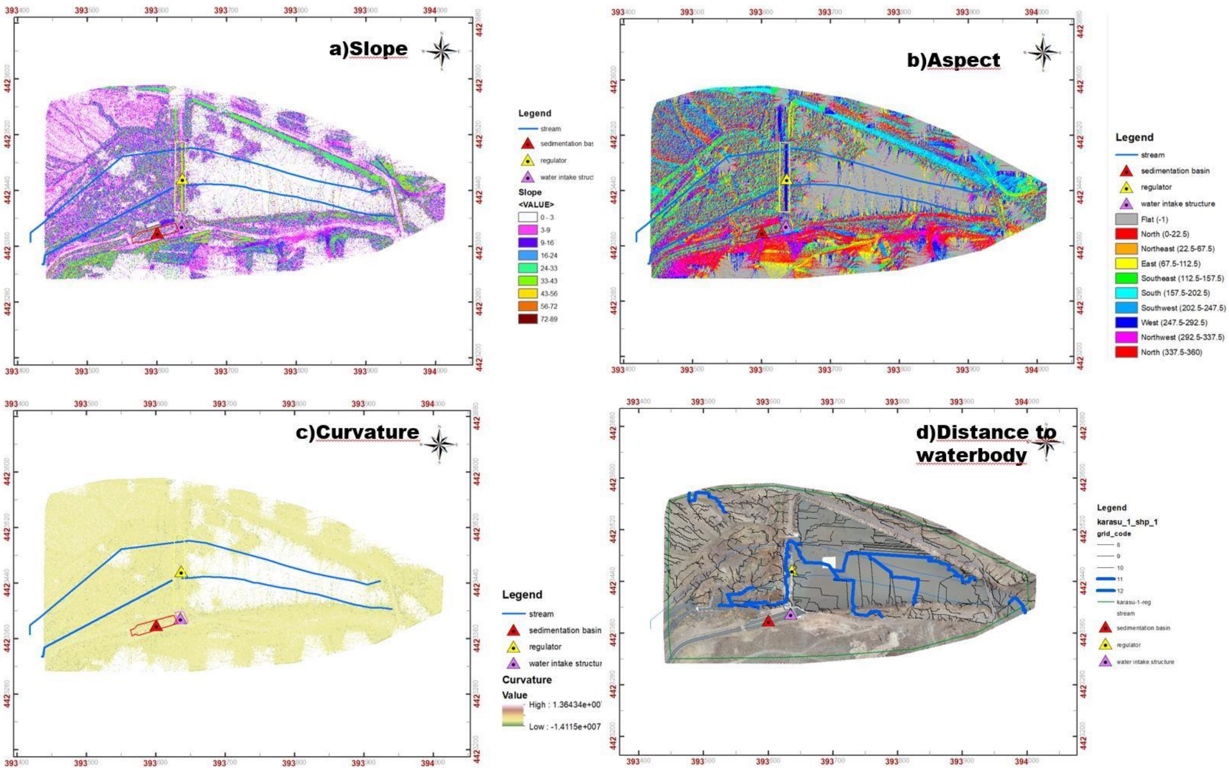

Figure 6. Criteria reclassified images of the study area

Aspect analysis was produced from the DEM image with all direction data and was also reclassified and included in the scoring. The regulator structure carrying risky. The slope in most of the study area is slightly above 3%. It has a slope range of 3% to 9%. The sections in the north and south directions have meadow areas with a slope of 24% and more. The main stream line passes parallel to the transmission channel, and the side branches are quite dense as a result of the analysis.The results of the analysis of Slope, Aspect, Curvature and proximity to the stream, which were studied in stages using the DEM, are shown in Figure 6.

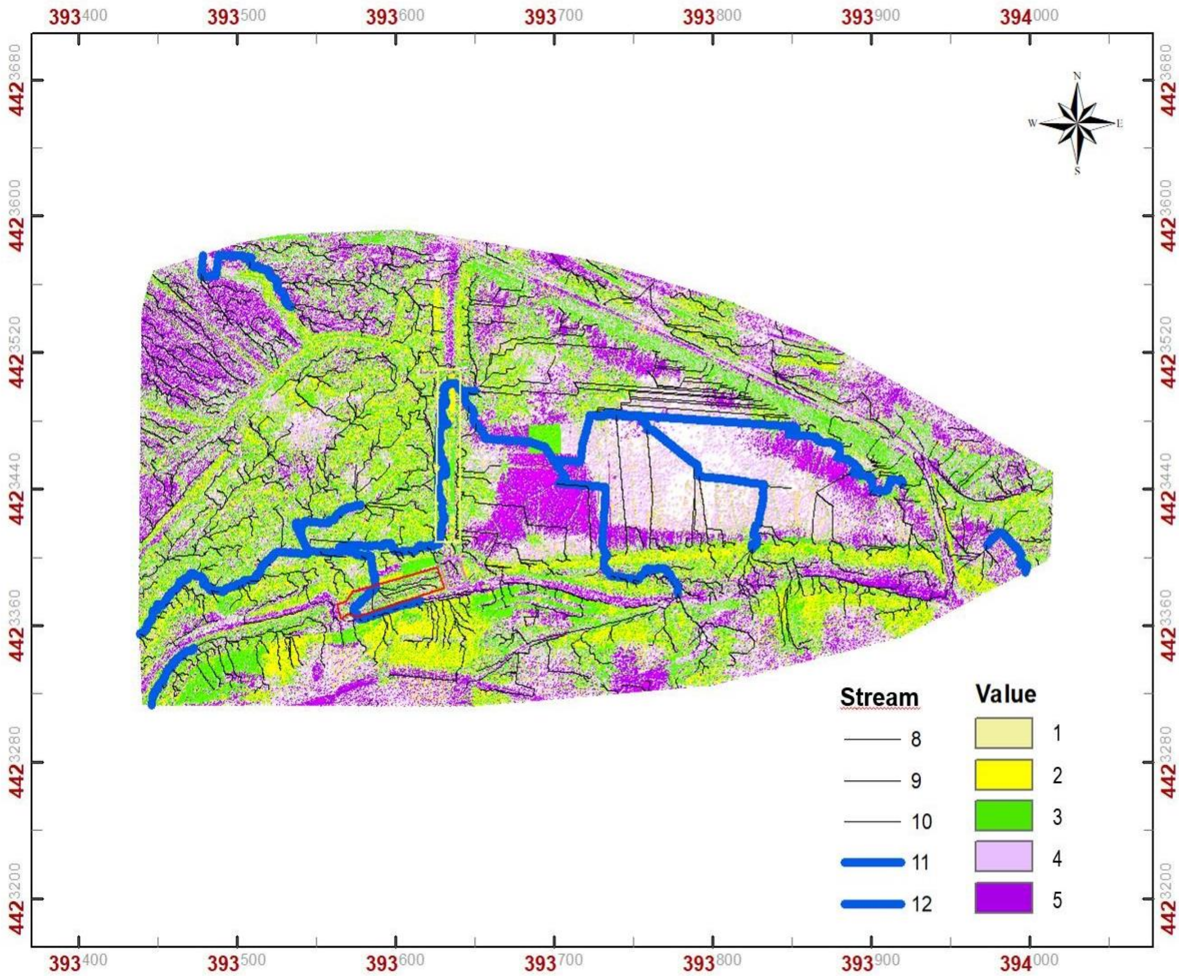

Figure 7. The resulted ımage produced by weighted overlay analysis

Conclusion

In this test study conducted for the Karasu 1 HEPP regulator area, which is the first stage of the application; the weighted overlap model determined according to the criteria explained in the methodology section shows that the risk of being affected by unexpected extraordinary rainfall in the Karasu 1 HEPP regulator area is focused on the southern part of the study area. Areas where the risk is relatively low but should be considered are scored with 4 and 5 points, average suitability areas are scored with 3 points, and areas with the least risk are scored as 1 and 2 (Figure 7).

According to the evaluated data and the climatic anomalies experienced in Turkey and the world in recent years, it can be predicted that the region is in very harsh climatic conditions and when it rains, the snow load at an ellipsoidal height exceeding 1700 meters should be added to the risk factor. In decision-making processes, it is possible to periodically monitor the region with very high-precision images made specifically for drones and to apply risk analyses to the entirety of the power stations. The multi-criteria decision-making method used in this study aims to draw attention to possible precipitation anomalies. The determined dynamics were evaluated with the data studied specifically for the regulator. Sub-criteria such as settlement, economy, geology were not added to the decision-making process, and the area was not expanded so that the main structures in the regulator were evaluated primarily specifically for the water intake structure. In the next stages of this study, it would be appropriate to include geological data and settlement areas in the decision-making process. In addition, meteorological data should be obtained on a monthly basis and this complex world climate process should be monitored.

Recommendations

When the study is evaluated in terms of its rich data, integrity of its methods and environmental quality It is anticipated that this planned work will be permanent in the long term. A different decision-making process can also be created by taking into account the interaction of these HEPPs in series equipped with power plant buildings, transmission structures and regulators.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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