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Spatial Analysis of Floods in Mazandaran Province and Strategies to Increase Resilience Using the Crisis Management Approach

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Original Article

Abstract

INTRODUCTION: According to the flood records in Mazandaran province, this region is regarded as one of the flood-prone regions of the country, and due to the floods, it has suffered many casualties and financial losses. Therefore, this study aimed to investigate the settlements at risk of flooding as one of the main goals of this research.

METHODS: This descriptive-analytical study was conducted based on extensive and exploratory research approaches. The required data were collected from monthly discharge and the maximum instantaneous discharge in the stations of Mazandaran province along with the population statistics of the provincial cities, as well as the statistics of the Natural Resources and Watershed Management Organization concerning the floods. Accordingly, the statistics of hydrometric stations from 1971 to 2021 of Iran's water resources management main company, the population statistics of the province based on the census of 2015, and the statistics of floods that occurred from the beginning to 2021 have been used in this study. Flood return periods were obtained in the study stations in different statistical distributions using Hyfa software. Finally, Arc GIS software (version 10.3) was used to zone floods in Mazandaran province.

FINDINGS: Based on the results, about 1013 square kilometers of the province's surface accounting for 4.25% of its total area is located in the boundaries of large floods that have a return period of 50 to 100 years. Moreover, due to the high altitude, rainy-snowy events, and the significant amount of precipitation in Sarab (Dali Chai and Lar basins) and Payab, Haraz basin has a significant runoff rate discharge so that about 500 to 600 liters of water flow from this basin annually per square meter.

CONCLUSION: According to the obtained results, strategies have been proposed to increase resilience against flood risk using different methods.

Keywords: Crisis management; Flood; Mazandaran province; Return period

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Introduction

One of the natural hazards that causes many casualties in different regions of the world annually is "flood" the extent and intensity of which have increased worldwide due to the changes in the climate (1). Accordingly, damage assessment of natural events, such as floods, provides a lot of information to support decision-making and policy development in natural hazard management and necessary planning according to climate changes (2). Based on available statistics and information, flood is the most common and one of the most destructive natural events in the world. Iran is also among the moderately prone regions across the world in terms of the number of flood events. Therefore, flooding, as well as financial losses and casualties, are of particular importance in Iran.

Every decade, the world faces about 2,800 natural disasters. Due to natural disasters (floods: 58%, earthquakes: 26%, as well as storms and other disasters: 16%), about 39,000 people were

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killed from 1977 to 1988. The total losses in these 10 years were about 700 billion dollars owing to floods (33%), storms (29%), and earthquakes (28%). In this regard, the alarming signal has been the increasing rate of flood casualties and damage across the world in recent decades as a result of an increase in population and assets, changes in hydro systems, and the destructive effects of human activities (3).

The phenomenon of flooding in Iran is a consequence of the changes in the natural ecosystems of the country other than rains with a low probability extent. As can be noted, normal rainfall causes floods in most watersheds of the country. Based on the available statistics, damages by floods in some parts of the world, especially in Asia and the Pacific, account for the highest amount of losses by natural disasters. Although no comparative statistics have been reported about the damage caused by floods and earthquakes in Iran, it is considered a flood-prone country due to its dry and semi-arid climatic conditions (4).

In 2019, Yamani and Abbasi evaluated the flooding properties of sub-basins in Gadar based on morphometric parameters and statistical correlation. According to the flood potential method based on 12 morphometric parameters, Sheykhan Chai and Sufian Chai sub-basins had a high potential for flooding, followed by Cheshmeh Do sub-basin which had a moderate potential, and Godarchai and Nahre Nelivan sub-basins that had a low potential for flooding (5). Iran is one of the countries that face two problems, namely water shortage and water flooding. Often, in a short period of the year, flooding and overflowing of water, water waste, and the damages caused by them along with lack of water and the urgent need for water in agriculture, industry, and consumption make it necessary to take measures to restrain and prevent water wasting (6).

In 2021, Estelahi et al. conducted flood zoning in the Lorestan region and presented strategies to increase resilience using a crisis management approach. According to the output map, the eastern and northeastern regions of the province were the most hazardous of the flood hazard areas, whereas the central and northern regions of the province showed a moderate flood potential, and the southern and western regions of the province were the least hazardous zones (7).

Similarly, Dodangeh et al. (2021) extracted the flooded areas based on the integration of Sentinel 2 and MODIS satellite imagery using a deep learning network. Finally, the flood extent map has been estimated with different usages consecutively during the flood period. According to the proposed method, the land use maps before the flood obtained an accuracy of 73, and considering time, the maps after the flood obtained accuracy rates of 75, 77.5, and 79, respectively (8).

As one of the water-rich provinces of the country, Mazandaran has many permanent rivers and surface currents; however, many floods occur in this province annually, which causes damage to the residents of the region. Therefore, this study mainly aimed at flood zoning in Mazandaran province and provided strategies to increase resilience using a crisis management approach.

Methods

This descriptive, analytical and exploratory survey was conducted based on applied and extensive research methods. The data used in this study included the monthly discharge and the maximum instantaneous discharge in the stations of Mazandaran province along with the population statistics of the provincial cities, as well as the statistics of the Natural Resources and Watershed Management Organization concerning the floods. The statistics of hydrometric stations from 1971 to 2021 of Iran's water resources management main company were used in order to obtain flood zones in Mazandaran province.

Afterward, the amount of flood and the volume of runoff in the river basins were assessed employing the maximum instantaneous discharge, which represents the highest volume of flood passing through a certain site. The most important index in flood studies, on which the frequency analysis is conducted to determine the specific return period, is the data related to this index, which has been calculated using the Hyfa software for the return periods of each of the stations. This software is one of the most powerful tools for determining return periods in hydrology and its results are expressed based on different distributions.

In order to estimate the maximum values with different return periods, numerical series available from this parameter were used in different statistical distributions, such as normal

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distribution, 2-Parameter Log-Normal, 3-Parameter Log-Normal, Pearson Type 3, and Log-Pearson Type 3. They were then processed based on torques foundations and maximum tolerance, and finally, according to the table of minimum standard error and minimum coefficient in triple tests, the most appropriate distribution was selected and extracted based on different return periods which is Log Pearson Type 3 Distribution.

Following that, they were used according to the population statistics by city. In addition, flood zoning has been conducted using Arc GIS software (version 10.3). The current maximum discharge statistics and the volume of runoff available at each station with a certain return period were used for flood zoning in catchment basins. Moreover, according to the ordering of the river branches, the specific discharge values in a zone and the flood volume were determined linearly along the rivers of the province.

Study setting

This study was conducted in Mazandaran province, which has an area of about 23,833 square kilometers. In terms of surface water resources, this province includes a series of rivers that originate from the northern heights of Alborz, as well as Ramsar to the end of Gorgan Bay. Regarding area, these rivers are classified into three categories: large (10 rivers), medium (16 rivers), and small (21 rivers) (9). Figure 1 shows the compatibility of the catchment basins and the border of Mazandaran province.

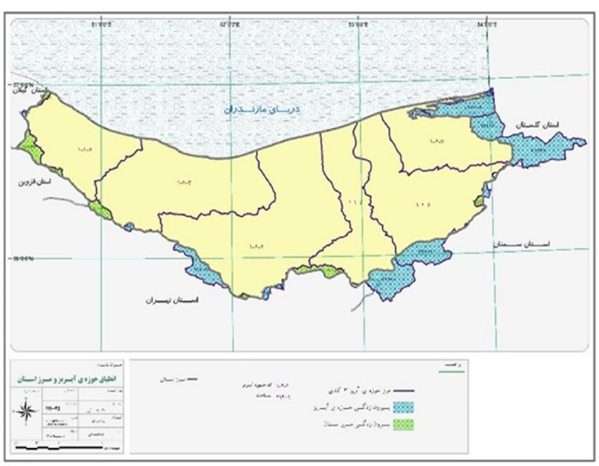

Figure 1. Compatibility of catchment basins and the border of Mazandaran province (source: authors)

Findings

The Strahler method was used to order the river flows, and the results showed that the stable flows of the Haraz and Tajan rivers have reached the 5th and 6th, which shows the large extent of these basins. Figure 2 illustrates the order of the waterway network of the province based on 1:50000-scale maps. The large basins that are ordered 4th, 5th, and 6th in Mazandaran province, have fixed and relatively stable beds due to the large size and density of the waterway network. Accordingly, owing to the abundance of natural drainage and large riverbeds, they are very effective in reducing the possibility of flooding.

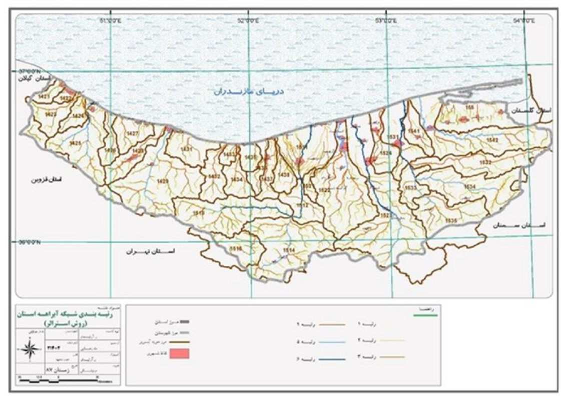

Figure 2. Order of the province's waterways network (Strahler method) (source: authors)

Frequency analysis of maximum instantaneous data

"Flood frequency analysis" is the evaluation of the maximum instantaneous recorded data with various types of statistical distributions and fitting with the most appropriate type of statistical distribution, which indicates the possibility of predicting and the probability of occurrence of specific values based on the most appropriate distribution (10). Since flood is one of the phenomena that becomes threatening every few years, it is significant to determine the return period and the values that increase the probability of damage. The data relating to each station was analyzed using Hyfa software, and the most suitable statistical distribution that fits the data of that station was determined employing the chi-square test and relative average deviation. It is also possible to determine the return period of 2 to 100 years by using an appropriate distribution (Table 1).

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The data obtained from "Flood frequency analysis" in the studied stations have been used in two different ways. In both methods, the relative comparison of the flood capacity of the basins has been determined by implementing flood data on hydrographic maps and river basins.

The linear model of flood and determination of periodic boundary for waterway networks

The linear distribution of flood in the basins and the relative comparison of their flood capacity are depicted in Figure 3. This section initially includes the 2-100-year values of flood and runoff at each station which have been implemented on the ordered map of the hydrographic network. Regarding the relatively equal-weighted average among the river basins, zones were determined with a width of 20 to 500 meters surrounding the river networks considering their order. This map defines the main axis of the riverbeds and the primary flood zone in the province. In other words, heavy rains that cause large floods first affect the beds or areas specified in this map. Moreover, this map specifies the first threatened areas during a flood and illustrates the hazardous areas linearly considering the capacity of runoff generation in each basin or each river network.

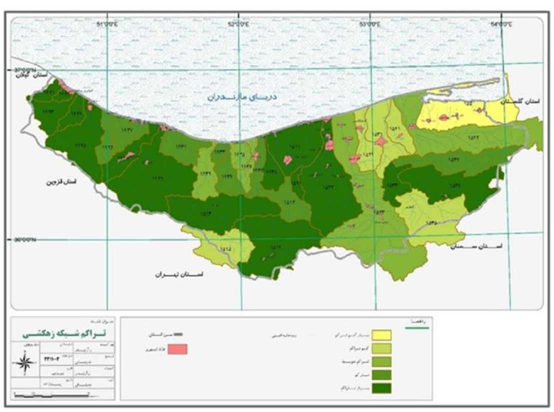

Figure 3. Drainage network density in Mazandaran province (source: authors)

As can be observed, about 1013 square kilometers of the province's surface, which accounts for 4.25% of its total area, is located in the boundaries of large floods that have a return period of 50 to 100 years (Figure 4). These zones in mountainous areas are defined as steep valleys with deposits or cliffs and waterfalls. At the foothills, periodic overflows are always associated with the destruction of agricultural lands or gardens, and in the tail waters, they create flood zones in the form of water waste and extensive runoff. According to the above model, the strategies to control or reduce the intensity of the flood will be presented in the next section.

Model of flood zoning

In order to analyze the capacity of flooding in each of the river basins of the province, the values of specific discharges, including annual runoff-specific discharge, daily maximum specific discharge, and instantaneous maximum specific discharge have been studied in each catchment basin.

Annual runoff-specific discharge

The total volume of annual runoff has been prepared using the province's Isohyetal map. Afterward, according to the return period of rainfall, the runoff values have been maximized from 2 to 100 years. Considering the values listed in Table 2, the volume of annual runoff with a return period of two years, which is regarded as the average with a 50% probability of occurrence, is divided by the area of the hydrological basins, and the amount of water is illustrated per square meter with the basins in m^3. In order to compare the average runoff with the volume of 50-year and 100-year runoff, which is considered to be the maximum possible runoff during the flood periods, a column chart with 2-year, 50-year, and 100-year values is shown on each basin. Figure 5 illustrates the specific discharge of annual runoff in the watersheds of the province. As can be observed, the Haraz basin has a significant runoff discharge due to its high altitude, snowy-rainy events, and a significant amount of precipitation in Sarab (Dali Chai and Lar basins) and Payab. Accordingly, about 500-600 liters of water flow in every square meter of this basin.

Daily specific discharge

Another index used in zone analysis of flood is daily specific discharge, which is estimated using the frequency analysis on this index. Accordingly, the total volume of flow during 24 h is assessed for each basin. Following that, the maximum flow with a return period of 2 years is divided by the area of the basin to obtain the daily specific discharge value.

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Table 1. Instantaneous maximum discharge in m^3/s (source: authors' calculations)

Return period (years) Station	2	5	10	20	25	50	100
Babol	254.43	369.21	448.53	526.75	552.01	631.21	712.12
Razan	28.47	47.54	52.35	77.87	83.09	11.014	118.15
Tange Lavij	21094	28.51	48.15	74.015	83.89	120.05	165.76
Pol zoghal	71.31	113.7	145.11	177.48	188.21	222.64	258.96
Harat bar Cheshmeh	66.4	130.97	186.81	250.46	172.8	348.4	434.14
Ramsar	22.95	52.68	81.31	116.38	129.2	174.24	228.023
Harat bar samoosh	43.24	69.052	88.188	107.93	114.47	135.48	157.65
Shalman	251.22	350.3	416.79	481.11	501.65	565.45	629.74
Payab Haraz	60.3	95.8	122.9	151.6	161.3	193.1	227.5
Kari	44669	37.6	54.3	73.4	80.1	102.8	128.8
Babolrud	123.7	183.9	226.8	270.2	284.5	329.8	377.2
Talar	199.1	288.4	350.2	411	430.6	492.1	554.9
Seyahrud	49.8	81.3	105.8	132.1	141.1	170.6	202.9
Payab Tajan	71.8	111.7	141.7	173.1	183.7	217.9	254.7
Darab kola	28	51	70.1	91.4	98.8	123.6	151.5
Neka	104.9	157.8	196	235.1	248	289.3	332.9
Chalus	147.1	216.3	265.1	314	329.9	380.2	432.4
Bin Chah and Kajoor	90.3	137.4	172	207.7	219.6	257.7	298.3
Kajoor	55.2	88.6	114.5	142.1	151.4	182	215.5
Bin Kajoor and Kaland	44831	50.8	69.8	44874	98.5	123.3	151.2
Galandrud	41.4	69.6	92	116.4	124.7	152.4	183.1
Noor	44.4	73.8	96.9	122	130.6	158.9	190.2
Lavijrud	44741	53.1	72.6	94.3	101.8	126.9	155.2
Vazrud	36.4	62.5	83.7	106.9	114.9	141.5	171.1
Alash	40.2	67.9	90	114.2	122.4	149.9	180.3
Safarud	53.6	86.5	111.9	139.1	148.3	178.6	211.7
Gerakoleye	35.5	61.4	82.4	105.4	113.3	139.8	169.2
Chalakrud	93.3	141.6	176.9	213.3	225.4	264.2	305.4
Shiroud	64.6	101.8	130	159.8	169.8	202.5	237.9
Cheshmeh Gile	124.4	184.7	227.8	271.4	285.7	331.1	378.7
Azadrud	49.7	81.1	105.6	132	140.9	170.4	202.7
Namakabrud	98.7	149.1	185.8	223.4	235.9	275.9	318.2
Sardabrud	63.3	100	127.8	157.3	167.2	199.6	234.7

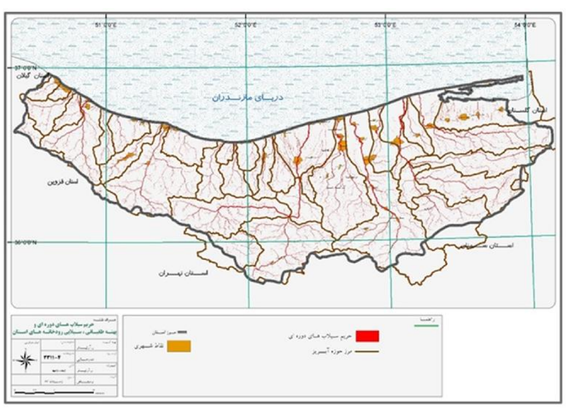

Figure 4. Periodic floods boundary and flood zones of rivers in Mazandaran province (source: authors)

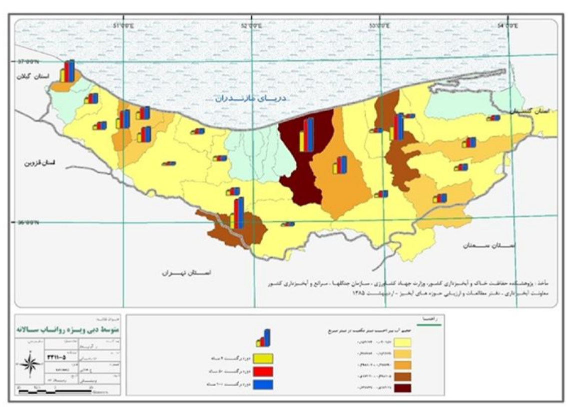

Figure 5. Average discharge of annual runoff (source: authors)

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Table 2. The total volume of annual runoff with different return periods at the hydrometric stations (source: authors' calculations)

Row	Station	Code	Longitude	Altitude	The total volume of annual flow with different return periods (million cubic meters)						
					2	5	10	15	25	50	100
1	Khorram Abad	14334	5148	3634	53	55	57	57	58	59	60
2	Kheyrrud	14312	5134	3637	37	50	57	59	64	68	72
3	Doab	14315	5120	3630	83	101	111	114	121	127	133
4	Dinarsara	14213	5059	3640	81	107	121	126	136	146	154
5	Ramsar	14218	5038	3655	67	84	94	97	103	110	116
6	Rezayat	14222	5049	3646	35	46	53	55	59	63	67
7	Valet	14319	5123	3641	119	153	171	178	190	203	214
8	Abbasabad	14212	5105	3643	66	83	92	95	101	108	113
9	Ghale Gordan	14215	5051	3645	115	156	178	186	201	216	229
10	Kelarabad	14210	5112	3642	11	15	17	17	19	20	21
11	Kelarabad	14219	5115	3642	12	15	17	18	19	21	22
12	Rudbarak	14317	5107	3629	92	120	134	139	149	159	168

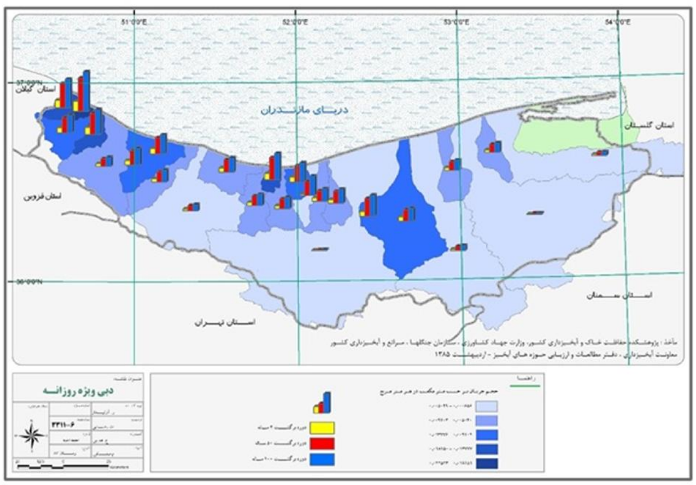

Figure 6. Specific daily discharge of the watersheds of Mazandaran province (source: authors)

Figure 6 depicts the distribution and dispersion of daily specific discharge with a return period of 2 years at the watershed level of the province. As can be observed, the small and medium basins located on the northern slopes of Alborz and the small river basins in the west of the province have very high daily specific discharge. It is worth mentioning that the flood power in these basins is much higher than in other large river basins.

As can be noted, on the small basins in the west of the province, such as Azarud Basin (Nishtarud) and Esperud (Abbas Abad and Klar Abad), an average of 18 to 22 m^3 of water per square meter flows during a 24 h. This coincides with the maximum rainfall of 24 h (about 200 millimeters).

Since in large river basins, there is no possibility of widespread storms with such intensity of rainfall, the daily specific discharge has decreased in these basins. Babolrud River basin, which originates from the high slopes of northern Alborz, is one of the basins that takes a critical state with 24-hour rainfall.

Instantaneous specific discharge

The instantaneous maximum discharge index indicates the highest amount of river flow volume during a certain period. According to the time series data of instantaneous maximum floods, the instantaneous maximum discharge value that indicates the flood volume in a section of the river has been extracted. The instantaneous maximum discharge in the 50-year and 100-year return periods is known as the flood index of the province's basins, and as a result, the estimated values in each basin are shown graphically on the average annual maximum flood map.

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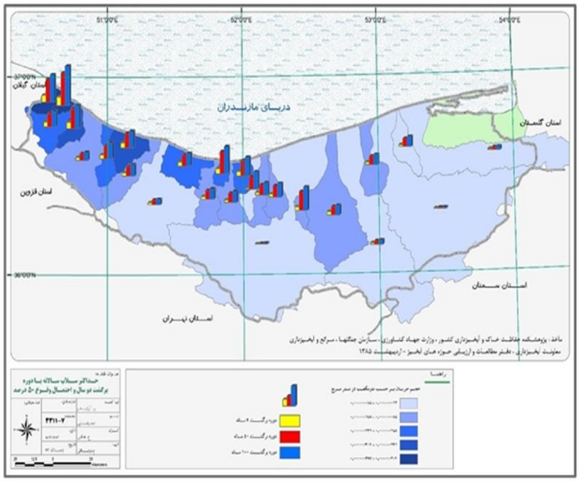

Figure 7. The maximum annual flood with a return period of two years and a probability of 50% (source: authors)

Figure 7 presents the average maximum instantaneous flood in the river basins of the province. Considering that the instantaneous maximum discharge with a return period of two years is considered the maximum possible flood indicator with a probability of 50%, the instantaneous specific discharge is also extracted from the same index, and the province zones are separated from each other based on hydrological units. As can be observed, the small river basins in the western half of the province have a high potential for flooding.

Spatial analysis of flood hazards in population and economic centers of the province

In the previous sections, the flood capacity of each area was obtained using the ranking criteria, the volume of runoff generation, as well as the generalization of maximum instantaneous and daily data on the hydrological zones of the province. In this part, with more accurate zoning and the use of basic criteria, the zoning of the flood spots has been conducted, and by identifying the villages and settlements located in these zones, the hazardous population centers have been identified and shown on the map. Figure 8 shows the distribution of flood-prone areas in the plains and overflowing beds of the rivers in the foothills and mountains.

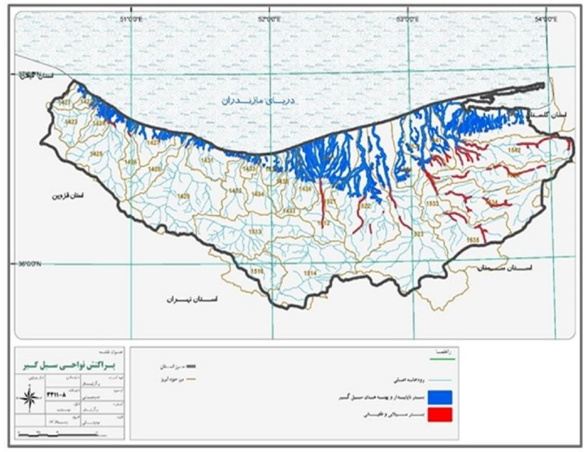

Figure 8. Distribution of flood-prone areas (source: authors)

Table 3 tabulates the number and population of the settlements located in the flood-prone areas of the cities in this province. As can be seen, the flood zones are in the plain area and at an altitude of fewer than 100 meters per unit in the floodplains and alluvial fans. These lands are mainly located on the margins of big rivers and their branches, and on geological maps, they are part of the AL unit (alluvial bed of the present era) and the surrounding low-slope lands. It should be noted that these lands sink under water during heavy rains. Mountainous parts and foothills are completely flooded and face the intensity of water flow due to the slope. The riverbeds are unstable in floodplain basins and have water flow; however, the flow intensity is decreased in these parts due to the decrease in the slope of the land. On the other hand, the flood zone is thin to relatively thick, and depending on the volume of the flow and the intensity of the flood, all the land uses can be threatened in these areas. In the mountainous parts, the high intensity of the water flow leads to the wide area of sediments, and the fall on the sides and the beds.

Table 4 summarizes the distribution of the flood-prone areas in the plains and floodplains at the foothills and the mountains in each of the hydrological units of the province.

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Table 3. Distribution of the population in flood-prone areas by city (source: authors)

City	Area (Square kilometer)	Number of villages in the city	City population	Zone type	Zone area (Square kilometre)	The number of villages in the flood zone	Proportion in relation to all the villages of the city	Village population (In person)	Proportion in relation to the total population of the city
Ramsar	737.5	137	67675	Overflowing-flooding beds	44633	11	0.08	5202	0.08
Ramsar	737.5	137	67675	Unstable beds and flood-prone zones	44562	0	0.00	0	0.00
Tonekabon	2059.6	301	193428	Unstable beds and flood-prone zones	90.6	61	0.20	31854	0.16
Tonekabon	2059.6	301	193428	Overflowing-flooding beds	8.0	3	0.01	1024	0.01
Chalus	1600.6	164	119559	Overflowing-flooding beds	44784	13	0.08	7065	0.06
Chalus	1600.6	164	119559	Unstable beds and flood-prone zones	1.0	0	0.00	0	0.00
Noshahr	1734.6	138	116334	Unstable beds and flood-prone zones	30.2	24	0.17	23886	0.21
Noshahr	1734.6	138	116334	Overflowing-flooding beds	44743	0	0.00	0	0.00
Nour	2692.9	181	104807	Unstable beds and flood-prone zones	51.4	93	0.51	42360	0.40
Nour	2692.9	181	104807	Overflowing-flooding beds	44652	0	0.00	0	0.00
Mahmoudabad	258.1	90	90054	Unstable beds and flood-prone zones	75.8	68	0.76	32776	0.36
Mahmoudabad	258.1	90	90054	Overflowing-flooding beds	0.0	0	0.00	0	0.00
Amol	3077.0	342	343747	Unstable beds and flood-prone zones	102.5	61	0.18	36426	0.1
Babolsar	347.0	89	172600	Unstable beds and flood-prone zones	35.8	66	0.74	31496	0.18
Babolsar	347.0	89	172600	Overflowing-flooding beds	0.0	3	0.03	127	0.00
Babol	1568.1	528	464538	Unstable beds and flood-prone zones	138.8	128	0.24	92680	0.20
Babol	1568.1	528	464538	Overflowing-flooding beds	44813	3	0.01	127	0.00
Joybar	288.4	73	70204	Unstable beds and flood-prone zones	44660	6	0.08	7785	0.11
Ghaemshahr	457.2	151	293721	Unstable beds and flood-prone zones	54.5	95	0.63	80780	0.28
Ghaemshahr	457.2	151	293721	Overflowing-flooding beds	44653	0	0.00	0	0.00
Savadkooh	2120.6	179	66430	Overflowing-flooding beds	44660	1	0.01	46	0.00
Sari	3662.5	440	490830	Overflowing-flooding beds	115.3	57	0.13	39362	0.08
Sari	3662.5	440	490830	Unstable beds and flood-prone zones	64.9	15	0.03	3945	0.01
Neka	1360.4	123	104753	Unstable beds and flood-prone zones	52.3	13	0.11	10889	0.10
Neka	1360.4	123	104753	Overflowing-flooding beds	31.2	4	0.03	1729	0.02
Behshahr	1397.6	114	154957	Unstable beds and flood-prone zones	87.6	7	0.06	5403	0.03
Behshahr	1397.6	114	154957	Overflowing-flooding beds	44790	4	0.04	1626	0.01
Gelogah	451.4	31	39450	Unstable beds and flood-prone zones	44638	2	0.06	2094	0.05
Gelogah	451.4	31	39450	Overflowing-flooding beds	44566	2	0.06	288	0.01

In the Payab Haraz basin, 230.60 km of the area of the basin is made up of unstable beds and flood zones. This area covers the largest area among all the studied watersheds. After this basin, Babolrud Basin has the largest area (120.79 km), which is in second place. Regarding the flood bed, it can be seen that the Zaram River basin has the largest area (19.40 square kilometers). In total, it can be observed that Payab Haraz has the largest area at risk of flooding (208.81 km). Accordingly, it is necessary to take measures to control floods in these basins.

In total, about 1,060 square kilometers of the area of the province are known as high-risk areas in terms of floods, of which about 887 square kilometers are flood-prone areas on the plains, which are mainly in the foothills of the Haraz River, small river basins located in the east of the province, the Gorgan Bay basin, and in the western end of the province in the Tiram (Shirud) basin. The distribution and dispersion of flood-prone areas based on the national division system and according to the cities of the province are shown in Figure 9.

Table 4. Distribution of the flood-prone areas and floodplains of the province's basins (in square kilometers) (source: authors' calculations)

Code	Basin	Basin area (square kilometres)	Area of unstable beds and flood zones (square kilometres)	Area of the flood plains and beds (square kilometres)	Total area (square kilometres)	Proportion (percent) in relation to the total watershed
155	Gorgan Bay	1760	107.47	2.60	110.06	0.06
1421	Safarud	171	4.77	0.32	5.09	0.03
1422	Gerakokele	94	4.72	0.56	5.27	0.06
1423	Chalakrud	430	6.10	0.25	6.35	0.01
1424	Tiram	226	22.32	1.33	23.66	0.10
1425	Cheshmekileh	1056	30.45	3.78	34.23	0.03
1426	Azarus	278	10.01	1.34	11.34	0.04
1427	Aspehrud	412	26.46	1.55	28.01	0.07
1428	Sardabrud	460	7.37	0.24	7.61	0.02
1429	Chalus	1772	4.14	0.76	7.61	0.00
1431	Noshahr	513	18.92	0.76	19.68	0.04
1438	Kajur	451	2.63	0.08	2.71	0.01
1433	Kenesrud	122	6.01	0.75	6.76	0.06
1434	Gelandrud	355	2.52	0.29	2.81	0.01
1435	Nour	225	10.06	0.53	10.59	0.05
1436	Lavijrud	208	4.78	0.05	4.82	0.02
1437	Vazrud	303	19.88	0.19	20.07	0.07
1438	Alashrud	289	19.69	0.58	20.27	0.07
1511	Payab Haraz	978	230.60	5.21	208.81	0.21
1512	Hrazmeyani	435	0	6.13	6.13	0.01
1515	Lar-Dali chai	765	0	7.23	7.23	0.01
1521	Kari	122	2.15	0.08	2.22	0.02
1522	Babolrud	1631	120.79	11.20	131.99	0.08
1523	Talar	2867	56.80	9.75	66.55	0.02
1524	Seyahrud	451	38.85	1.28	40.13	0.09
1531	Payab Tajan	633	63.02	14.19	77.93	0.12
1532	Zaramrud	880	0	19.40	19.40	0.02
1533	Tajanmeyani	358	0	8.61	8.61	0.02
1534	Chardange	1190	0	18.63	18.63	0.02
1535	Sarab Tajan	1249	0	13.66	13.66	0.01
1541	Soorak	339	28.53	1.99	30.52	0.09
1542	Neka	2251	65.45	38.95	104.40	0.05
Total area		**23247**	**887.48**	**172.98**	**1060.46**	**0.05**

As can be observed, Amol and Qaemshahr with the largest number of villages and the largest population are at risk of flooding.

The frequency of flood events in population and economic centers

The basic information needed in the analysis of the frequency of flood events has been obtained from the Flood Information Bank. Accordingly, flood events from 1954 to 2021 were extracted from the aforementioned bank. After the initial processing and digitization of the recorded events, their location was determined and converted into digital maps. Table 5 shows the number of floods that occurred in each of the hydrological areas of the province.

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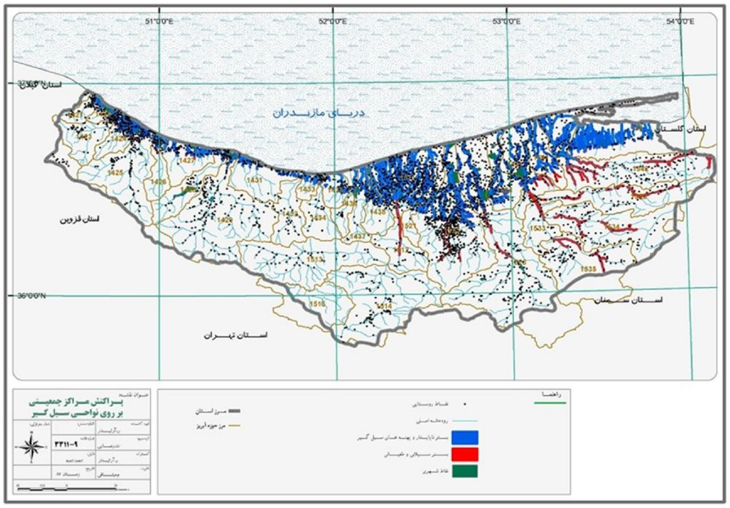

Figure 9. Distribution of population centers in flood-prone areas (source: authors)

Table 5. The number of floods in the sub-basins of the province (source: authors' calculations)

Code	Basin	Flood occurrence with recorded data	Proportion (per cent) in relation to the total occurrence rate	Flood occurrence without recorded data	Proportion (percent) in relation to the total occurrence rate
1421	Safarud	1	0.40	5	44686
1425	Cheshmekile	2	0.81	1	44562
1427	Azarud	10	44685	0	0
1428	Sardabrud	1	0.40	0	0
1429	Chalus	3	44197	0	0
1431	Noshahr Andrud	4	22647	0	0
1434	Gelanrud	4	22647	2	44594
1435	Nour	2	0.81	1	44562
1436	Lavijrud	7	30348	5	44687
1437	Vazrud	5	44594	5	44687
1438	Alashrud	6	15738	1	44562
155	Gorgan Bay	104	42.11	39	43.3
1511	Payab Haraz	5	44594	1	44562
1513	Nour	7	30348	4	44655
1514	Harazbalaee	11	16528	4	44655
1521	Kari	1	0.40	0	0
1522	Babolrud	16	17685	6	44719
1523	Talar	7	30348	1	44562
1531	Payab Tajan	5	44594	0	0
1534	Chardange	2	0.81	0	0
1535	Sarab Tajan	8	45352	2	44594
1542	Neka	36	14.57	13	41730
	Total	**247**	**100/00**	**90**	**100**

As can be observed, in the past 70 years, 337 flood events have been reported in the province, and the highest number of flood events in this period is related to the Gorgan Bay basin (n=104), and the least is related to Kari, Sardab Rood, and Safarud basins (n=1). It is of crucial importance to mention that out of a total of 337 incidents, 90 flood incidents had no statistics and information on casualties and financial losses, and just the flood and its location were mentioned. This probably indicates that these floods caused no damage. In the frequency analysis of the floods, 247 incidents were reported with damage, and 90 incidents showed no losses. However, after

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evaluating the remaining indicators, such as financial losses, casualties, population exposed to floods, and the density of residential centers exposed to flood, only flood events with flood damage information could be used.

Discussion and Conclusion

Floods are among the most significant hazards that always cause great damage to residential areas. One of the basic measures to minimize the harmful effects of floods is the identification of flood-prone areas and the classification of these areas in terms of flood risk. This study aimed at flood-risk zoning in Mazandaran province using the statistics of the instantaneous maximum discharges of the stations located on the rivers of the Mazandaran province basins.

Following that, the rivers in the city were ordered employing the Strahler method. After completing the tables and generating the final required data, Hyfa software was used to conduct the analysis of frequencies and the selection of the best statistical distribution to trace the period of certain returns. Afterward, the amounts of 2-100-year flood and runoff at each station were identified on the ordered map of the hydrographic network considering the relatively equal-weighted average among the river basins of the zones with a width of 20 to 500 meters surrounding the river networks depending on their order.

Based on the results obtained, about 1,013 square kilometers of the province's surface accounting for 25.4% of its total area are located in the boundaries of large floods that have a return period of 50 to 100 years. In mountainous areas, these zones are defined as steep valleys with sinkholes or ravines and waterfalls, which are not intended for any other use, except for watershed management purposes, such as gabions and dry stone dams. Furthermore, the results show that the Haraz basin has a significant runoff due to its high altitude, rainy-snowy events, and the significant amount of precipitation in Sarab (Dali Chai and Lar basins) and Payab. Accordingly, about 500 to 600 liters of water flow per square meter from this basin every year.

Based on the results of the maximum instantaneous flood, it can be observed that the small river basins in the western half of the province have a high potential for flooding. In total, about 1,060 square kilometers of the province area are regarded as high-risk zones in terms of floods, of which about 887 square kilometers are flood-prone areas in plains, which are mainly in the foothills of the Haraz River, small river basins located in the east of the province, Gorgan Bay basin, and the western end of the province in the Tiram (Shirud) basin. Consequently, Amol and Ghaemshahr, with the largest number of villages and the largest population, are at risk of flooding.

Shamsipour et al. (11) investigated flood zoning in Karaj using Hyfa software in 2013, and they confirmed the efficiency and appropriateness of this model and software. The results of their study are consistent with the findings of the present research. Moreover, Hodaei and Feizi (12) in 2021 used the Hyfa software to analyze the dispersion of rural settlements against natural disasters in South Khorasan province and obtained acceptable results that are in line with the findings of this study.

In 2019, Estelaji et al. (7) conducted flood zoning in Lorestan province and stated that construction management should be prioritized in planning along with crisis management in this province. The results of this study also reveal worrying conditions in this province since it is flood-prone, and there is no monitoring and control of the construction. Therefore, to tackle this problem, plans should be developed using the crisis management approach and resilience in these areas. Furthermore, Riahi et al. (13) in 2019 identified the effective factors in reducing the vulnerability of settlements. Accordingly, it is possible to help reduce these damages by zoning flood-prone areas in this study.

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None

Conflict of Interests

The authors declare that there were no conflicts of interest in this study.

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