DETERMINING AND MANAGEMENT OF FLOOD RISK USING GIS AND REMOTELY SENSED DATA; LOWER SAKARYA BASIN

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ABSTRACT

In this study, management of flood risk in watersheds is considered in lower Sakarya basin. Information produced from remotely sensed data was modeled and flood risk analysis were realized and mapped by GIS. In the modeling phase, 2 different methods, Multi Criteria Decision Analysis (MCDA) and Hydrological Modeling are used and compared according to boundary condition in the study. Considering boundary conditions of two modeling methods which are used for flood risk analysis in the basin, it is shown that results produced from Hydrological Modeling is comparatively more accurate. As a result of Hydrological Modeling, a risky area is calculated as 3950 ha in total and 620 ha of this area is residential and rest of them is agricultural area. Various risk management scenarios were produced for possible floods alternatives in the region.

INTRODUCTION

River floods are triggered by heavy rainfall or snow melt in upstream areas, or tidal influence from the downstream. Ground conditions such as soil, vegetation cover, and land use have a direct bearing on the amount of runoff generated. River floods occur when the river run-off volume exceeds local flow capacities. The river levels rise slowly and the period of rise and fall is particularly long, lasting a few weeks or even months, particularly in areas with flat slopes and deltaic areas. Failure or bad operation of drainage or flood control works upstream can also sometimes lead to riverine flooding (APFM, 2008).

Urban areas situated on the low-lying areas in the middle or lower reaches of rivers are particularly exposed to extensive riverine floods. In most major river basins, flood plains are subjected to annual flooding. Often, urban growth expands over some of the floodplains, reducing the area into which floods can naturally overflow. Where parts of the city are below flood level and are protected by artificial levees, there is risk that they may be breached and cause devastating urban flooding.

Cities in many developing countries are growing rapidly. Unprecedented migration from rural areas to cities has led to uncontrolled urban sprawl with increasing human settlements, industrial growth and infrastructure development in hazard areas such as riversides, wetlands, and land below the river, sea or reservoir level or even inside dried up river beds where floods will occur sooner or later. While people cannot do much about floods, they can influence the nature and extent of flood losses (Anthoff, et al., 2006).

In addition, due to global warming many subsystems of the global water cycle are likely to intensify, resulting in many regions in an increase of flood magnitude as well as flood frequency. Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely. Heavy thunderstorm rains appear to have increased in frequency. Urban areas may help to increase thunderstorm activity because their built-up surfaces attain higher temperatures than surrounding areas and create a local air circulation that produces an ’urban heat island’. Dust particles caught up in that circulation act as nuclei on which moisture in clouds condenses, forming rain droplets that eventually may develop into the large rain drops of a major thunderstorm (IPCC, 2007).

Occurrence of floods is cannot be linked only meteorological conditions. Parallel to improvement in the industrialization in the watersheds, human activities are heavily increased. Thus, the hydrological balance in whole watershed is deteriorated and this situation causes raise in flood risk. Floods result from a combination of meteorological and hydrological extremes as indicated in table 1. In most cases floods are additionally influenced by human factors. Although these influences are very diverse, they generally tend to aggravate flood hazards by accentuating flood peaks. Thus flood hazards in built environments have to be seen as the consequence of natural and man-made factors. Due to enlargement of settlements, newly open roads and new establishments, land use characteristics of the watersheds is changed, inconvenient agricultural activities are increased, the area of forest and meadows are degraded and flood risk are became frequent (Ozcan, et al., 2008)

Table 1: Factors contributing to flooding (APFM, 2008)

Meteorological Factors	Hydrological factors	Human factors aggravating natural flood hazards
• Rainfall • Cyclonic storms • Small-scale storms • Temperature • Snowfall and snowmelt	• Soil moisture level • Groundwater level prior to storm • Natural surface infiltration rate • Presence of impervious cover • Channel cross-sectional shape and roughness • Presence or absence of over bank flow, channel network • Synchronization of run-offs from various parts of watershed • High tide impeding drainage	• Land-use changes (e.g. surface sealing due to urbanization, deforestation) increase run-off and may be sedimentation • Occupation of the flood plain obstructing flows • Inefficiency or non-maintenance of infrastructure • Too efficient drainage of upstream areas increases flood peaks • Climate change affects magnitude and frequency of precipitations and floods • Urban microclimate may enforce precipitation events

Preventing flood damages is one important element of flood management. Flood management is a broad spectrum of activities aimed at reducing potential harmful impact of floods on the people, environment and economy of the region. Flood management process can be divided into three major stages: (1) planning; (2) flood emergency management; and (3) post flood recovery (Simonovic, 1999). During the *planning* stage, different alternative measures (structural and non-structural) are analyzed and compared for possible implementation in order to reduce flood damages in the region. *Flood emergency management* includes regular real-time appraisal of the flood situation and daily operation of flood control works. *Post flood recovery* involves numerous hard decisions regarding return to the 'normal life' (evaluation of damages, rehabilitation of damaged properties and provision of flood assistance to flood victims). The most basic information for flood planning and preparedness concerns hydrologic and hydraulic data that require reliable and appropriate hydrometric and meteorological networks within the basin.

An underlying assumption supporting flood modeling and floodplain is stationarity – the climate, weather and runoff processes and patterns of the past will operate in the future. Analysis of future flood control measures, operation of existing flood control structures, and evaluation of different hydrologic scenarios depends on the adequate topographical representation of the basin. Scenario technique is a collective term for all qualitative and quantitative methods used to generate, analyze and use scenarios (Sträter, 1988). Scenarios are no fairy tales or speculations and do not originate from pure imagination. A scenario depicts a possible future situation and beyond that it includes a description of the developments, which have led to that particular future (Gausemeier et.al. 1996).

Furthermore, control structures such as dams, reservoirs, channel adjustments and water diversions can drastically alter the river ecosystem in addition to the hydrological cycle due to their grand scale and/or alterations to the landscape. Hunt (1999) noted several impacts of dam and levee construction that severely altered riverine environments or disrupted aquatic ecology and organisms along the river system. Research of new structural designs, operational procedures, and management approaches is needed to protect not only lives and property but also the natural environment.

Natural disasters can nowadays be evaluated and contingency plans and mitigation programs can be prepared, prior to a new event by means of Remote Sensing (RS) and GIS technology utilizing satellite images via extracting necessary data and executing necessary risk analysis. RS provides a reliable and cost-effective way for field data collection, allowing for continuous and large-area coverage of many variables (Ozcan, 2007). The main advantage of using GIS for flood management is that it not only generates a visualization of flooding, but also creates potential to further analyze this product to estimate probable damage due to floods (Eroglu, 2006). Future flood and indeed all hazard policies should be grounded in hazard identification and assessment. These require reliable and accessible data. In the context of flooding, these foundations are achieved through data collection and analysis on parameters such as precipitation patterns, water flows on historical and real-time levels, risks, warnings, preparedness levels, remedial measures, and lessons from previous floods (Handmer and Parker, 1992).

The aim of this study is to determine and manage the flood risk in lower Sakarya basin using GIS and Remote Sensing. In the study area, a hydrological model and Multi Criteria Decision Analysis are developed on the possible areas under flood risk, and related environmental effects were analyzed.

THEORY AND METHOD

Flood frequency analysis based on the historic record of annual peak floods is a fundamental tool in determining the design discharge for floodplain zoning, flood protection infrastructure, and structures that span rivers. A basic assumption in frequency analysis is that climatic trends or cycles do not affect flood flows, but there is clear evidence that this is not the case (Gosnold *et al*., 2000), and that even modest changes in climate can result in large changes in flood magnitude (Knox, 1993).

Mathematical models play a key role in flood forecasting and in improving our understanding of hydrologic processes. In its simplest sense a model could consist of a rainfall-runoff relation and a routing equation. There are two trends; first, the increasing availability of remotely sensed data such as precipitation, snow water equivalent or evapotranspiration requires modifying models to accept spatial as well as point data. Improvements to the algorithms for transforming data to useful information as well as improvements to forecast models are required. Second, physically based models allow a more rigorous examination of discrete hydrological processes such as precipitation, interception, infiltration, interflow, and baseflow (Soulis *et al.,* 2000).

Overland flow and channel routing may be incorporated directly in the model or calculated in a hydraulic model. Research into physically based distributed hydrologic models that could be used for forecasting and for planning and design is needed. Such models could be used to examine anthropogenic impacts on a watershed. Issues such as the effects of conversion of a land surface to agricultural purposes, drainage development or wetland destruction on runoff volumes and peaks generate considerable public debate. Producing findings that are publicly acceptable requires considerable effort using very detailed models. In addition, these models could ultimately be coupled with atmospheric models to examine issues such as climate change impacts on water resources. Global circulation models could provide the boundary conditions for regional scale models (Pietroniro *et al*., 2001*).*

For the application of hydrological modeling the used data included 1:25000 scaled topographical maps, SPOT satellite images within 1999-2006 and maximum discharges between 1953 and 1980. Digitized topographical maps were used for analyzing the terrain and geometric structure of the Sakarya River. The detailed flow chart used in hydrological modeling is shown in Figure 2.

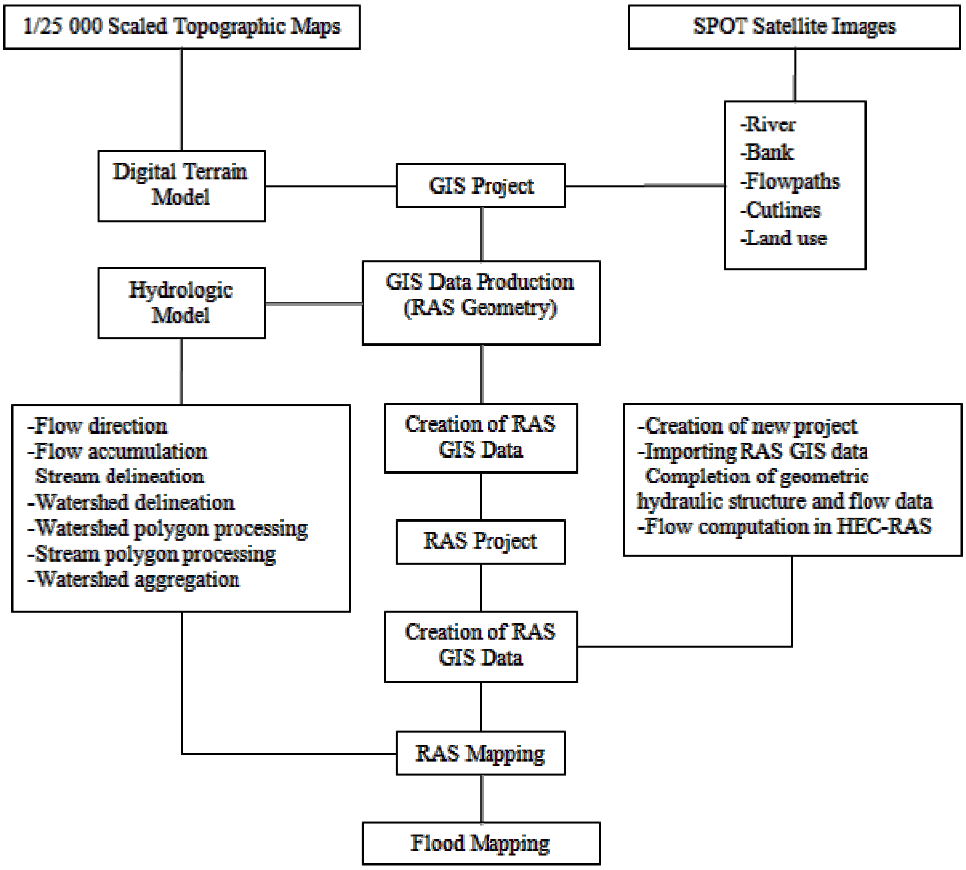


Figure 2: Flow chart of Hydrological Modeling.

In this study, hydrological parameters were constituted of using remotely sensed data and GIS. In hydrological modeling, most of the parameters have the characteristics of random variables that cannot be fully expressed by physical laws. The most important reason for this fact is the random variety of the rainfall. So that, in the discharge variables randomness is also observed. The random characteristics of hydrological system, sampling errors in hydrological data and the errors in the model that was accepted as hydrological period results in the random variation of the hydrological parameters.

In this study, 28 year of discharge data was used for lower Sakarya basin discharge observations. Thus, the flood discharges having 5, 10, 20 and 100 years return period are calculated using Log Pearson Type III probability distribution functions (USACE, 1993) (Table 2).

Table 2: Flood discharges having 5, 10, 20 and 100 years return period.

T	σ	Cskew	K	ZT	Q (m^3/s)
5	0.224	-0.227	0.850	2.557	**360.68**
10	0.224	-0.227	1.258	2.648	**445.09**
20	0.224	-0.227	1.586	2.722	**527.07**
100	0.224	-0.227	2.178	2.854	**715.12**

In this table, T is the return periods, σ is the standard deviation of the flood discharges, C_{skew} is the skewness coefficient, K is the flood frequency factor, Z_T is the Log Pearson Type III distribution function and Q is the calculated flood discharges.

The possible flood risk areas having 100-year return period is evaluated using the model and as a result residential and agricultural areas that under the flood risk are displayed on Figure

3. Consequently, the total flood area under the risk is calculated as 3950 ha, 620 ha of this risky area are residential and rest of them is agricultural areas.

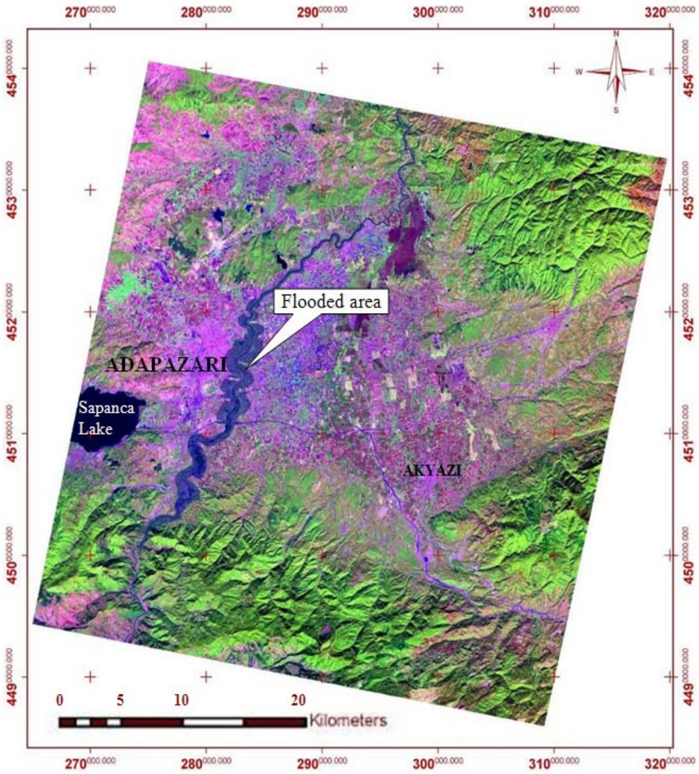


Figure 3: Flooded area covering residential and agricultural areas on SPOT image.

On the other hand, parameters were handled one by one in MCDA in order to determine the risky areas. Basic components of flood risk are constituted of flood characteristics and geographic properties of the basin. The detailed flow chart used in the MCDA is shown in Figure 4.

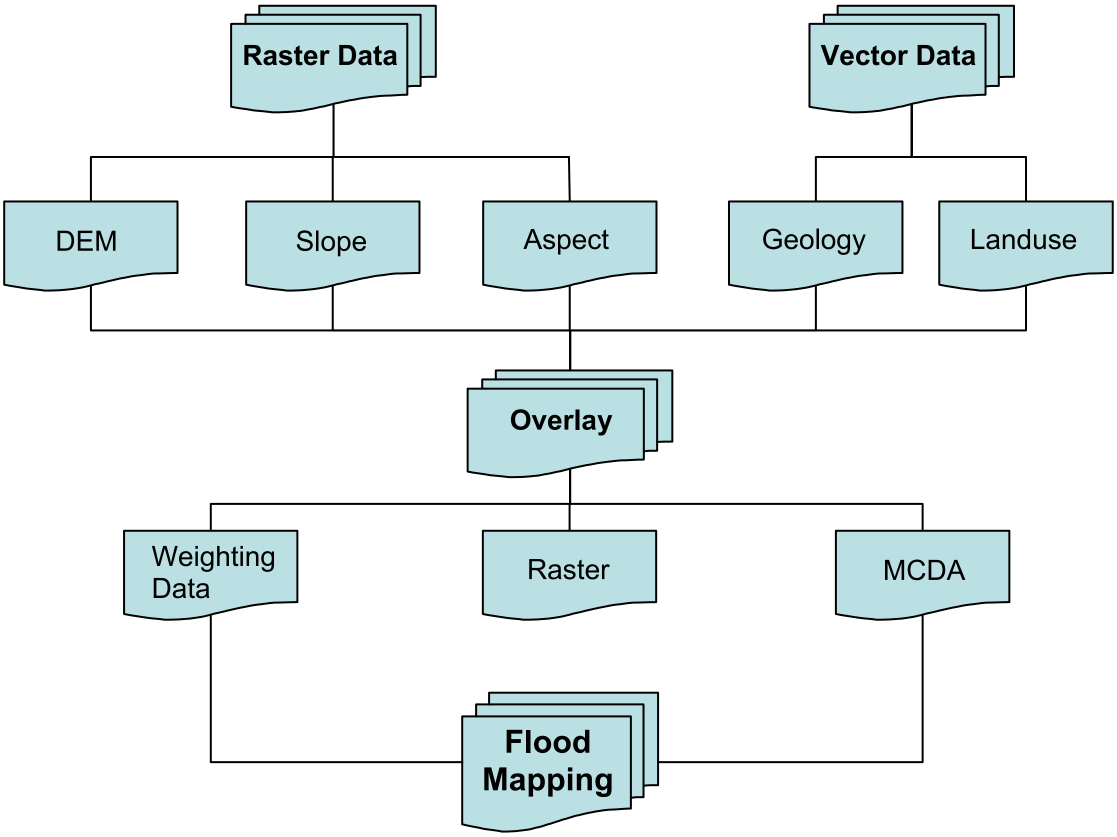


Figure 4: Flow chart of MCDA.

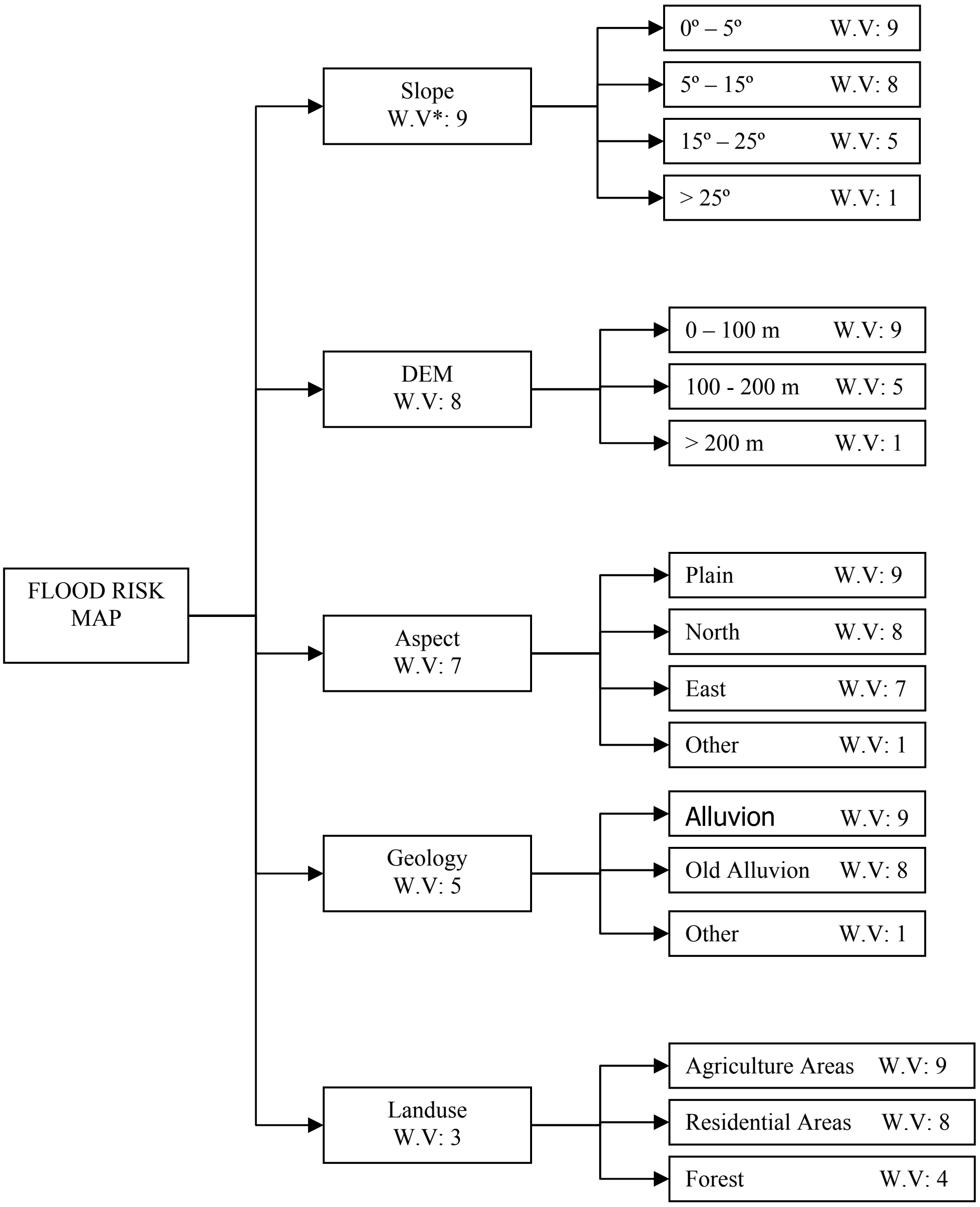
MCDA is making preference decisions (selecting, ranking, screening, prioritization, classification) over the available alternatives (finite number) that are characterized by attributes (multiple, conflicting, weighted, and incommensurable) (Yoon and Hwang, 1995)

Decision making process was executed on 3 main steps.

1. Structuring the Problem: Exploring the issue and determining whether or not MCDA is an appropriate tool.
2. Constructing the Decision Model: Elicitation of preferences, performance values, and weights.
3. Analyzing (Solving) the Problem: Using a solution method to synthesize and explore results

In the application of MCDA, concerning parameters of the flood risk in the study area have been evaluated and weighted (Figure 5).

Weight values are changing in a range from 1 to 9. The values which are closed to 1 have the minimum risk and similarly the maximum risky areas have values closed to 9. Since the effects of the parameters that are related to the disasters are in different proportion, each of them has different input values.



(*W.V: Weight Value)

Figure 5: The hierarchical structure of the parameters that constitute flood risk.

After the value input process the overlay process has been done. The most logical and reliable consequence in constructing flood risk map was evaluated by the parameters of the study area and that are related to different interpretations and related given data.

The flood risk map evaluated by implementation of the MCDA method. Five different degrees were chosen for flood risk (Figure 6).

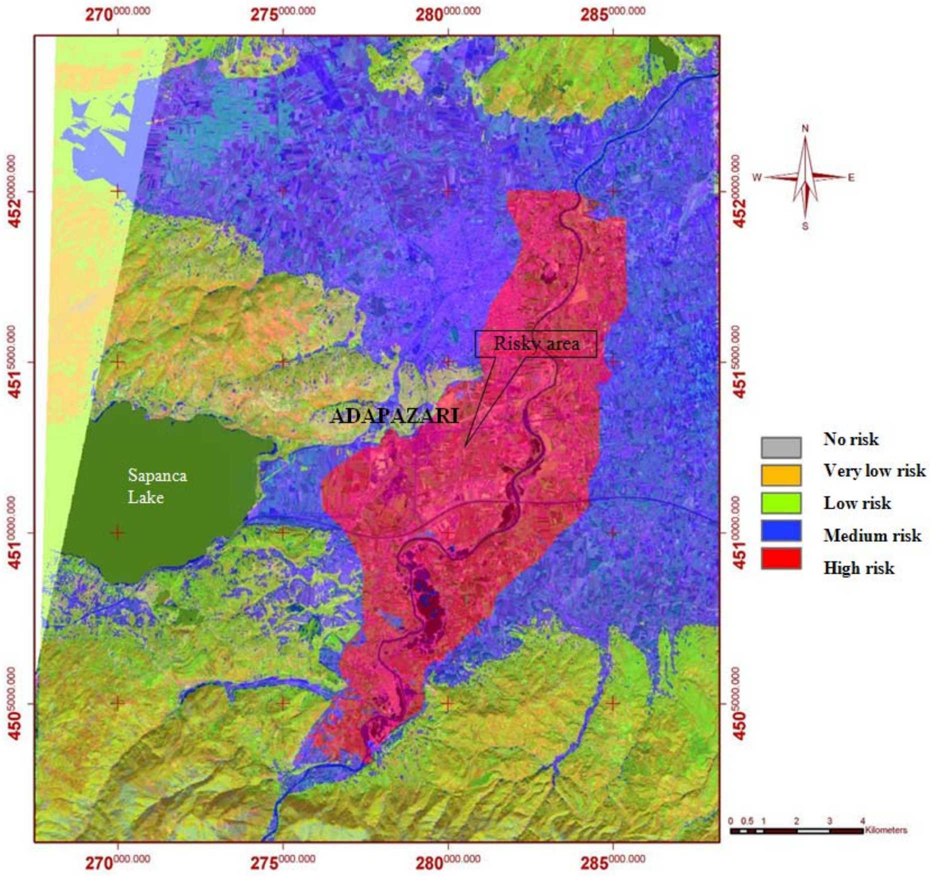


Figure 6: Flood risk map of the lower Sakarya Basin

RESULTS AND DISCUSSION

Considering boundary conditions of two methods which are used for flood risk analysis in the watershed, it is shown that results produced from Hydrological Modeling is more accurate. As a result of Hydrological Modeling, risky areas calculated as 620 ha of settlements area and 3330 ha of agricultural area. Main sectors in the area are industry and agriculture. Due to rapid increase in industrial sectors caused increase in residential area. Also two main highways of the country cut the study area. Thus, changes in land use/cover and negative effects of the transportation network make the region more vulnerable.

The hydrometric and meteorological networks will need to be upgraded in order to satisfy data needs for flood forecasting and water management in general. Additional satellite data, airborne data, and weather radar data may also improve flood management and preparedness. Airborne laser (LIDAR) mapping today can be a fast, reliable and cost effective method of obtaining three-dimensional data for the creation of a DEM. These data can be accurate to within the range of 1 m to ±15 cm depending on the terrain and ground control employed . Thus, further reductions in the number of gauging stations are not acceptable and indeed more gauging stations are likely required. There is also a need for better data and understanding of flood damages, risks and vulnerability. Risk assessments or analyses of flood events could prove to be useful for collecting various information regarding flood impacts and associated data. A database or information repository should be available through the World Wide Web that would be useful for anyone seeking access to this information. This database could contain technical, socio-economic and environmental information for past flood events, including types of flood mitigation measures taken (their advantages and disadvantages, and costs versus benefits). The database would be beneficial in summarizing and disseminating the knowledge of flood impacts. It would also provide data that could be used for assessing flood impacts in comparison to various flood mitigative options (ICLR, 2003).

Community participation in flood risk assessment as well as in planning and implementation of risk management measures is key for the success of flood risk management plans. Successful urban flood risk management is only possible if different measures, comprising structural and non-structural, spatial and organizational, are combined. In conclusion, flood management measures have to be planned across administrative and sectoral boundaries.

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