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Flash flood risk assessment modelling and methods: Kyrenia Region, Northern Cyprus

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Abstract

Flash flooding risk impacts can be reduced through the implementation of mitigation strategies plan (MSP) for flood management. This study aims to develop a flash-floods risk mitigation plan, which appears to be beneficial for municipalities, provincial administrators, and authorities to reduce the impact of the flash flood in the Kyrenia region, Northern Cyprus. In this work, rainfall data were collected from the nearest stations for 22 years. The return periods of maximum daily rainfall are also determined by using six formulas. Furthermore, flood inundation and hazard maps were defined by utilizing SAGA, QGIS, ArcGIS, 2D HEC RAS, and HEC -HMS software then determining the degree of risk and identifying strategies based on quantitative risk analysis by developing a risk matrix. As a final result, catastrophic risk areas are distributed significantly downstream. In conclusion, the proposed flash flood mitigation plan includes strategies to reduce flood losses of human life and constructed structures across Kyrenia and proposed hazard and inundation risk maps to assess planners and decision-makers for the potential impact of floods to avoid.

Keywords: DEM; Flash Flood; Hazard map; HEC-RA Mitigation plan; Risk matrix.

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1. Introduction

This work discusses the flood risk models including Geographic Information Systems (GIS); hence, it is important to briefly introduce the subject before commencing with the literature review. Generally, Geographic Information Systems (GIS) are important as common data analysis frameworks in modeling. In hydrological modeling specifically, ssGIS can be used to construct flooding projection models in catchments and to prepare and analyze multi-scale and multi-source spatial data (Santos, Tavares, Freire & Rilo, 2018; Tang et al., 2020). When creating hydrological models to investigate flood hazards in catchments, Digital Elevation Models (DEMs) are used in a GIS background to acquire essential topographical variables such as stream networks, flow direction, catchment geometry, and slope from raster data on elevation. According to previous studies, it can be concluded that:

- Researchers have recently focused on analyzing the risk of flood in a specific region using several models such as GIS, Hydraulic modeling, Remote Sensing, and artificial intelligence models.
- The most common input parameters that are utilized to analyze the flood risk in specific regions are slope, elevation, precipitation/rainfall, and land use.
- Few studies (Pham 2021; Santos et al., 2019) have used flow accumulation as input data for the empirical model to analyze the flood risk.
- Few studies (Gautam 2021; Zeleňáková 2019) have utilized the HEC-RAS model based on unsteady flow analysis for various design periods.
- According to the authors' review, there are no detailed studies in Cyprus regarding flood risk assessment between 2015 and 2021.

1.1. Purpose of study

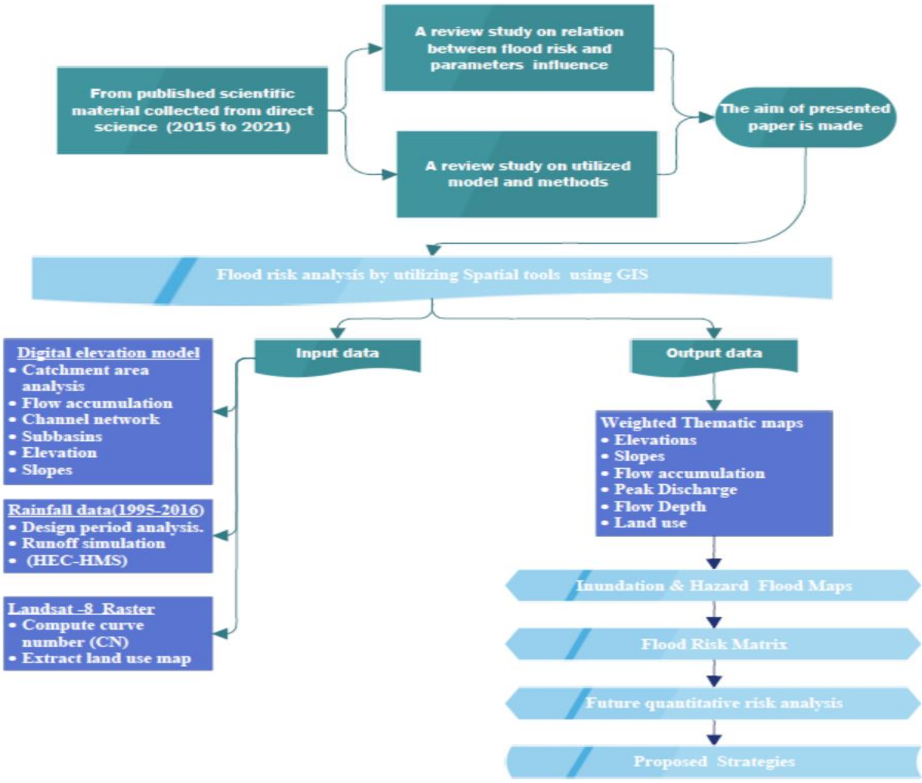
The main goal of this paper is to produce a flood risk map with limited hydrological and hydraulic data using SAGA, QGIS, ArcGIS, 2D HEC RAS, and HEC-HMS software. The flood conditioning factors used in modeling were elevations, slopes, flow accumulation, peak discharge, flow depth, and land use. In addition, the weight of these conditioning factors was determined based on applying Jenk's Natural Breaks method. This study aims to develop a flash-floods risk mitigation plan, which appears to be beneficial for municipalities, provincial administrators, and authorities to reduce the impact of the flash flood in the Kyrenia region, Northern Cyprus.

2. Materials and Methods

The proposed methodology to generate a flood risk mitigation plan for the Girne (Kyrenia) region in Northern Cyprus as shown in Fig. 1below based on the data collected of rainfall for a design period starting from 1995 to 2016, extracted digital elevation model from USG earth explorer in Geo-Tiff format in addition of Landsat images to extract land use and soil characteristic. By utilizing hydrological modeling system software HEC-HMS peak discharge was calculated based on the runoff simulation. Also, flood depth was calculated by generating an inundation flood map using hydrological river analysis software HEC-RAS. Spatial analysis using ArcGIS was utilized to generate a flood hazard map, for the selected parameters namely: elevations, slopes, flow accumulation, peak discharge, flow depth, and land use. A risk flood matrix is generated to estimate the probability and impact of flood hazards based on a previous study (Moser1997; Elfeki et al. 2017; Ritter et al., 2020).

Figure 1

Proposed methodology schematic (own elaboration)

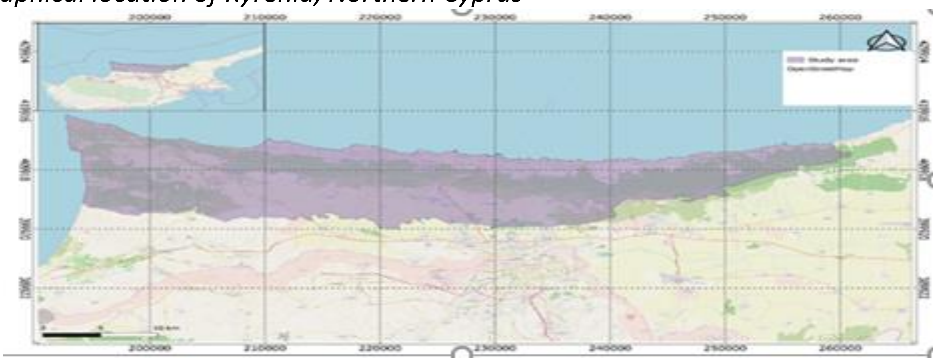


2.1. Study area

Kyrenia is located in the northwestern part of Cyprus (see Fig. 2) at a latitude of 35°20’30.00” N, the longitude of 33°19’00.00” E and surrounded by the five fingers mountain (Beşparmak), where elevations range from -2 to 1026 m above sea level, which has major impact into defining the weather on the island and slopes range from 0 % to 20%.

Figure 2

The geographical location of Kyrenia, Northern Cyprus



Girne region, having an area of 690m2 with a population of 20851, has been inflicted by negative impacts from flooding due to heavy and torrential rainfall in its urban environment. Many flash floods that occurred in the Girne region were reported by news and social media, which can be summarized as the following:

- In February 2010, heavy rainfall in Girne (Girne) and Lefkosa (Nicosia) affected more than 3000 people without any reported cases of death and injury, around 700 homes, 56 offices, and 27 vehicles were informed to damage.
- In January 2014, heavy rain in the Girne region led to flooding in many houses and workplaces, which built-in riverbeds, the response to the flood was to build an embankment around the main river.
- In November 2017, heavy rain in the Girne region has caused severe flooding, causing traffic chaos, the response to floods was advising people to avoid using roads until the water subsides.
- In December 2018, torrential rainfall has caused a flash flood causing damage road network in the Cypriot capital Nicosia and the partial closure of a motorway linking the city to Girne, a historic harbor town on the northern coast, and four people were killed when their car was swept away during heavy rain.
- In January 2020, heavy rain and thunderstorms caused a flood in Girne, which affected shops, businesses, and homes also of Güzelyurt reservoir is overflowing.

3. Results

Based on extracted hazard and inundation prone areas at high flood risk can be identified and to be used for risk matrix identification and quantitative analysis. Five thematic maps were developed and classified based on the selected method according to previous studies as explained below.

3.1. Catchment Area and flow delineation

The catchment consists of 56 sub-catchments with a total area is about 640 km2. The Geometric and morphological parameters of the sub-catchment material were extracted from the QGIS using the Saga plug. The parameters were used as main inputs to simulate runoff by utilizing the HEC-HMS model to calculate an excess of precipitation and peak discharge. Also, by utilizing the SCS method, time lag (Tlag) and time of concentrations (Tc) were calculated based on the geometric and morphological parameters.

*3.2. **Land use -land Cover and Curve Number Estimate***

Remote sensing techniques were employed to classify Land use and land cover (LULC). Kyrenia LULC were extracted from the high-resolution Landsat-8 rasters, by utilizing spatial tool analysis in ArcGIS and Maximum likelihood classifications based on NVDI. Five categories were used to calculate curve number (CN), namely: road, woods, urban areas, vegetation, and pasture. The maximum value of CN was 86.64 for sub-basin (1) which consists of 85% of pasture area, the minimum value was 82.52 for sub-basin (35) which consists of 65% wood area and 30% building area.

3.3. Return periods analysis

Six different methods were employed to calculate the **design period for the annual maximum rainfall for** the **kyrenia region, as a result**, **the design return period of infrastructure hydraulic design is less or equal to the recorded period data,** and **the estimation of quantiles by empirical distribution function or plotting point methods is suggested as agreed in the selected methods. As a result, the return period of the 40.14 mm event was within** the **range of 23-44 years. According to that rainfall, depth was calculated and summarized in table 1.**

Table 1

Design rainfall for the study area

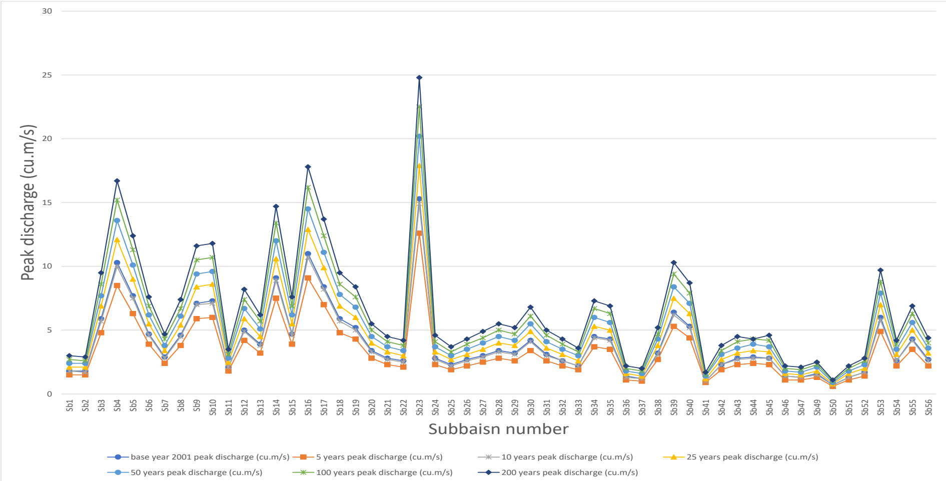
Design period	5 Years	10 Years	25 Years	50 Years	100 Years	200 Years
Rainfall	32.46	39.03	47.71	54.28	60.85	67.41

3.4. Rainfall-runoff simulation

In this study, the selected region is within ungagged catchments, and no records are available for runoff. A synthetic unit hydrograph (SUH) was utilized to calculate direct runoff and excess rainfall by using HEC-HMS. the main parameters in the utilized model are hydrological data and sub-catchments physical features. Computed runoff characteristics were illustrated in Fig. 3 for various design periods. Calculated maximum peak discharge value for the selected design period base year 2001,5,10 ,25 , 50,100 and 200 were 15.3, 12.6, 14.9,17.9,20.2, 22.5 and 24.8 respectively for sub-basin (23) with total area 41.40 km2 , while minimum peak discharge values were 0.7, 0.6, 0.7, 0.8, 0.9, 1 and 1.1 respectively for sub-basin(50) with total area 1.90 km2. the output from the model will be used as input for the hydraulic model.

Figure 3

Peak discharge based on HEC- HMS simulation



3.5. Parameters Weighting and Map Classifications

The selected parameters have the most substantial impact on flood risk their rate and weight, taking into consideration the cross-pollination between parameters. The calculated percentage in table 8 was concluded by multiplying RL and FR by the overall total weight.

Five thematic maps were extracted and georeferenced to EPSG Projection 6312(Cyprus Coordinate System CGRS93 / Cyprus Local Transverse Mercator). Reclassification of maps was done by utilizing a spatial analysis tool in ArcGIS software taking into consideration the calculated percentage for each thematic map.

These observations can be supported by other scientific researchers who analyzed the parameter weightage, for instance, (Kourgialas & Karatzas, 2016) found that the parameter weight (PW) for elevation influence on the flood was 29.03% and in our study was 29%, PW for land use influence was 19.35 %, 20% respectively, PW for slopes was 12.9%, 17% respectively.

Topographic parameters such as elevation and slope (Table 2) are inversely proportional to the appearance of floods((Kourgialas & Karatzas, 2011). In this study, the high-risk areas are shown in blue colors such as Akdeniz, Grine,karakum, Geçitköy, Cape Kormakitis, and Karaoğlanoğlu with slopes less than 3.6 % and elevations less than 129 m. while the higher elevation and slope had minimal impact on the flood risk, the low-risk areas were shown in red color for the five fingers mountain (Beşparmak).

Also, a land-use map was extracted from the land sat -8 image. As a result, urban areas without vegetation increase the risk of the flood while impenetrable vegetation in forest areas can reduce the flood risk as shown in Table 2. The outcome was compared and observed in the study (Kourgialas & Karatzas, 2016; Ahmadalipour & Moradkhani, 2019). Besides, peak discharge was calculated by utilizing runoff simulation, by employing IDW (Inverse distance weighting) tool (Table 2) was generated. Finally, the flow accumulation thematic map (Table 2) was extracted, the higher value of the flow accumulation in a pixel-cell is the higher risk level as shown in blue colors for sub-basins 4 &2

Table 2

Categorization—calibration and weight evaluation of the factors affecting flood risk areas in Kyrenia

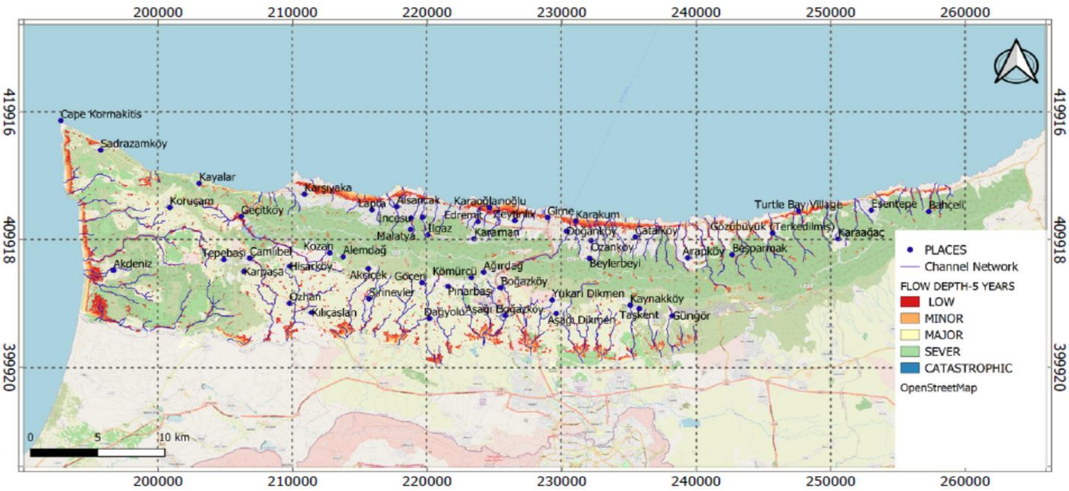
FACTORS	Domain of effect	Descriptive level (flood risk level)	Proposed weight of effect (RL)	Rate (FR)	Weighted rating (FR*RL)	Total weight	Percentage (%)
Slope	0-7.5	Catastrophic	5	2.0	10	30.0	17%
	7.5-15.0	Sever	4		8		
	15.0-25.0	Major	3		6		
	25.0-93.0	Minor	2		4		
	93.0 and above	Low	1		2		
Elevation	-5.0_ 129	Catastrophic	5	3.5	17.5	52.5	29%
	129.0-251.0	Sever	4		14		
	251-398	Major	3		10.5		
	398-603	Minor	2		7		
	603-1020	Low	1		3.5		
Land use (L)	Urban & bare area	Catastrophic	5	2.5	12.5	37.5	20%
	Scrub, annual crops	Sever	4		10		
	Permanent crops	Major	3		7.5		
	Pastures	Minor	2		5		
	Forest-woods	Low	1		2.5		
Flow accumulation (F)	27875 - 52789	Catastrophic	5	1.5	7.5	22.5	13%
	14087 - 27875	Sever	4		6		
	5798 - 14087	Major	3		4.5		
	1525 - 5798	Minor	2		3		
	0 - 1525	Low	1		1.5		
Peak Discharge (P)	8.8 - 15.30	Catastrophic	5	1.5	12.5	37.5	21%
	6.4 - 8.8	Sever	4		10		
	4.5 - 6.4	Major	3		7.5		
	3.0 - 4.5	Minor	2		5		
	0.7 - 3.0	Low	1		2.5		

3.6. 2D flood mapping and hydraulic model using HEC-RAS

Hydraulic 2D flood mapping was done based on the excess precipitation and inflow hydrograph under unsteady flow conditions using HEC-RAS. For five years inundation map (Fig.4) estimates the maximum depth of 10.25m downstream and a minimum of 0.002m at high elevations area classified as the catastrophic degree of risk, for 25 years map a bit spread of water around mainstream and channel networks was shown while in 50 years map more stream spreading was shown. for the 100 and 200 maps, the flood was significant and dominant. These observations can be supported by other scientific researchers who analyzed the inundation depth (Zhang, 2019; Alam, Ahmed & Sammonds, 2020).

Figure 4

Flood inundation map-5 years design period

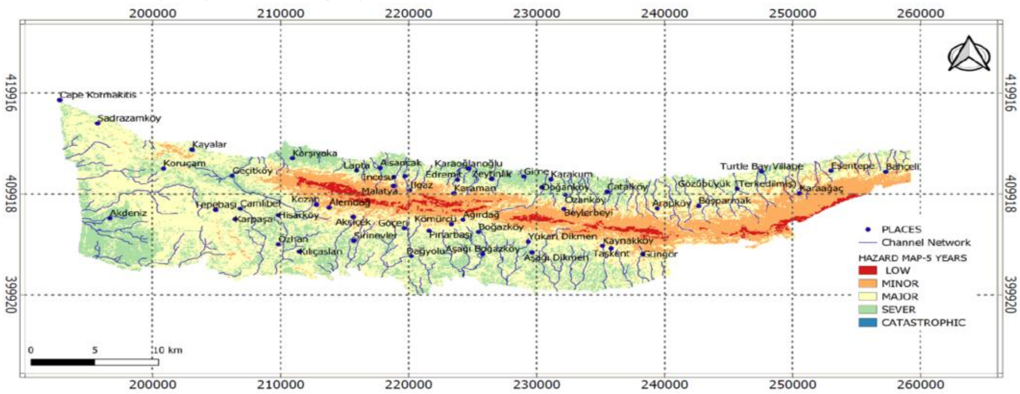


3.7. Flash Flood Hazard Map

A flood hazard map (Fig. 6) generated from the combined five thematics for different design periods was utilized to identify prone areas in Kyrenia. In the context, lowlands are most vulnerable to flood occurrence such in Geçitköy located in the sub-basin (23) and Akdeniz in the sub-basin(4) and while the low and minor risk areas at the highest land such as five fingers mountain, while catastrophic risk areas in blue color are spreading in major downstream in Geçitköy.

Figure 2

Flash flood hazard map-5 years design period

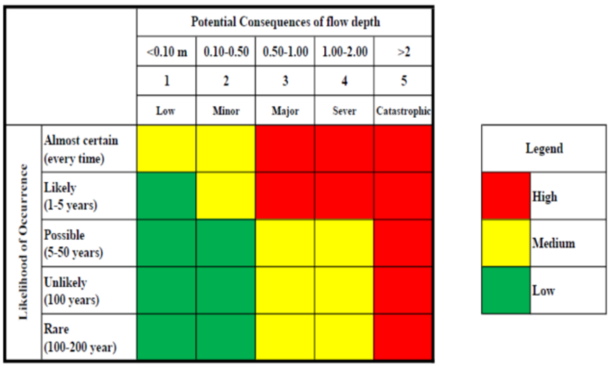


3.8. Generate a risk flood matrix

The proposed risk matrix (Fig. 6) was prepared based on the impact and probability of occurrence of flow depth. a horizontal row represents classified consequences namely: low, minor, major, severe, and catastrophic, and a vertical row represents the probability of occurrence of return period to almost certain(every time), likely(1-5 years), possible(25 years), unlikely(25-50 years), rare(100-200 years), the degree of risk was determined by multiply impact by probability than the outcome classified into low, medium and high, represented green, yellow and red respectively—future quantitative and cost analysis for the risk to be conducted to identify strategies.

Figure 3

Flood risk matrix



3.9. Define Strategies

Based on the previous studies strategies (Samela,2018) were classified into two categories namely: vulnerable local communities and structural. The vulnerable local community's strategy aims to eliminate and mitigate risk (Associated,1970). due to lack of response and emergency. while the structural strategy aims to control risk by reducing the impact of the flood. tables 3 and 4 illustrate classified straggles and examples for each category.

Table 3

Proposed strategies

	local communities'	structural strategies	
Strategies	**Indications for evaluation**	**Strategies**	**Examples and goals**
Warning system & response	• Flood warnings are to be increased to reach the most flooded areas. • Warning responses to be identified • provide evacuation paths. • Implement a flash flood warning system based on the France experience using the AIGA method in 2017 (Javelle,2016).	• Catchment area and flow path activities	• Terraced surrounding land and farms constructed stone walls. • Small wadi branches bed stabilization. • Add barriers and sandbags • Add dikes
Response after the Awareness-raising through learning	• Flood insurance, • Provide flood assistance plan • Warning systems and responses to be learned in schools and companies • Internet pages,	• Wadi diversion to redirect • Shaping retention to reduce flood wave	• Depth Control • Slope Control using chutes, • Propose small reservoirs to collect water in a permanent or temporary fashion

Mental models analysis	• Improving communication and public decision-making related to flash flood risk (Lazrus,2016).	• Catchment area and flow path activities	• Terraced surrounding land and farms constructed stone walls. • Small wadi branches bed stabilization.
Spatial Planning	• Flood damage limitation, • Natural retention protection for the catchment area. • Negative environmental fallout limitation from other flood	• Wadi diversion to redirect floodwater	• Depth Control • Slope Control using chutes, concrete lining

4. Conclusion

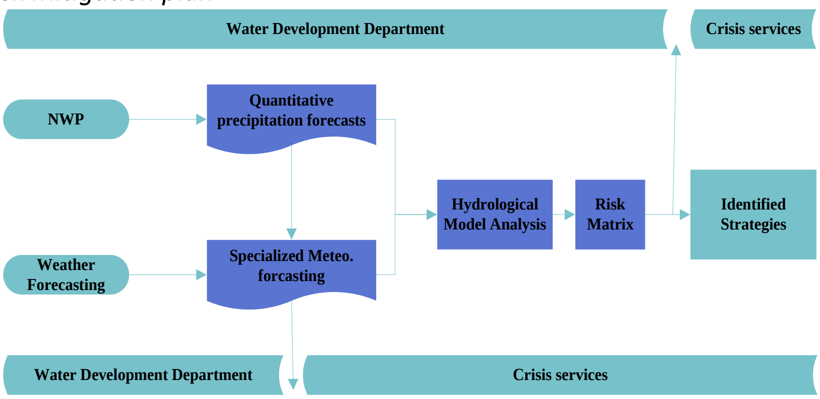
As a final result, catastrophic risk areas are distributed significantly downstream. Also, lowlands are most vulnerable to flood occurrence while the low and minor risk areas are at the highest land, such as five mountains. Based on that risk matrix was developed to determine degrees of risk and then to define strategies. In conclusion, the proposed flash flood mitigation plan includes strategies to reduce flood losses of human life and constructed structures across Kyrenia and proposed hazard and inundation risk maps to assess planners and decision-makers for the potential impact of floods to avoid. In addition of developed web platform data and information to be shared globally and locally.

The proposed strategies to mitigate the risk of flood which results from human life losses and structural damage across Kyrenia due to the likeliness changes of climate and landscape which result in further increase of flood risk, being aware of the experiences and lessons learned during a flash flood in Kyrenia area, Proposed recommendations were summarized as per the following:

- flood risk and hazard maps to be generated and updated to identify a prone area to flood to assess planners and decision-makers for the potential impact of floods.
- A shared and developed web platform data, information, and floods awareness among related stakeholders such as educational institutions, civil defense National Meteorological and Hydrological Services (NMHSs).
- Flash flood guidelines and global meteorological data to be monitored by nowcasting procedures and Numerical Weather Prediction (NWP).
- Spatial planning and analysis are to be conducted by local authorities such as the water development department.
- The proposed flood risk mitigation plan was self-explained in Fig. 7.

Figure 4

proposed flood risk mitigation plan



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