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Development of a Location-Based Solution for Flood Risk Analysis and Reducing its Effects in Agriculture (Case Study: Nekarud)

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Abstract

Floods are among the most devastating and widespread natural disasters, resulting in loss of life and significant financial damage. Therefore, flood control poses a significant challenge worldwide, including in our country. One effective approach to mitigating this risk is through the implementation of zoning strategies. Consequently, the objective of this study is to conduct a spatial analysis of flooding in the Nekarud region. For this research, a 2-kilometer stretch along the downstream section of the Nekarud River, near Neka city, was selected. Spatial data, including geographical maps and reference land information, were utilized and processed to facilitate the analysis. The study focused on simulating flood-prone areas along the main route for return periods of 10, 25, 50, 100, 200, and 500 years. The resulting flood map illustrates the spatial extent of potential flooding under different scenarios. The study employed elevation data at a scale of 1:1000, as well as river discharge data specific to the study area, to construct a base map. In a GIS (Geographic Information System) environment, topographic data was extracted and used to generate a triangulated irregular network (TIN). Additionally, by utilizing a database that incorporates information on agricultural land use and flood zoning within the study area, the researchers calculated the extent of damage caused by flooding. Based on the land use map within the GIS environment, the study estimated that, during different return periods, the affected land area within the study region would measure 144.17 hectares, 175.14 hectares, 182.56 hectares, 190.14 hectares, 193.97 hectares, and 198.298 hectares, respectively. These findings underscore the importance of implementing appropriate flood management strategies, particularly in low-lying areas prone to flooding, to minimize the adverse impacts of such events. Overall, this study highlights the significance of spatial analysis in flood management and provides valuable insights for effective flood control measures.

***Keywords**:* Flood, Nekarud, GIS, Use, TIN

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1. Introduction

Throughout its history, Iran has consistently faced natural hazards and disasters, resulting in significant damages each year (Neumayer, Plümper, and Barthel, 2014). The northern region of Iran, in particular, due to its Mediterranean climate and high variability of maximum daily rainfall, stands as one of the most vulnerable areas in the country prone to floods (Jalilzadeh and Behzadi, 2020). Climate scenarios for 2050 indicate that floods with a current 100-year return period will occur at least twice in 40% of the global scale and 60% in Southeast Asia, Central Africa, Eastern Europe, and Canada, highlighting the substantial increase in flood risks attributable to climate change (De Groeve, Kugler, and Brakenridge, 2007). Extensive studies and investigations conducted in the Mazandaran province, within the studied basin, have revealed over 100 flood events occurring in the last decade, predominantly in the eastern basin. The flood analysis encompassed a comprehensive assessment of precipitation, runoff, sediment, water flow, reservoir storage, reservoir release, and flood control. The primary factors contributing to these results include persistent rainfall, snow melting during certain seasons, an elevated runoff coefficient due to saturated soil profiles, altered waterway and river boundaries caused by sediment accumulation and human activities such as construction and land use changes. Additionally, a reduction in infiltration levels and the presence of low-capacity cross structures, as well as constrictions within the flow channel, significantly contribute to increased flow depth and velocity, representing critical causes of floods. The majority of flood-prone areas are located in agricultural sectors, specifically in lowlands and plains situated along the meandering paths of rivers.

An ongoing challenge faced by our country is the recognition of the substantial threat posed by floods, along with the lack of sufficient motivation among both the general public and officials to undertake the necessary programs aimed at mitigating flood risks (Ali, 2018).

Climate change, land use change, migration, and urbanization play crucial roles in flood management as human activities can significantly impact the capacity of ecosystems to generate floods (Behzadi and Jalilzadeh, 2020; Karimi et al., 2022). This study focuses on analyzing the spatio-temporal impact on the ecosystem's regulation of flood events to support planning for watershed management. The combination of climate effects has resulted in an expansion of potential flood areas and an increase in water depth (Behzadi, Mousavi, and Norouzi, 2019). In order to effectively address the increased risk of flooding in the future due to climate change, it is imperative to enhance flood modeling techniques and tools. Mapping the floodplain and assessing the probability of flooding are valuable for implementing risk management strategies and facilitating land use planning (Mousavi and Behzadi, 2019a). Consequently, the identification of flood-prone areas within watersheds stands as a significant strategy to control and mitigate the destructive effects of floods.

Floodplains and the areas in close proximity to rivers are inherently susceptible to the risks posed by floods due to their unique conditions. Consequently, it becomes crucial to accurately assess the extent and elevation of floodwaters in relation to the ground level in these regions. Additionally, understanding the characteristics of floods based on different return periods is essential. This process, commonly referred to as flood zoning, plays a vital role in identifying and delineating the areas prone to flooding (Rod, faithful, and Fard, 2018). By conducting flood zoning studies, it becomes possible to determine the spatial boundaries of flood-prone areas and establish appropriate measures to manage and mitigate the impacts of floods in these regions.

In the agricultural sector, the economic damage caused by floods is generally lower compared to urban areas, even when subjected to the same level of flood exposure. As a result, while various methods have been developed to estimate monetary losses in the agricultural sector, damage assessment in rural areas has often relied on simple and approximate approaches. Therefore, there is a need to develop a method that considers the key elements involved in the production process and enables accurate estimation of crop losses resulting from flooding. Numerous methods, varying in complexity, have been proposed for assessing flood damage in the agricultural sector, with a majority of them originating from European countries. These methods aim to provide comprehensive frameworks for evaluating the impact of floods on agricultural production and guiding appropriate measures for risk reduction and recovery.

Floods can directly damage various elements including crops, perennial plant materials, soil, buildings, machinery, livestock, animal products, and stored materials. While the focus is often on the assessment of damage to agricultural products in agricultural areas, damage to infrastructure such as highways and roads is less commonly mentioned. However, it is important to consider the overall impact on agriculture, including damage to agricultural houses and infrastructure, as well as other related sectors. The assessment of flood damage encompasses a comprehensive evaluation of the impacts on agriculture and related areas (Veja-Serratos, Domínguez-Mora, and Posada-Vanegas, 2018). This comprehensive approach enables a more accurate understanding of the overall economic and social consequences of floods on agricultural communities and facilitates the implementation of effective mitigation and recovery measures.

In their research, Nabi Darzi et al. (2021) focused on flood zoning in the Cheshme Kileh Tankabon river area. They employed cross-sections and utilized topographic maps, GIS (Geographic Information System), and HEC-RAS software to conduct their analysis. By calculating the Manning coefficient and discharge, they were able to determine the extent of flooding for various return periods. Additionally, they calculated the areas of agricultural, residential, forest, and garden lands that were affected by the floods. This comprehensive assessment provides valuable insights into the specific areas and land types impacted by floods in the Cheshme Kileh Tankabon river area.

In a study conducted by Fisher (2016), the potential damages caused by floods on agricultural products throughout Austria were estimated. The researcher utilized network data on land use and flood risk areas to assess the impact. The findings of the study indicated that the areas along the main river axes in Austria were more significantly affected compared to other regions. Croplands experienced severe damage, and annual loss estimates were calculated based on crop-specific margin data. However, the validation of the results using observed flood losses in 2002 revealed the need for additional measures to improve the situation. The study underscores the importance of further enhancing flood management strategies to mitigate the damages inflicted on agricultural sectors in Austria.

Molo et al. (2021) conducted a study to map flood inundation areas along the Fatam River utilizing GIS and HEC-RAS (Hydrologic Engineering Center-River Analysis System). The researchers employed the HEC-RAS model to estimate flooded areas based on a 5% peak flow for different return periods. GIS was utilized for spatial data processing, and HEC-GeoRAS served as the interface between HEC-RAS and GIS. According to the study's findings, the flooded areas along the banks of the Fatam River measured 27.31 square kilometers, 24.85 square kilometers, 20.47 square kilometers, 17.34 square kilometers, and 13.78 square kilometers for different return periods. Notably, the study revealed that the upstream and middle portions of the Fatam River experienced more significant flooding compared to the downstream areas. These findings provide valuable insights into the distribution and extent of flood-prone areas along the Fatam River, aiding in the development of effective flood management strategies in the region.

In recent decades, the frequency and significance of floods have led national and international authorities to seek more information in order to mitigate flood risks (Ebrahimi, Soleimani, and Shahidi, 2016). In the context of Mazandaran province, flood zoning was conducted along the Neka Shahr River, which spans 6 kilometers in length. Using GIS software and the HEC-RAS model, flood zoning was calculated for various return periods, including 10, 25, 50, 100, 200, and 500 years. The HEC Geo RAS extension was also employed as an interface between GIS and HEC-RAS. This analysis provides valuable insights into the spatial distribution and extent of flood-prone areas along the Neka Shahr River, assisting in the development of effective flood management strategies in the region.

The research conducted by Fisher (2016) highlights the importance of accurately estimating the extent of flood damage on agricultural products as the initial step towards conducting an integrated assessment of flood impacts. This estimation is crucial for developing effective strategies and action plans while considering the associated risks. The primary research objective of the study is to determine the flood risk zoning and quantify the amount of agricultural land affected by flooding. By addressing this research question, the study aims to provide valuable insights for flood risk management and enable informed decision-making in agricultural planning.

2. Material and Methods

2.1. Study Area

The Nekarud watershed is situated among the Caspian Sea watersheds and spans an area of approximately 2274 square kilometers. Neka city is located at coordinates 39 and 36 degrees north latitude and 19 and 53 degrees east longitude from the Greenwich meridian. It is positioned at an elevation of 5 meters above the surface of open water, as depicted in Figure 1.

The Neka catchment area encompasses diverse geographical features. To the north, it extends from the foothills and plains, while to the south, it covers a portion of the Alborz mountain range and the height that separates the catchment areas of the Naka-Roud, Zarm-Roud rivers. The western boundary of the catchment area reaches Sari city and the lands under the Tejn watershed, while the eastern limit is defined by the heights of Shahvar and Gaw Khasban. The overall length of the Nekarud is 176 kilometers, and it comprises seven sub-basins: Laksha, Glord, Burma, Metgazmin, Kiasar, Elarz, and Sarkh Grih. Among these sub-basins, Laksha has the largest area (252.37 square kilometers), while Metgazmin has the smallest area (38.36 square kilometers) based on the topographic map of the region (Mahjoobi and Behzadi, 2022). The Nekarud catchment is distributed between Mazandaran province (61% of the area) and Golestan province (39% of the area) (Haidari et al., 2018). This highlights the cross-provincial nature of the Nekarud watershed and the need for coordinated efforts in managing its water resources and mitigating flood risks.

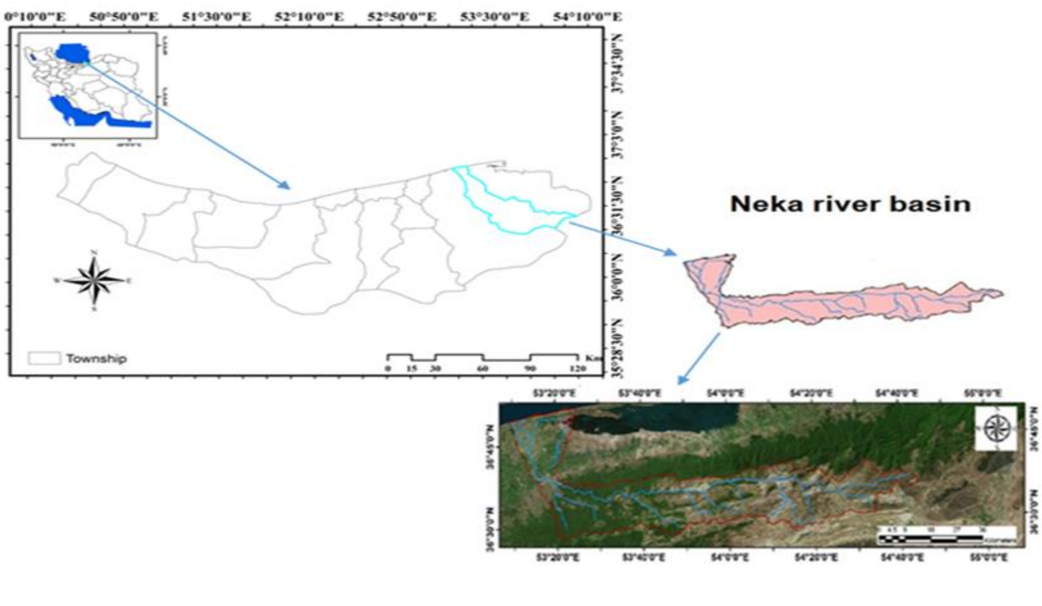

Figure 1. The location of the Nekarud catchment area

The hydraulic analysis in this study was conducted using the HEC-RAS 6.0 software, and the following steps were undertaken:

1. The elevation map was converted into a Triangular Irregular Network (TIN) format.
2. The course of the river was determined from upstream to downstream using the Stream Centerline tool.

3. Floodplains were defined by specifying Bank Lines.
4. The Flow Path layer was placed to outline the boundaries of the floodplains.
5. Cross-sections were included in the analysis, taking into account straight paths and close distances between arcs. This was done to accommodate extreme changes in flow characteristics in these areas, utilizing the XS Cutlines layer.
6. The modeling process was completed in HEC-GeoRAS, and the output was transferred for utilization within the HEC-RAS environment.

For flood modeling, data from hydrometric stations were utilized, which were obtained from the regional water organization of Mazandaran province. The data from these stations were deemed suitable for the study area after investigating the Ablo hydrometric station, the information of which is detailed in Table 1. These data play a crucial role in accurately simulating and analyzing the flood conditions in the study area.

In this research project, the application of GIS 10.8 in hydraulic studies of river engineering was a significant component. To model the area and simulate river behavior and flood levels, the researchers utilized the features of the geographic information system, specifically the latest version of ArcGIS, along with the HEC-GeoRAS, Spatial Analyst, and 3D Analyst extensions (Behzadi and Alesheikh, 2008; Behzadi and Alesheikh, 2014). These software tools enabled the researchers to effectively analyze and visualize the data, conduct hydraulic simulations, and generate flood zone maps (Chatrsimab et al., 2020).

By preparing flood zone maps, the study aimed to identify the areas susceptible to flooding under different return periods. Furthermore, the research focused on determining the damages caused by floods and developing suitable management strategies for flood control, taking into account the specific conditions of the study region. These findings and management patterns provide valuable insights and guidelines for effective flood risk management and mitigation in the area.

Table 1. Discharge table of Ablo station

wet Year	**October**	**November**	**December**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**Annual average**	**A moment at most**
2001-02	1.04	0.75	0.98	1.07	1.16	2.47	4.8	2.82	0.31	0.1	0.06	0.84	1.367	47.89
2002-03	0.63	1.1	2.42	3.23	1.19	7.27	6.57	4.18	9.42	1.76	1	1.42	3.349	361
2003-04	1.39	2.08	7.57	3.73	3.75	5.87	17.5	6.55	1.84	2.77	0.34	3.65	4.753	84.9
2004-05	1.7	2.77	9.05	19.96	18.33	22.33	13.96	8.02	2.67	1.2	0.37	1.18	8.462	90
2005-06	3.53	13	5.28	7.5	10.3	6.71	4.58	1.73	0.6	0.34	0.25	1.12	4.577	217
2006-07	1.66	1.53	3.4	5.07	4.83	12.1	14.4	5.24	1.6	1.71	0.26	1.53	4.444	19
2007-08	2.3	2.2	2.28	1.31	2.7	8.36	1.89	0.1	0.17	0.18	0.12	1.12	1.893	31.9
2008-09	3.44	1.44	3.02	1.41	8.91	6.99	7.56	2.51	0.684	0.338	0.907	2.56	3.314	130
2009-10	4.492	2.757	8.45	4.001	8.974	14.133	6.534	6.339	0.513	0.998	0.164	1.926	4.94	169
2010-11	1.87	1.84	1.83	1.2	1.22	3.26	1.81	0.108	0.066	0.158	0.625	2.01	1.333	20
2011-12	5.761	8.21	5.641	6.373	14.456	28.159	18.834	5.551	2.062	1.818	1.18	6.208	8.688	185
2012-13	9.69	5.82	9.6	7.69	14.3	14.2	5.99	3.65	0.935	0.752	1.19	1.51	6.277	133
2013-14	4.45	0.913	5.55	1.58	0.831	1.81	2.84	0.112	1.3	0.116	0.09	0.242	1.653	145.5
2014-15	1.18	0.791	1.04	0.565	0.684	3.62	1.92	0.092	0.029	0.695	0.183	4.26	1.255	80
2015-16	0.764	2.33	2.08	3.09	3.54	6.69	9.01	3.18	2.71	0.948	0.958	11.7	3.917	190
2016-17	3.71	4.13	5.8	1.71	3.38	3.67	4.12	0.975	0.018	0.019	0.033	0.041	2.301	45.3
2017-18	1.44	1.55	0.49	2.5	2.86	2.1	1.8	1.78	0.074	0.481	1.28	0.585	1.412	18.5
2018-19	1.74	1.67	0.947	4.98	11.5	18	15.8	9.48	2.82	1.8	1.32	1.45	5.959	453
2019-20	1.8	6.12	3.65	1.98	5.69	12.1	9.9	4.23	1.48	0.569	1.7	1.09	4.192	82
2020-21	9.69	5.82	9.6	7.69	14.3	14.2	5.99	3.65	0.935	0.752	1.19	1.51	6.277	133
2001-02	4.45	0.913	5.55	1.58	0.831	1.81	2.84	0.112	1.3	0.116	0.09	0.242	1.653	145.5
2002-03	1.18	0.791	1.04	0.565	0.684	3.62	1.92	0.092	0.029	0.695	0.183	4.26	1.255	80
2003-04	0.764	2.33	2.08	3.09	3.54	6.69	9.01	3.18	2.71	0.948	0.958	11.7	3.917	190
2004-05	3.71	4.13	5.8	1.71	3.38	3.67	4.12	0.975	0.018	0.019	0.033	0.041	2.301	45.3

2005-06	1.44	1.55	0.49	2.5	2.86	2.1	1.8	1.78	0.074	0.481	1.28	0.585	1.412	18.5
2006-07	1.74	1.67	0.947	4.98	11.5	18	15.8	9.48	2.82	1.8	1.32	1.45	5.959	453
2007-08	1.8	6.12	3.65	1.98	5.69	12.1	9.9	4.23	1.48	0.569	1.7	1.09	4.192	82

In this research project, several methods were implemented to achieve the objectives and answer the research questions. The proposed methods for land use analysis and flood zoning were carried out following the flowchart below:

1. The base map used in the study was a 1:1000 AutoCAD map of the river in the study area.
2. Topographic data was extracted and processed in the ArcGIS environment to generate TIN triangulation.
3. To access floodplain information, the HEC-GeoRAS add-on in the GIS environment was utilized to prepare and input data into the HEC-RAS software.
4. Hydraulic analysis of the flow was performed in the HEC-RAS software.
5. The flood zones were displayed in the GIS environment using ArcView software.
6. Representative points of the river's bed and floodplain were mapped from cross-section data to create a map.
7. A TIN of the study period was generated using the mapped points.
8. Utilizing the HEC-GeoRAS add-on and the prepared maps, geometric information, including flow paths, left and right banks, and cross sections, were introduced as new information layers in GIS for hydraulic analysis within the HEC-RAS model.
9. The roughness coefficient for each channel section was determined for all cross sections, taking into account the defined geometric conditions.

By implementing these methods, the research aimed to effectively analyze land use and perform flood zoning in the study area, providing valuable information and insights for flood risk management and decision-making processes (Figure 2).

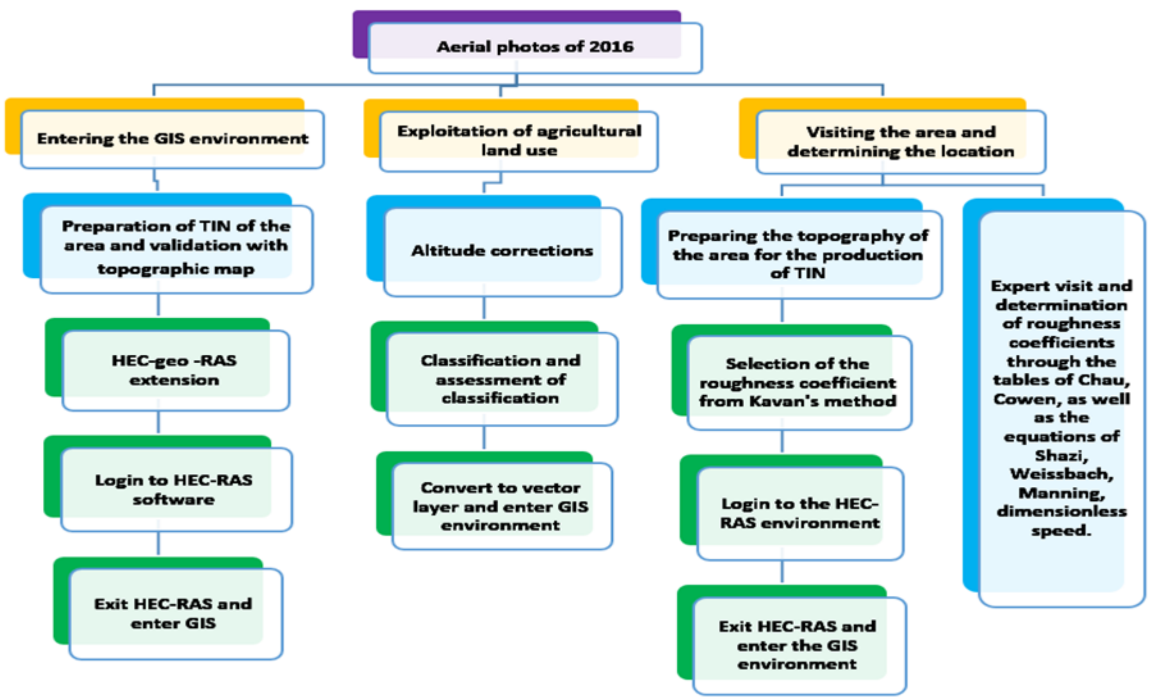

Figure 2. The study method is classified in the flowchart

3. Research Findings and Discussion

In this research, the HEC-RAS software, a widely used tool for estimating the impacts and damages caused by floods, was employed to calculate flood damages in the Nekarud watersheds. The inundation maps for floods with different return periods, generated through HEC-RAS and HEC-GeoRAS, were utilized in this model. The collected database pertaining to agricultural use in the region was integrated with the inundation maps (Mousavi and Behzadi, 2019b). This integration allowed for a comprehensive assessment of the potential damages to agricultural areas caused by flooding. By combining the flood modeling outputs and the agricultural database, the research aimed to quantify and analyze the potential impacts of floods on agricultural lands within the Nekarud watersheds. This information is vital for understanding the extent of potential damage and implementing suitable measures for flood risk management and mitigation in the region (Figure 3).

In the study, the AutoCAD file obtained from the regional water organization of Mazandaran province was utilized. From this file, the required elevation data was extracted and further processed in the GIS environment. The data was used to create both Triangular Irregular Network (TIN) and Digital Elevation Model (DEM) representations, which are displayed in Figure 4. These representations serve as essential tools for the subsequent steps of the zoning process, enabling a comprehensive analysis of the study area's topography and elevation characteristics.

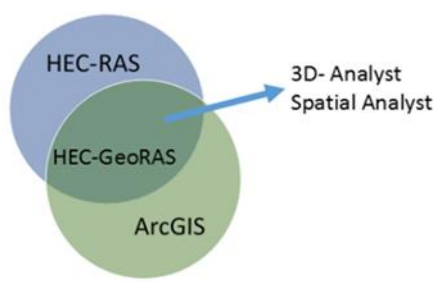

Figure 3. HEC-GeoRAS Chart

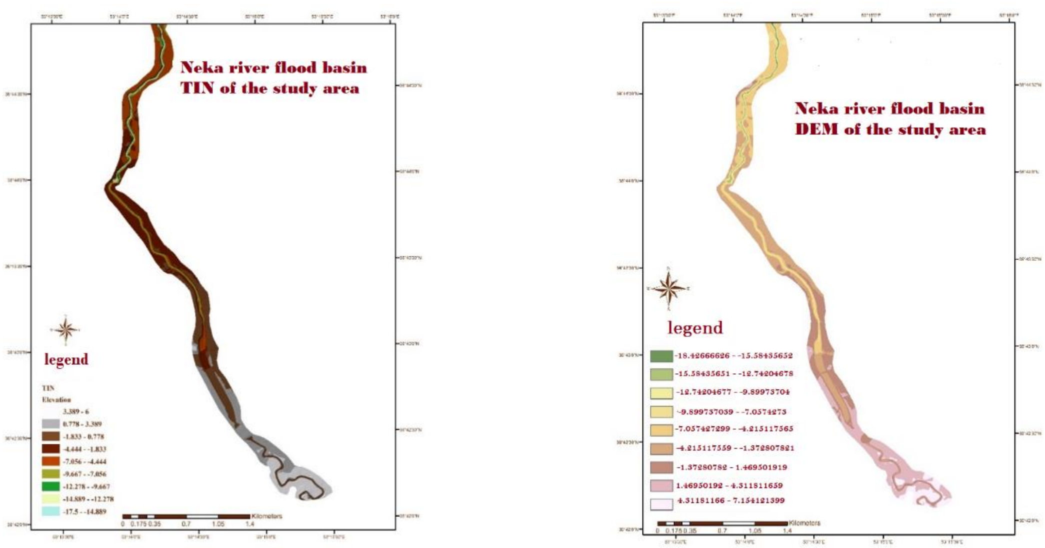

Figure 4. Digital earth model in the form of DEM and TIN in the environment

In the HEC-RAS software, the water level profile is simulated using the standard step-by-step method, which relies on the energy equation. This method operates on the basis of calculations that initiate from one end of the interval and progress step by step from one section to the next. The calculations are performed iteratively, allowing the water level to be determined for each section along the river reach. By considering the energy equation, the software calculates and updates the water levels based on the hydraulic characteristics of the channel, including cross-sectional geometry, roughness coefficients, and flow rates. This step-by-step approach enables the simulation of the water level profile accurately and efficiently within the HEC-RAS software.

- Preparation of the central line of flow

The initial step in preparing the input file for the HEC-RAS environment involves creating the centerline layer of the river course. This layer is generated region by region, starting from the upstream section of the river and proceeding towards the downstream. Each region within the layer includes the name of the river and the corresponding interval.

The centerline layer serves several purposes within the HEC-RAS model. Firstly, it helps determine the spatial range of sections along the river, ensuring accurate placement and alignment of cross-sections within the model. Additionally, it visually represents the position and alignment of the river in the HEC-RAS model, aiding in the visualization and understanding of the hydraulic model. Finally, the centerline layer assists in defining the direction of flow within the river, allowing for accurate representation of the water flow dynamics within the HEC-RAS model.

- Preparing the layer of river banks

The centerline layer plays a crucial role in separating the main flow channel of the river from its banks. It defines the position of the river's shores for each section, where the centerline layer intersects with the surface layer of the sections. This separation allows for the accurate representation of the river's flow channel within the HEC-RAS model. By precisely delineating the position of the river banks in relation to the centerline, the model can simulate and analyze the hydraulic behavior of the flow, considering the interactions between the main channel and the surrounding banks.

- Preparation of flow path dimension layer

The flow path layer, created in the previous steps, serves the purpose of determining the dimensions of the hydrological path within the main channel of the stream, as well as the right and left banks within the flood catchment area. To define the path in the main flow channel, a copy of the flow centerline can be used.

It is important to create the flow path layer in the flow direction, starting from the upstream section and progressing towards the downstream. By calculating the distance between consecutive points along the flow path lines for the main flow channel, right bank, and left bank, the length of the banks can be determined. This information is then incorporated into the HEC-RAS input file, providing the necessary dimensions and spatial data for accurately representing the main flow channel and the associated banks within the hydraulic model.

- Drawing the section layer

The section layer is used to define the position, status, and width of sections within the HEC-RAS model. It serves as the basis for providing the necessary information about each section's points, which are extracted from the digital terrain model and incorporated into the HEC-RAS file.

When drawing lines in the section layer, it is important to consider the following guidelines:

1. Representative lines of the sections should be drawn from the left bank to the right bank of the river.
2. These lines should intersect the central line of the river and the flow direction lines at only one point.
3. The lines should be perpendicular to the flow direction in the main channel of the river.
4. Care should be taken to ensure that the lines drawn in this layer do not cross each other.

By adhering to these guidelines, the section layer can accurately represent the sections within the HEC-RAS model, enabling the appropriate allocation of points and facilitating hydraulic analysis of the river's flow dynamics (Figure 5).

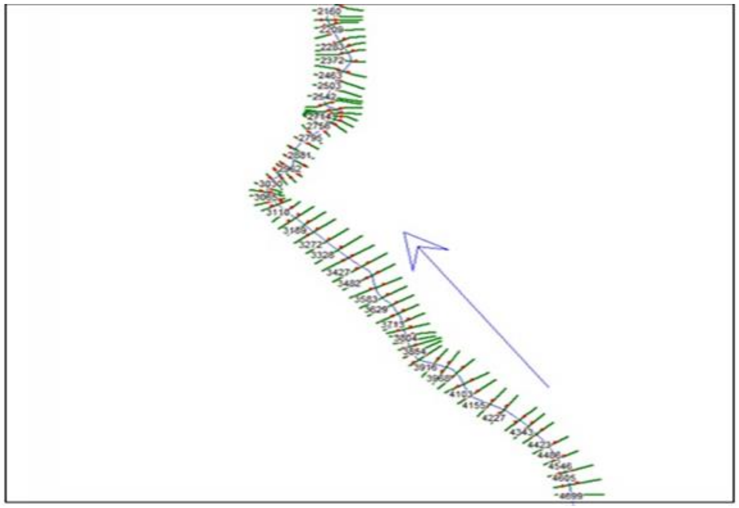

Figure 5. Determining the cross sections in the GIS environment and entering the HEC-RAS environment and converting the layers for processing in the software modules.

The roughness coefficient, which determines the flow velocity and discharge in open channels such as rivers, has been defined using various methods. The relationships proposed for flow rate and flow velocity can generally be categorized into the following five groups:

- Shazi* relationship
- Darcy Weissbach relation†
- Manning's relationship‡
- Dimensionless speed relation§
- Correlation between flow rate and hydraulic factors

A number of methods presented the flow formulas without explicitly presenting the roughness coefficient, which are classified in the last category.

3.1. Kaavan Method

The Kaavan method, which was later refined by the US Soil Conservation Service and the US Geological Survey, does not consider all the factors mentioned. In addition to the previously mentioned factors of roughness caused by the shape of the bed and roughness caused by the high concentration of sediment, there are two additional factors that influence the roughness coefficient (Norouzi and Behzadi, 2019; Norouzi and Behzadi, 2021). These factors are taken into account in determining the roughness coefficient for the entire waterway and floodplain (Eq.1):

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* Chezy

† Dary & Weisback

‡ Manning

§ Dimensionless Velocity Coefficient

$$n = (nb + n1 + n2 + n3 + n4) \times m \quad (1)$$

- The roughness of the waterway or floodplain caused by sediment grains (nb)
- The roughness of the waterway or floodplain surface (n1)
- Roughness caused by obstacles in the waterway or floodplain (n3)
- The coefficient related to the vegetation cover of the waterway or floodplain (n4)
- Roughness correction coefficient based on the degree of meandering of the main waterway

Due to the relatively high accuracy of the Cowen method in calculating Manning values, it has been utilized in this research. The obtained values are presented in the following table:

Table 2. Calculated Manning coefficient

Row	River Station	Frctn(n/k)	n#1	n#2	n#3
1	7763	N	0.045	0.043	0.065

- Determining the flood zone

In the subsequent stage, once the hydraulic model of the river has been prepared in HEC-RAS and implemented, the flood zoning is determined. Within the HEC-RAS mathematical model, the flood zone is calculated as a water level value and displayed at the location of cross-sections. Using the water level values at each cross-section and the post-processor macros provided by the HEC-GeoRAS add-on, a TIN exchange file is created to represent the extent of flooding. This involves combining the TIN of the water surface with the TIN of the land, enabling visualization of the flood extent.

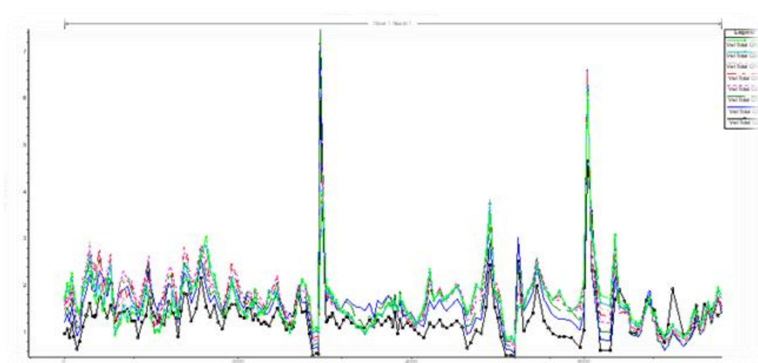

Figure 5. Velocity values in the flood zones of the sub-critical, critical and super-critical sections of the return period of 10 to 500 years

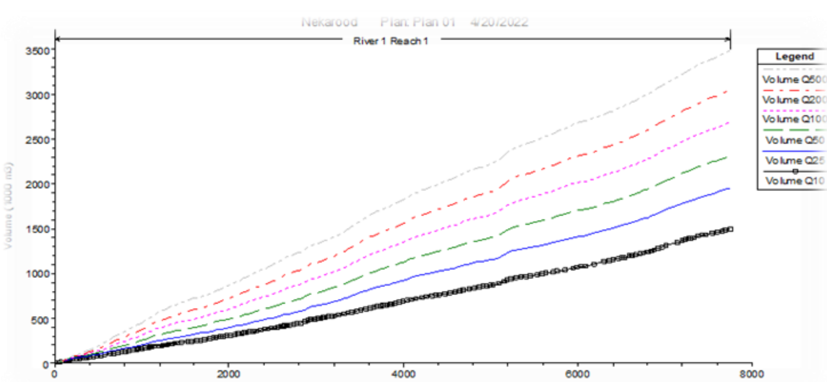

Figure 6. Flood volume of the studied area in the return period of 10 to 500 years

Figure 7. Longitudinal profile of the river from upstream to downstream in the study area

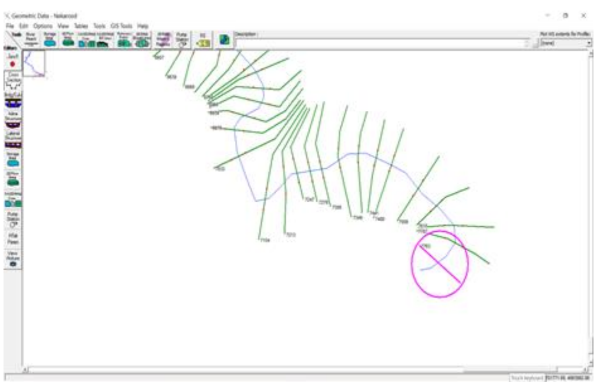

Figure 8. The location of the transverse profile in the upper reaches of the Nekarud

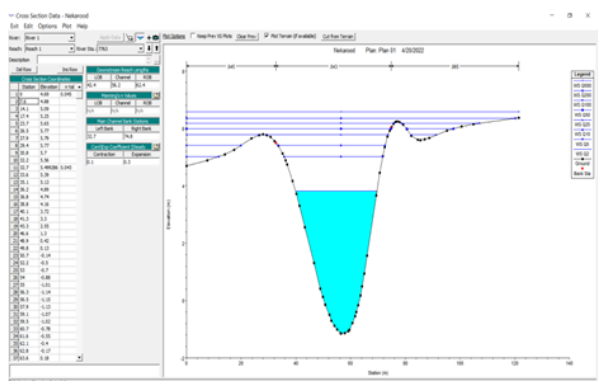

Figure 9. Transverse profile upstream of the river Nekarud with a return period of 10 to 500 years

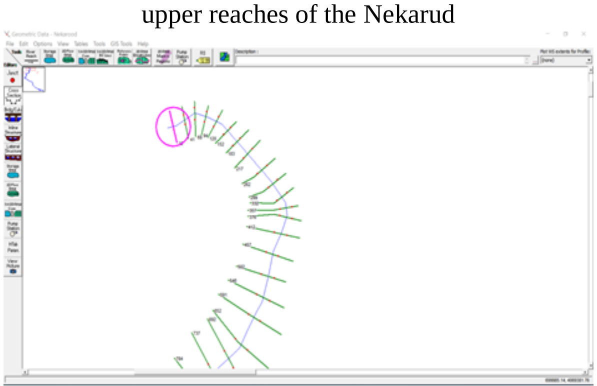

Figure 10. The location of the transverse profile in the downstream of the Nekarud

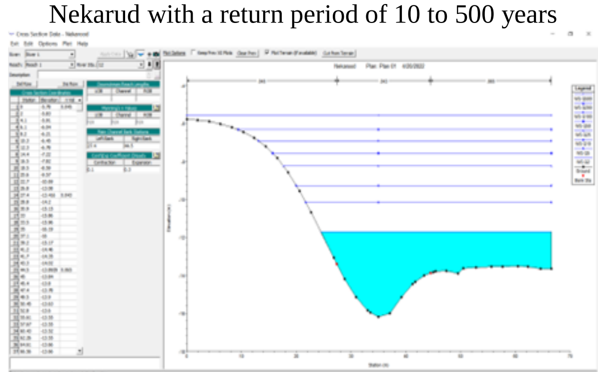

Figure 11. Transverse profile downstream of the Nekarud with a return period of 10 to 500 years

- Determining the area of agricultural lands affected by floods

The flood zoning process involves determining flood extents for various return periods such as 10, 25, 50, 100, 200, and 500 years within the HEC-RAS environment. Once the flood zone data is generated, it is exported as a shapefile and transferred to the ArcGIS environment (Pasha, Sorbi, and Behzadi, 2018). Using the Clip operation, the flood extent is specified specifically for the agricultural lands under consideration.

By delineating the flood zone within the agricultural areas, the areas of specified land uses can be determined. This information enables the assessment of the amount of land that is affected by the flood for each return period. By quantifying the affected land, a better understanding of the extent of flood impact on agricultural areas can be obtained.

- Determining the amount of damage

To accurately estimate the potential losses caused by flooding in agricultural areas within the study region, it is crucial to gather information regarding the specific crop types cultivated in arable lands. Farmers make decisions on crop selection based on factors such as cost-benefit analysis, individual farming goals, and soil characteristics. In the studied area, the prominent crops include black root and citrus orchards.

In developing damage functions, hydraulic parameters such as flood depth, duration, and occurrence during specific seasons were taken into account. These parameters play a significant role in assessing the potential impact of flooding on agricultural productivity.

The agricultural sector in Neka city is highly susceptible to various hydro-meteorological risks, which have the potential to cause severe negative consequences. These repercussions can result in substantial property damages for farmers and their households, including the complete or partial loss of investments and expected income. Moreover, they can significantly disrupt regional economies by interrupting the production cycle, reducing profits, and leading to unemployment and food shortages, among other detrimental effects (Figure 12).

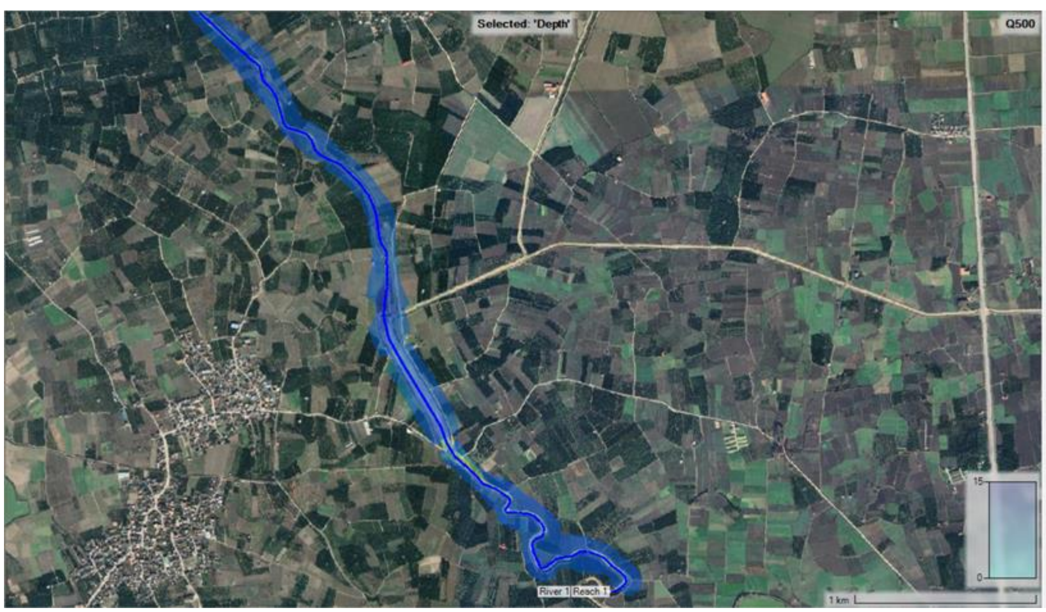

Figure 12. Lands in flood

Significant improvements have been achieved in terms of reducing the volume of field operations and mapping requirements for drawing cross-sections, enabling the ability to create a larger number of cross-sections within a shorter timeframe. The accurate determination of Manning's roughness coefficient and the slope of the path have a substantial impact on the water surface profile.

In order to ensure precise roughness values, extensive field observations were conducted along the designated route using carefully prepared diagrams and photographs. This meticulous approach aimed to achieve the closest possible approximation to the actual Manning's roughness coefficients, resulting in highly accurate assessments of the roughness coefficient within the studied area (Ogras & Onen, 2020).

By considering the changes in land use, particularly in paddy fields and gardens, the flood zone has been comprehensively determined for various return periods, including 10, 25, 50, 100, 200, and 500 years (Chatrsimab et al., 2021; Karimi et al., 2022; Shiravand, Khaledi, and Behzadi, 2019). This assessment provides valuable insights into the potential extent of flooding in these specific agricultural areas.

4. Flooded Area

Within the GIS environment, flood zoning was conducted for various return periods, including 10, 25, 50, 100, 200, and 500 years. The final boundary of the flood zone was carefully examined, considering the inclusion of the land use layer. The extent of flooding was determined both with and without the land use layer, providing comprehensive results for analysis. The findings are outlined as follows:

Table 3. Flood zone in the return period of 10 to 500 years

return period	Flooded area (Square meters)	Garden area (Square meters)	Agriculture area (Square meters)
10 years old	1441712.35	1397031.15	44681.20
25 years old	1751433.85	1698748.40	52685.45
50years old	1825573.70	1777835.45	52685.45
100years old	1901378.57	1848693.12	52685.45
200years old	1939665.83	1878051.46	61614.37
500 years old	1982849.90	1921235.53	61614.37

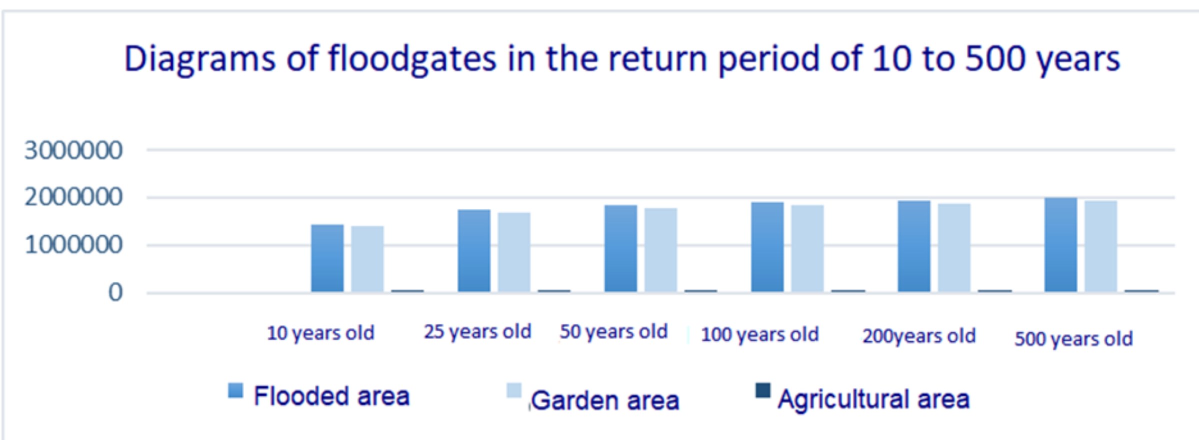

Figure 13. Flooded lands in the return period of 10 to 500 years

5. Damage Estimation

Various models exist for estimating flood damage in the agricultural sector (Jafarian and Behzadi, 2020; Jalilzadeh and Behzadi, 2019; Khaledi and Behzadi, 2020). In this research, the assessment of agricultural damage resulting from the flood focuses on the impact of damage and the costs associated with crop production during the harvest season, considering the various stages of work.

To determine the cost per hectare, factors such as the timing and season of the event, as well as the specific crop type in the area, are taken into account. Additionally, the cost of damage can be estimated based on the extent of the flood-affected area and the regional value of the agricultural products. Based on the gathered information, the average yield per hectare for rice production in the region is estimated to be 2400 kg, while the composite garden products yield approximately 50000 kg.

Table 4. The amount of damage caused to agricultural and garden crops in the study area

Turn back period	**Usable area of a flooded garden (Sq. m)**	**Product amount Produced (kg)**	**Price Each kg of product (Rial)**	**Price Total damage (Rial)**	**Agricultural area affected by flood (Square meters)**	**Product amount Produced (kg)**	**Price the product in kg (Rial)**	**Price Total damage (Rial)**
10 years	1397031.15	7000000	80000	$56*10^{10}$	44681.20	10800	1000000	$108*10^{7}$
25 years	1698748.40	8500000	80000	$68*10^{10}$	52685.45	12480	1000000	$124.8*10^{7}$
50 years	1777835.45	8900000	80000	71.2*10	52685.45	12480	1000000	$124.8*10^{7}$
100 years	1848693.12	9250000	80000	$74*10^{10}$	52685.45	12480	1000000	$124.8*10^{7}$
200 years	1878051.46	9400000	80000	$75.2*10^{10}$	61614.37	14880	1000000	$148.8*10^{7}$
500 years	1921235.53	9600000	80000	$76.8*10^{10}$	61614.37	14880	1000000	$148.8*10^{7}$

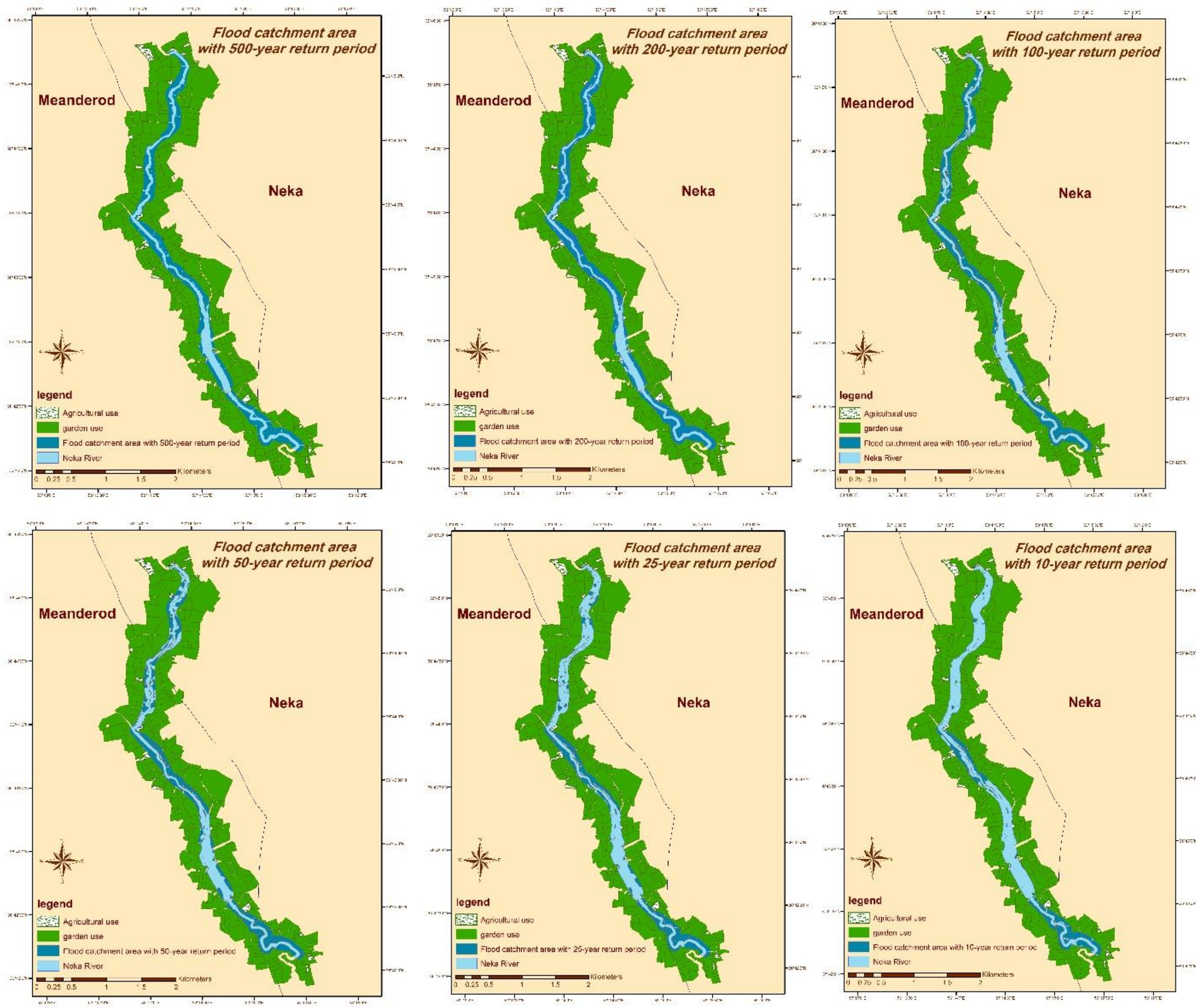

Figure 14. Flood zoning map in the 10, 25, 50, 100, 200 and 500 year return period in the study area - Nekarud

6. Discussion and Conclusion

Water, being a divine gift, possesses the dual nature of both good and evil. With proper planning and effort, humans can harness its potential as a catalyst for development. The term "flood" is commonly associated with damage and displacement in people's minds. It is undeniable that floods often result in the destruction of houses, infrastructure, farmlands, loss of livestock, and unfortunately, loss of human lives. The increasing trend of floods in recent years has affected various regions of the country, leading to periodic and devastating flood events. The financial and human losses incurred by floods have intensified (Haidari et al., 2018).

In the study area, particularly in the plain regions near the river, certain areas face annual flooding due to non-compliance with construction regulations along the riverbanks and the proximity of rice fields to the river (Mohseni, Spitael, and Stefan, 2005). Development in rural areas along rivers and floodplains without proper understanding and consideration of dynamic hydrological conditions and upstream areas increases the risk of floods and associated human and financial losses. Flood zoning plays a vital role in floodplain management (Golshan, Jahanshahi, and Afzali, 2016).

During the investigation of floods with different return periods, it was observed that some areas of the river experience sharp bends, causing the flood to deviate from its original path. The morphological shape of the river and insufficient cross-sectional area for the current to pass are among the contributing factors (Mohseni, 2004).

Rainfall-runoff estimation using hydrological models is employed in water basins without statistical data. This assessment helps evaluate flood conditions in the basin and aids in effective flood management, including the preparation of flood water zoning maps (Roostaei et al., 2022). The generated inundation map provides a spatial representation of potential flooding scenarios, with variations in depth and extent across different return periods. The HEC-RAS and HEC-GeoRAS extensions in the GIS environment are utilized to determine flood levels for return periods ranging from 10 to 500 years.

Similar studies and research conducted in the target area have contributed to the development of flood maps for various return periods. These maps illustrate the extent and depth of water along the modeled channel for different return periods. The water depth ranges from 0 to 6 meters, with the maximum depth typically occurring around the main channel. As the return period increases, the water depth and flood extent also increase. Notably, water spills over into canal sides and surrounding areas, encroaching upon the space where businesses are established. The water dynamics along the respective riverbanks will be further analyzed in subsequent sections.

Therefore, implementing proper flood management measures becomes crucial to mitigate the adverse effects of floods, especially in low-lying flood-prone areas.

Effective environmental resource management requires comprehensive information about the complex aspects of human activities and land cover across the Earth's surface. Land use, being a critical aspect, plays a significant role in understanding and addressing uncontrolled development, environmental quality deterioration, agricultural land damage, flood distribution, and identification of high-risk areas. Accurate knowledge of land use proportions is essential. Land use changes, driven by the need for food production and increased residential areas, significantly impact the global environment and regional hydrological processes. In the northern region of Iran, land use changes often result in a decrease in organic matter and nutrient content in the soil, leading to soil structure degradation and alterations in soil stability distribution. These land use changes in the Nekarud basin elevate flood potential and intensify flood risks, indicating a movement towards detrimental outcomes. By accurately determining the extent of land affected by floods and estimating the associated damages, informed and effective management strategies can be implemented to mitigate these risks.

While mathematical and statistical methods, particularly in the field of hydrology, cannot precisely predict the occurrence of floods and frosts, they provide valuable insights into the probability of past events, enabling informed planning processes. Therefore, data and variable analysis are essential for predicting and planning flood and frost risks in rural and environmental planning. In this research, Ultracamp aerial photos from 2016 were utilized to determine land use in the study area within the GIS environment. Flood zoning for return periods of 10, 25, 50, 100, 200, and 500 years was established based on changes in the utilization of paddy fields and gardens.

The significant impact of land use changes on expanding the flood zone is evident, particularly with the rapid urban growth and reduction of forested areas. The combination of the HEC-RAS model with GIS offers a powerful tool for determining flood zones with varying return periods, aiding engineers in river engineering operations and facilitating informed decision-making (Ebrahimi Soleimani, and Shahidi, 2016).

Restoring roads can significantly reduce roughness coefficients, resulting in decreased flood levels and mitigating potential flood losses.

7. Suggestion

The conclusive findings of this case study offer valuable insights for hydrological modelers, engineers, and stakeholders engaged in flood monitoring. Based on the results and findings of this research, it is recommended to further enhance the study process by focusing on governmental initiatives and implementing local solutions. The suggested actions are outlined in the table below:

Table 5. The suggested local and governmental actions

Local solutions	Government duties
Taking effective steps to carry out watershed operations and revitalizing the vegetation of the area (increasing the density of vegetation at the level of the basin can be an effective help for the infiltration of runoff water and prevent the flow of runoff from a height in the area.	Studying and implementing flood warning system plans in appropriate routes.
Plowing along the slope in sloping lands, terracing and allocating sloping lands to gardens or perennial fodder crops with correct and principled management.	By reducing the roughness coefficient of the river bed, which will increase along with the increase in the speed of the water flow, the spread of flooding will be reduced.
Allocation of lands adjacent to rivers to gardens instead of agriculture; Perennial trees are more resistant to possible floods compared to crops, and the damage caused to them is much less.	Proper deepening and dredging of the river bed and widening of the river bed in suitable places.
Adherence to crop rotation and the development of pulses cultivation, especially in areas facing water and wind erosion.	Construction of dykes, walls and suitable structures in accordance with the principles of structural engineering in suitable places to improve and reduce land use flooding.
Utilizing the capacity of non-governmental organizations to promote the culture of nature conservation.	Conducting similar research in different seasons of the year in order to concretely study the temporal changes of precipitation in the amount and intensity of flooding in addition to spatial changes.
	Determining the rainfall distribution pattern in the study area.
	A study on the location of flood warning stations.
	Determining the effects of the temporal distribution of precipitation from the amount of peak flood flow volume at the outlet of the basin.
	Investigating the effects of the amount of vegetation in different seasons on the amount of flooding and the volume of the watershed.
	Appropriate drainage design according to the topography of the area and the direction of runoff outside the agricultural lands.
	Creating a vertical drain (well) and directing the runoff to the underground drain.
	Introducing types of rice that are later to germinate and are safe from the damages of floods that occur at the end of the season. It is better to propagate and distribute modified varieties of these floating rices.
	Promotion of conservation agriculture by maintaining straw and stubble on the soil surface in agricultural lands, especially in sloping lands. Changing the planting calendar according to the season and history of flooding if possible.
	Implementation of basic operations of watershed management and water and soil and biological

	protection; Preparing a flood zoning map using the provincial flood bank can be very useful for providing the best possible management plans and watershed projects.
	It is also very effective to implement watershed management plans along the seasonal and permanent rivers to evenly spread the flood in the fields and benefit the fields from the seasonal and monsoon rains without causing destruction and preventing the speed of the flood along the rivers.
	Identifying waterways, respecting river privacy and avoiding building any construction near waterways and river privacy; In this regard, preventing encroachment on the boundaries of rivers and banning cultivation in riverbeds that have dried up in the long term due to the decrease in rainfall and farmers have allocated riverbeds for cultivation due to lack of necessary knowledge can also be useful. The restoration of these rivers will be possible through their spatial identification through aerial maps in the past.
	Failure to issue permits for the construction of facilities in flood-prone and flood-prone areas.
	Introducing types of rice that are later to germinate and are safe from the damages of floods that occur at the end of the season. It is better to propagate and distribute modified varieties of these floating rices.
	Preparing a flood risk map for agricultural lands to prepare and think about the necessary measures to deal with future floods.
	Special prosecution to prevent the burning of straw and stubble in fields.
	Studying and implementing flood warning system plans in appropriate routes.

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