



International Journal of Environment and Geoinformatics (IJEGEO) is an international, multidisciplinary, peer reviewed, open access journal.

## Calculation of Flood Risk Index for Yeşilirmak Basin-TURKEY

**Ezgi Nur MENTEŞ, Şinasi KAYA, Ayşegül TANIK, Cem GAZİOĞLU**

### Chief in Editor

Prof. Dr. Cem Gazioğlu

### Co-Editors

Prof. Dr. Dursun Zafer Şeker, Prof. Dr. Şinasi Kaya,

Prof. Dr. Ayşegül Tanık and Assist. Prof. Dr. Volkan Demir

### Editorial Committee (December 2019)

Assos. Prof. Dr. Abdullah Aksu (TR), Assit. Prof. Dr. Uğur Algancı (TR), Prof. Dr. Bedri Alpar (TR), Prof. Dr. Lale Balas (TR), Prof. Dr. Levent Bat (TR), Prof. Dr. Paul Bates (UK), Prof. Dr. Bülent Bayram (TR), Prof. Dr. Luis M. Botana (ES), Prof. Dr. Nuray Çağlar (TR), Prof. Dr. Sukanta Dash (IN), Dr. Soofia T. Elias (UK), Prof. Dr. A. Evren Erginal (TR), Assoc. Prof. Dr. Cüneyt Erenoğlu (TR), Dr. Dieter Fritsch (DE), Assos. Prof. Dr. Çiğdem Göksel (TR), Prof. Dr. Lena Halounova (CZ), Prof. Dr. Manik Kalubarme (IN), Dr. Hakan Kaya (TR), Assist. Prof. Dr. Serkan Kükrer (TR), Assoc. Prof. Dr. Maged Marghany (MY), Prof. Dr. Michael Meadows (ZA), Prof. Dr. Nebiye Musaoğlu (TR), Prof. Dr. Erhan Mutlu (TR), Prof. Dr. Masafumi Nakagawa (JP), Prof. Dr. Hasan Özdemir (TR), Prof. Dr. Chryssy Potsiou (GR), Prof. Dr. Erol Sarı (TR), Prof. Dr. Maria Paradiso (IT), Prof. Dr. Petros Patias (GR), Prof. Dr. Elif Sertel (TR), Prof. Dr. Nüket Sivri (TR), Prof. Dr. Füsün Balık Şanlı (TR), Prof. Dr. Uğur Şanlı (TR), Duygu Ülker (TR), Assoc. Prof. Dr. Oral Yağcı (TR), Prof. Dr. Seyfettin Taş (TR), Assoc. Prof. Dr. Ömer Suat Taşkın (US), Dr. İnese Varna (LV), Dr. Petra Visser (NL), Prof. Dr. Selma Ünlü (TR), Assoc. Prof. Dr. İ. Noyan Yılmaz (AU), Prof. Dr. Murat Yakar (TR), Assit. Prof. Dr. Sibel Zeki (TR)

**Abstracting and Indexing:** DOAJ, Index Copernicus, OAJI, Scientific Indexing Services, International Scientific Indexing, Journal Factor, Google Scholar, Ulrich's Periodicals Directory, WorldCat, DRJI, ResearchBib, SOBIAD

## Calculation of Flood Risk Index for Yeşilirmak Basin-Turkey

Ezgi Nur Menteş<sup>1</sup>, Şinasi Kaya<sup>1,\*</sup>, Ayşegül Tanık<sup>2</sup>, Cem Gazioğlu<sup>3</sup>

<sup>1</sup> İTÜ, Civil Engineering Faculty, Geomatics Engineering Department, Ayazağa Campus 34469 Maslak-İSTANBUL/TR

<sup>2</sup> İTÜ, Civil Engineering Faculty, Environmental Engineering Department, Ayazağa Campus 34469 Maslak-İSTANBUL/TR

<sup>3</sup> İÜ, Institute of Marine Sciences and Management, Department of Marine Environment, 34134 VEFA Fatih-İSTANBUL/TR

\* Corresponding author: Sinasi Kaya  
E-mail: kayasina@itu.edu.tr

Received 12 Sep 2019  
Accepted 19 Dec. 2019

**How to cite:** Menteş et al., (2019). Calculation of Flood Risk Index for Yeşilirmak Basin-Turkey, *International Journal of Environment and Geoinformatics (IJECEO)*, 6(3): 244-259. DOI: 10.30897/ijegeo.661533

### Abstract

Flood risk, in the sense of damage that a 'flood event' can cause, was globally indexed and quantified to show the relationship between various natural and social factors. The Pressure and Release (PAR) model consisting of five key indexes, namely hazard, exposure, vulnerability, capacity soft countermeasures, and capacity hard countermeasures along with the entropy method was used to measure the uncertainty in information gathered. In this study, flood risk index was calculated for Yeşilirmak Basin of Turkey based on PAR. The basin is one of the coastal watersheds of Turkey experiencing frequent flood events. Damage data covering years from 2000 to 2015 have been obtained from the Ministry of Agriculture and Forestry for Turkey. Candidate data for hazard, vulnerability, countermeasures and exposure were collected in accordance with temporal and spatial scales, and the collected data were compiled on a watershed basis. When grouping the sub-indicators, AWDO (Asian Water Development Outlook) was used and selected from a group of parameters covering a wide range of characteristics such as economy, health, vegetation, population, river according to their global presence, and data consistency. As long-term data accessibility was highly limited under basin conditions, data was obtained from relatively more reliable global sources such as United Nations' databases on which data has been collected annually. The correlation among the collected parameter values was calculated based on the amount of damage that had occurred, and data with high correlation was included in the index account. Parameters that were not screened were rather weighted by using the entropy method and their effect on flood damage were determined. The calculated flood risk index based on PAR model was named as Yeşilirmak Basin Flood Risk Index (Y-FRI).

The resulting Y-FRI radar charts indicated that the most important variation occurred for the soft countermeasure index. In addition, the five main indices and the flood risk index was positively correlated with hazard, exposure and vulnerability indices, while negatively correlated with the countermeasures. This study showed that not only the hazard parameters directly contribute to flood formation, but also the vulnerability, exposure and countermeasure parameters that reflected the conditions of the region where the flood occurred have quantitatively influenced the flood damage.

**Keywords:** Flood Risk Index, PAR Model, Entropy, Vulnerability, Hazard, Exposure, Countermeasures, Yeşilirmak Basin

### Introduction

Floods, the most prevalent of natural risks, are anticipated to happen more strictly and regularly in the future because of climate change (Blöschl & Sivapalan, 1995; Sood et al., 2017; Ülker et al., 2018). The degree of damage caused by floods in a specified region depends on many natural and socio-economic factors, such as the density of population and assets, land use, infrastructure development, (e.g. trenches and dams), and on the speed and accuracy of information transmission (e.g. early warning systems). The relationship between various factors and flood risk has not been fully investigated so far by the scientists (Farhan et al., 2018; Aghayev & Mahmudov, 2019; Badalova et al., 2019). Measuring flood risk from a variety of natural and socio-economic factors will allow us to assess how flood risk will change in response to changes in population, climate and land use conditions, and how flood mitigation policy can potentially reduce the flood risk. There may be more than one disaster hazard in one region due to significant change

of nature and rapid population growth because of urbanization. In addition to multiple occurrence of hazards, the vulnerability qualities of humans also change the extent of disasters. These qualities change temporally and spatially. Education level, gender, age, dominant economic activity, disaster knowledge, religion and culture, state of health, income, land use methods and knowledge of hazards, ethnicity, and the ability to benefit from technological opportunities are among those quality items that could determine the capacity to which the population would be able to assess and cope with a flood efficiently, and is of great importance (Etkin, 1999; Ferrier & Haque, 2003; Şeker et al., 2016; Gazioğlu, 2018).

Sattler et al. (2000) studied the relationship of natural disaster preparedness with age, and found that age had a positive linkage with disaster prevention preliminaries. However, Coates (1999), French et al. (1983) and Mooney (1983) analysed deaths in flood disasters, and they have pointed out the increasing vulnerability of

young people and older individuals in flood disasters. Another example showed disaster awareness in the Rhine River Basin where two large floods of similar size occurred in 1993 and 1995. While people were less aware of flood risk in 1993, their experiences in the 1993 floods increased their awareness, and as a result, the amount of damage fell by half in 1995 compared to 1993 (Kron & Thumerer, 2002; Simav et al., 2015). Thus, risk perception can be a vulnerability factor in the readiness of communities and individuals to flood events.

While precipitation increases the number and severity of flood events (Trenberth, 2011), socio-economic activities, which have become widespread through rapid urbanization, increase the number and economic value of assets damaged in flood basins and increase flood risk (Wilby and Keenan, 2012). The concept of risk has been expressed in many ways by many researchers coming from different disciplines. Random House (1966) mentioned, "the risk includes the possibility of exposure to an injury or loss", Adams (1995) underlined it as "compound measure that combines the probability and magnitude of a negative effect "whereas Smith (1996) expressed it as "Probability x Damage (in the event that a particular hazard is)". On the other hand, Crichton (1999) focused on the concept of vulnerability and stated that "risk is the probability of loss and depends on three factors: hazard, vulnerability and exposure", whereas Downing et al. (2001) referred to "a specific area-specific hazard and estimated losses for the reference period (loss of life, injury, loss of property, deterioration of economic activity)" as defined.

As such, combination of different hazards and vulnerability causes risk. Flood risk can be expressed as a result of predicted hazard, exposure and vulnerability based on mathematical calculations that cannot be accurately predicted as a result of events / events that could potentially cause damage in a given location. However, since the risk has a complex structure due to many variables (Han et al., 2007; Kaya et al., 2008; Menteş, 2019), it is inevitable to make some neglects in determining flood risk.

The purpose of this study was to quantify the impact of flood damage on flood risk by not only considering the hazard parameters that directly cause flood formation, but also by taking into account the vulnerability parameters, such as housing and social characteristics that reflect the conditions of the region, and variables that explain the natural and social factors. In order to familiarize with the concepts of disaster, hazard, vulnerability and risk, brief definitions will be given prior to risk calculation.

The presence of hazards is just as effective as the vulnerabilities for disaster risk in an area. The joined interaction of both vulnerability and danger results in risk. In turn, the interaction of vulnerability and hazard poses a risk situation. Risk is the sum of the probable damages, and negative consequences of a dangerous event that may result in harm to humans and the environment in the event of a particular hazard.

### **Danger**

- All events that may lead to physical, economic and social losses of technological or human origin.
- Regardless of the level of sophistication, it is impossible to find a settlement, region or country free of danger on Earth. However, the fact that natural, technological or human hazards can have catastrophic consequences is directly related to the level of development of communities or countries.
- The danger varies by location, region or country. Depends on the location.

### **Vulnerability**

- Vulnerability is a measure of the damage that a community, a structure or service can face when danger occurs.
- Ideally, to achieve a comprehensive flood risk framework, flood losses need to cover all possible dimensions of damage, including social, psychological and environmental consequences.
- Flood risk includes flood hazard and vulnerability of exposed assets. As majority of vulnerability is caused by human-induced activities; education level, gender, age, dominant economic activity, disaster knowledge, religion and culture, state of health, income, land use methods and knowledge of hazards, ethnicity, and the ability to benefit from technological opportunities are some of the outstanding items that would determine the capacity to which the population would be able to assess and countermeasure a flood in a proper manner, and is of great importance. Figure 1 classifies the vulnerability concept as physical, social and economic vulnerability.

**Physical Vulnerability:** It covers the vulnerability of physical elements and the physical capacities (human-made structure, infrastructure, environment, agriculture, industry, production, etc. of human communities. It is the degree of damage that a physical element will suffer if a hazard of a certain magnitude occurs in a given area.

**Social Vulnerability:** Population density of societies includes population and education related factors such as age and sex ratios, knowledge and education levels. The fact that physical vulnerability levels and coping capacities differ among the social groups and that the elderly, children and disabled people are more affected and less coping capacity in the analysis of past events has caused such a definition of vulnerability.

**Economic Vulnerability:** How societies regulate their lives economically contains factors such as how they regulate their capacities and subsistence. Factors affecting vulnerability are poverty and underdevelopment; rapid population growth; rapid and unsupervised urbanization and industrialization; destruction of forests and

environment; ignorance, unconsciousness and lack of education; major changes in lifestyle; battles, etc.

**Risk**

It is expressed as possible losses due to danger in certain areas and time (human life, material damage, interruption of social and economic activities, etc.), and is defined as the result of danger and vulnerability formulated by

mathematical calculations. In order to address the risk, there would be an event or the danger of an event of a significant magnitude in a given location; it would be necessary to estimate to which extent the present values might be affected or the vulnerability of the event. Risk of flood is a function of flood hazard, exposure and vulnerability as given below.

$$\text{Risk of Flood} = f(\text{flood hazard}) * (\text{exposure}) * (\text{vulnerability})$$



Fig. 1. Classification of vulnerability concept.

**Study Area**

In the north of Anatolia, the drainage area that empties its waters into the Black Sea with the Yeşilirmak River formed the Yeşilirmak Basin of Turkey. It is one of the 25

hydrological watersheds of the country. The Yeşilirmak River that gives its name to the basin is 519 km long. The narrowest width is 30.5 km and the widest part is of 170 km. Figure 2 shows the geographical location of the basin.



Fig. 2. The location of Yeşilirmak Basin in Turkey (Kale et al., 2019).

The basin area is approximately 3,873,280 hectares accounting to 5% of the overall area of Turkey and to 3% of the country’s population. The average annual rainfall is 646 mm, average annual flow is 5.80 km<sup>3</sup> and average basin yield is 5.1 l/sec/km<sup>2</sup> (BPAP, 2010). Eleven

provinces share the basin. The basin encounters Central Black Sea, Western Black Sea and Central Anatolian climate. Hot summer, warm and rainy winter climate dominates along the coast. However, winters are cold and rainy, whereas the summers are cool in the interior regions

that are surrounded by the high mountains. The average annual temperature in the basin is around 12 °C. The average monthly precipitation is 50 mm. It increases during the winter months to 60-65 mm. During summer, the lowest rainfall amounts are recorded in July and August at approximately 26.5 and 24.6 mm, respectively.

Riverine floods that are generally widespread occur over time because of long-term rainfall events and affect the basin. Additionally, snow melting of the mountainous regions during spring can cause floods

**Data and Methodology Used**  
**Pressure and Release Model (PAR Model)**

Disaster management focuses on vulnerability and mitigation to minimize the impacts of disasters. In

addition to different geographical locations, different populations in a community have different levels of vulnerability, which may create unsafe conditions. In other words, vulnerability cannot be equally distributed as both physical and social (economic, political and cultural) environments affect disaster vulnerability. Although many models have been proposed in this respect, the PAR Model developed by Wisner et al. (2004) has been commonly used in practice.

PAR Model enables to understand the relationship between vulnerability and danger. The effects of vulnerability and hazard cause pressure, whereas release part of the model suggests the conditions that can be reversed, and that vulnerability may be reduced if it is known and mitigated. Figure 3 presents the PAR Model and its main drivers.

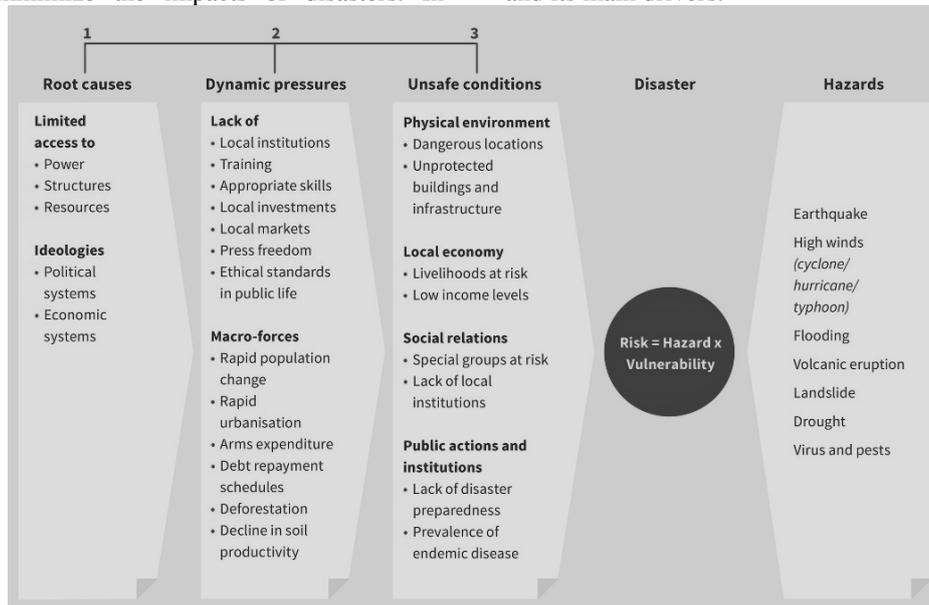


Fig. 3. PAR Model (Wisner et al., 2004).

**Entropy Method**

The entropy weighting method is an impartial weighting method and allows for weighting of evaluation criteria in the decision matrix. A high entropy value indicates that the criterion is of high importance. The entropy weight method is mostly used in determining the index weights. The implementation steps of the method are listed below;

*Step 1: Normalization of Decision Matrix*

To eliminate the different units of measure, normalization is done and  $P_{ij}$  is calculated.

$$P_{ij} = \frac{a_{ij}}{\sum_1^m a_{ij}} \tag{Eq.1}$$

Where,

- i: index for alternative,
- j: index for criterion,
- $p_{ij}$ : normalized values, and
- $a_{ij}$ : benefit value given for i. alternative j.

*Step 2: calculating the entropy value for each criterion*

$$E_j = -k \sum_{i=1}^m P_{ij} \ln(P_{ij}) \quad , \quad k = (\ln(n))^{-1} \tag{Eq.2}$$

Where,

- k: entropy coefficient,
- $P_{ij}$ : normalized value, and
- $E_j$ : entropy value

*Step 3: calculating the weight value of each criterion*

$$W_j = \frac{1-E_j}{\sum_1^m (1-E_j)} \tag{Eq.3}$$

$$\sum_1^m w_i = 1$$

$w_j$ : weight values

**Determination of Flood Risk Model Indices for the basin**

The sub-indicators were grouped according to their global availability and data consistency gathered from a range of parameters covering characteristics such as economy, health, vegetation, population, river, using Asian Water Development Outlook (AWDO). The data was obtained from relatively more reliable sources. UN databases collected annually with the most commonly used

frequency for time-varying parameters such as GDP, population and forest cover during the same period of the flood in concern were provided to be further utilized as flood damage data. Therefore, socio-economic conditions at the time of flooding could be reflected in the analysis of flood risk. Figure 4 illustrates the flow chart of methodology used in this study where the linkage among the components of the flood risk index are made clear.

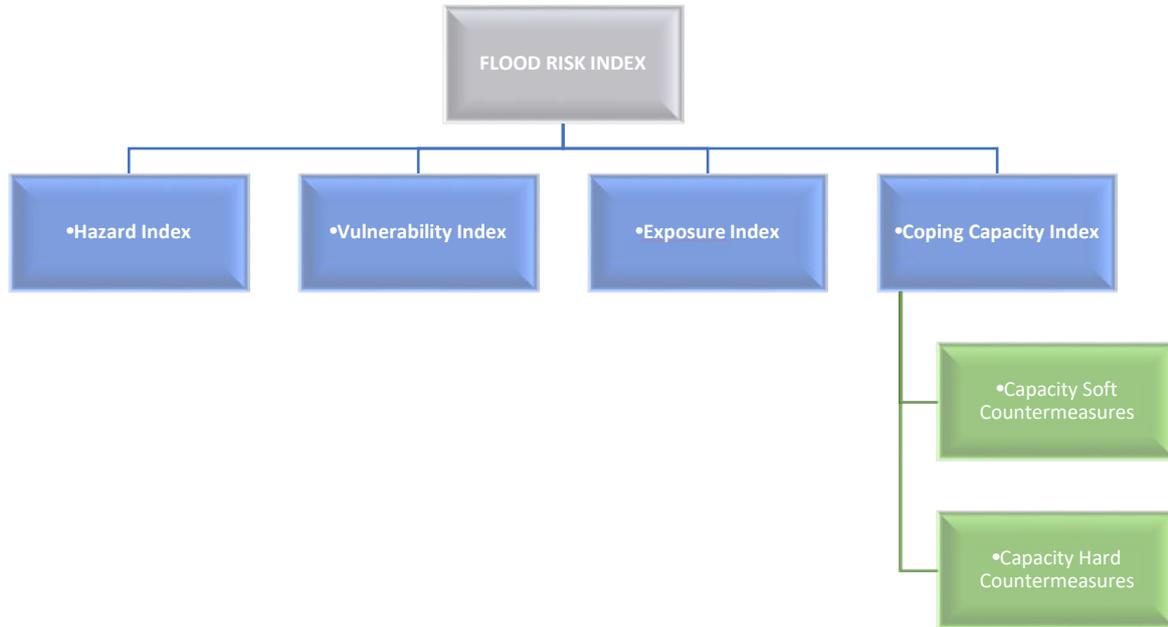


Fig. 4. Flood Risk Index Components.

Related data were collected from various governmental and institutional sources for the 2000-2015 inspection period for the overall country. Afterwards, data collected were reduced to Yeşilırmak Basin with respect to its area and population. Missing parameter values between the specified years were calculated by averaging the current years. Charts prepared within the context of Yeşilırmak Basin Flood Management Plan, index calculations for flood years (2000, 2001, 2005, 2006, 2007 and 2012) were made.

- **Hazard Index:** There are several factors related to flood damage; in this study, rainfall data as external force is a natural factor related to flood damage, and is defined as a Hazard parameter.
- **Vulnerability Index:** In order to assess the vulnerability in a particular study, it is of paramount importance to identify the factors and variables that make a particular urban system vulnerable to a particular danger, and to investigate how these factors are affected.

- **Exposure Index:** Exposure is described as sensitive items within the area affected by any hazard.
- **Coping Capacity Index:** Flood countermeasure parameters mean that flood disasters can be managed with structural and non-structural measures.
- **Capacity soft countermeasures:** Flood disasters can be managed by non-structural measures such as literacy rate, school enrolment rate, access to information.
- **Capacity hard countermeasures:** Flood disasters can be managed by structural measures such as schools, health facility, security audit, construction of water embankments, drainage facilities, etc.

**Calculation of Flood Risk Index**

The flood risk index calculated based on pressure and release model (PAR model) was named as Yeşilırmak Basin Flood Risk Index (Y-FRI) as given in Equation 4.

$$Y - FRI = \frac{\text{Hazard} \times \text{Exposure} \times \text{Vulnerability}}{\text{Capacity Soft Countermeasures} \times \text{Capacity Hard Countermeasures}} \quad (\text{Eq. 4})$$

Prior to the correlation of the raw data belonging to the sub-indicators was calculated, a process of standardization (normalization) must be applied. The standardization process was performed to establish indicators and to ensure that variables evenly spaced were collected. In other words, since the parameters used were measured at different scales and units, they were transformed into a common space by the normalization technique. During this process, non-proportional numerical data were compared according to the surface area of Yeşilirmak Basin and reduced to basin scale. Then, the standardization of variables was scaled to a common base using Equation 5.

$$\log_{10}(x_i) \tag{Eq.5}$$

$x_i$  : Input value

The correlation value between the sub-indicators was calculated using the Excel program. The sign of the correlation coefficient (+, -) defines the direction of the relationship, either positive or negative. A positive coefficient means that as the value of one variable increases, the value of the other variable also increases vice versa, as one decreases, the other decreases as well. A negative correlation coefficient indicates that as one variable increases, the other decreases. Table 1 shows these correlation values. The entropy method was applied by selecting the sub-indicators with correlation above 0.50.

Table 1: Correlation values for exposure, countermeasure and vulnerability parameters with damage parameter in Yeşilirmak Basin.

Group	ID	Data Name	Correlation Values with Damage Level
Damage	Y	Damage Level	1
Exposure	X1	Economically Active Population (1,000 people)	-0.601436716
Exposure	X2	Population within 100 km distance to the coast (per 1000 people)	-0.682866821
Exposure	X3	Population Density (person/km <sup>2</sup> )	-0.682271342
Exposure	X4	Total Population, Male	-0.681782352
Exposure	X5	Total Population, Female	-0.682732594
Exposure	X6	Total Population	-0.682271342
Exposure	X7	Rural Population-Total Population Percentage (%)	0.705102632
Exposure	X8	Urban Population-Percentage of Total Population (%)	-0.677850956
Exposure	X9	Population Growth Rate (%)	-0.217841051
Capacity Hard Countermeasures	X10	Agriculture Value Added-GDP%	0.594666291
Capacity Hard Countermeasures	X11	Percent Resistant Structure (%)	-0.431107015
Capacity Hard Countermeasures	X12	Agricultural Use Ratio (%)	0.972724979
Capacity Hard Countermeasures	X13	Share of Forest Lands in Land Area (%)	-0.703095598
Capacity Hard Countermeasures	X14	Number of Dams	-0.665946467
Capacity Hard Countermeasures	X15	Maximum Reservoir Storage Capacity (hm <sup>3</sup> )	-0.883727026
Capacity Hard Countermeasures	X16	Reservoir Area (km <sup>2</sup> )	-0.887812
Capacity Hard Countermeasures	X17	Population Covered by Sanitary Sewerage System (Rural) (%) (per 1000 people)	0.756891
Capacity Hard Countermeasures	X18	Population Coverage Rate of Sanitary Sewerage System (Total) (%) (per 1000 people)	-0.619293
Capacity Hard Countermeasures	X19	Population Covered by Sanitary Sewerage System (Urban) (%) (per 1000 people)	-0.738388
Capacity Hard Countermeasures	X20	Improved Drinking Water Service Provided-Rural Population (%) (per 1000 people)	0.683732
Capacity Hard Countermeasures	X21	Improved Drinking Water Service Provided-Total Population (%) (per 1000 people)	-0.550001
Capacity Hard Countermeasures	X22	Improved Drinking Water Service Provided-Urban Population (%) (per 1000 people)	-0.720357
Capacity Soft Countermeasures	X23	Number of Cell Phones (per 100 people)	-0.465336
Capacity Soft Countermeasures	X24	Number of Fixed Phones (per 100 people)	0.83222
Capacity Soft Countermeasures	X26	Percentage of Individuals Using the Internet	-0.611664
Capacity Soft Countermeasures	X27	Public Health Expenditure (million TL)	-0.522077

Capacity Soft Countermeasures	X28	Male Unemployment - % of male labour force	0.453149
Capacity Soft Countermeasures	X29	Female Unemployment - % of female labour force	-0.023485
Capacity Soft Countermeasures	X30	Total Unemployment - % of total labour force	0.291267
Capacity Soft Countermeasures	X31	Age Dependency Ratio (%)	0.647945
Capacity Soft Countermeasures	X32	Age Dependency Ratio, Young (%)	0.660962
Capacity Soft Countermeasures	X33	Age Dependency Ratio, Old (%)	-0.660477
Capacity Soft Countermeasures	X34	Education Index	-0.774394
Capacity Soft Countermeasures	X35	Adult Literacy Rate (%)	-0.763332
Capacity Soft Countermeasures	X36	Net Enrolment Rates in Primary Education, Male (%)	0.750297
Capacity Soft Countermeasures	X38	Net Enrolment Rates in Primary Education (%)	0.774964
Capacity Soft Countermeasures	X39	Net Enrolment Rates in Secondary Education, Female (%)	-0.477676
Capacity Soft Countermeasures	X40	Net Enrolment Rates in Secondary Education, Male (%)	-0.169798
Capacity Soft Countermeasures	X41	Net Enrolment Rates in Secondary Education (%)	-0.373978
Vulnerability	X25	GDP (current US \$)	-0.634277
Vulnerability	X42	General Final Consumption Expenditures (current US \$)	-0.664415
Vulnerability	X43	GINI Index	0.558338
Vulnerability	X44	Households and NPISHs Final consumption expenditure (current US \$)	-0.643388
Vulnerability	X45	Human Development Index (HDI)	-0.726854
Vulnerability	X46	GDP per capita (current US \$)	-0.62316
Vulnerability	X47	Net Official Development Assistance and Official Assistance	-0.833631
Vulnerability	X48	Percentage of Poverty Population (less than \$ 1.25 / consumption day) (%)	0.81343
Vulnerability	X49	Percentage of Poverty Population (less than \$ 2 / consumption day) (%)	0.80751
Vulnerability	X50	Life Expectancy, Female	-0.617104
Vulnerability	X51	Life Expectancy, Male	-0.599859
Vulnerability	X52	Life Expectancy	-0.609344
Vulnerability	X53	Mortality Rate, Adult Female (per 1000 Female Adults)	0.655515
Vulnerability	X54	Mortality Rate, Adult Male (per 1000 Male Adults)	0.659945
Vulnerability	X55	Infant Mortality (per 1,000 live births)	0.703599
Vulnerability	X56	Poverty Headcount Ratio at National Poverty Lines (% of Population)	0.806292
Hazard	X57	Precipitation Anomaly (%)	-0.568659
Hazard	X58	Annual Total Precipitation (mm)	0.487789

Table 2: Index values calculated according to the years in which flood events occurred.

Years	Flood Risk Index	Hazard Index	Vulnerability Index	Exposure Index	Capacity Soft Countermeasures Index	Capacity Hard Countermeasures Index
2000	0.441292981	0.179331305	0.167367505	0.166916237	0.067958739	0.167052702
2001	0.303079159	0.157637767	0.166984070	0.166903773	0.086752658	0.167094674
2005	0.165296468	0.169164079	0.167405592	0.166810190	0.171655277	0.166486857
2006	0.147206342	0.173183223	0.166831319	0.166784051	0.196493212	0.166595723
2007	0.132133913	0.165889798	0.166342056	0.166775752	0.208897004	0.166727848
2012	0.094666562	0.154793828	0.165069458	0.165809998	0.268243111	0.166842197

Each index consisted of sub-indicators whose weights were calculated by the entropy method and calculated by adding the weights of the sub-indicators as shown in Equation 6.

$$\text{Index} = \sum_{i=1}^n \text{Sub-index}(i) \quad (\text{Eq.6})$$

With the equations described above, five main index values were found and the (Y-FRI) was calculated separately for the six specific years in which flood events occurred. The mathematical equivalent of the calculated

index values is given in Table 2. When the correlation between hazard index, vulnerability index, exposure index and countermeasure indices with flood risk index is examined, it is seen that flood risk index values were positively correlated with hazard, exposure and vulnerability indices, while it was negatively correlated with countermeasures. The correlation values of the main indices were further calculated with the flood risk index as given in Table 3.

Table 3: Correlation values of exposure, countermeasure and vulnerability parameters with flood risk index.

	Flood Risk Index	Hazard Index	Vulnerability Index	Exposure Index	Capacity Soft Countermeasures Index	Capacity Hard Countermeasures Index
Flood Risk Index	1					
Hazard Index	0.487846	1				
Vulnerability Index	0.619134	0.692525	1			
Exposure Index	0.557844	0.620555	0.921889	1		
Capacity Soft Countermeasures Index	-0.938673	-0.439703	-0.784738	-0.752454	1	
Capacity Hard Countermeasures Index	-0.677548	-0.178012	-0.035985	0.038671	-0.589705	1

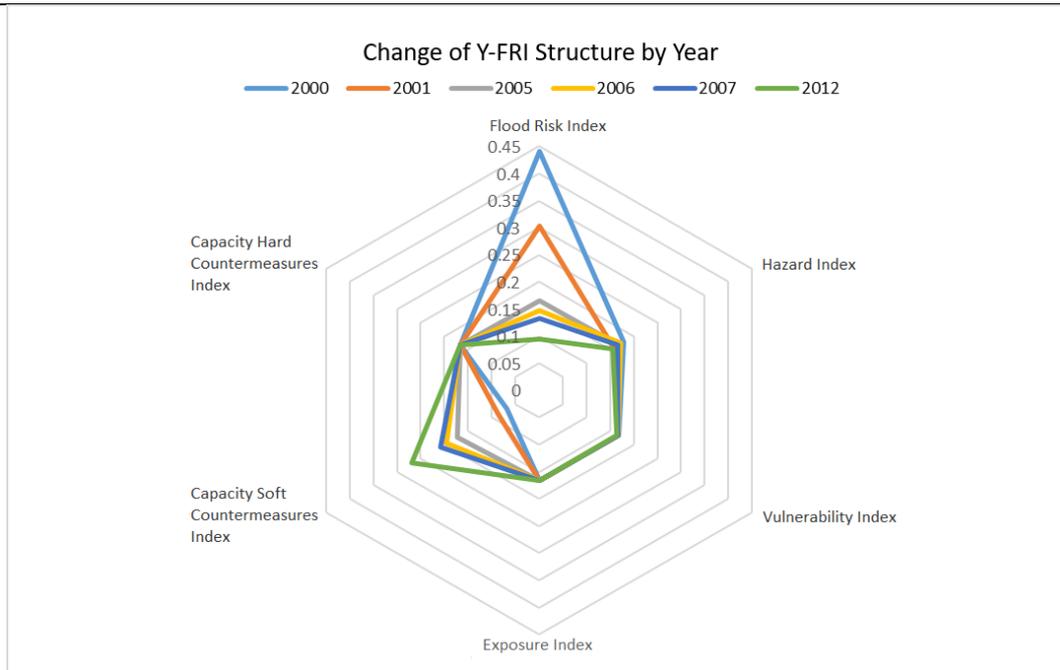


Fig. 5. Y-FRI radar chart.

**Results and Discussion**

In this study, a new global Flood Risk Index (FRI) has been developed based on both natural and socioeconomic factors. The indicators collected by taking into account the natural and social conditions of the Yeşilirmak Basin were identified as a component of the FRI. These datasets were selected in relation to the availability and quality of data (recording period), hazard, vulnerability, exposure, and countermeasure factors. Y-FRI was evaluated quantitatively based on the conceptual framework of the

pressure and oscillation (PAR) model using five indices. Y-FRI radar chart was prepared as given in Figure 5 to indicate the change in Y-FRI based on the flood events occurred at different years (2000, 2001, 2005, 2006, 2007 and 2012) during the inspection period. FRI is an event-based index that shows the expected damage from a single flood event. It can express the relative potential flood risk, i.e. the degree of expected damage so that the flood damage can be compared between different regions and periods. Therefore, Y-FRI will be able to evaluate the risk of floods now even without the use of historical flood damage data and will provide the structure of flood risk in

comparative and quantitative approaches. For example, Kannami (2008) and Fano (2010) aimed to evaluate FRI on country basis via PAR Model. These studies determined that the countries not affected by floods so far had a higher potential for flood damage. Myanmar for example has a high risk of flooding. There was no flood in Myanmar, which caused serious damage until 2007. However, in 2008, a flood event resulted a risk to take action towards more than 100,000 casualties. In other words, there are countries with FRI that do not suffer from floods; but are at high risk of flooding.

When the correlation between hazard index, vulnerability index, exposure index and countermeasure indices with flood risk index is examined as shown in Table 3, it is seen that flood risk index values were positively correlated with hazard, exposure and vulnerability indices, while it was negatively correlated with countermeasures. The softest countermeasure index presented the highest change compared to others when the Y-FRI radar graphs given in Figure 5 and Table 2 are examined. Soft countermeasure index values that increased in the basin from 2000 to 2012 decreased Y-FRI. The hard countermeasure index, exposure index and danger index values reflected almost no change in the index values that

would affect Y-FRI between the inspected years and the index values were highly close to each other. According to the results of this application, the increase in educational activities, health expenditures and access to communication tools reduced the flood risk index in the basin.

The amount of damage caused by disasters cannot be found per city or town basis, and even for overall Turkey. However, data corresponding to the socio-economic and socio-demographic structure of the basin needs to be obtained in order to calculate the indices better. Presently, there is no database from which such provincial and/or district based missing data can be accessed annually. For calculating Y-FRI global databases such as the World Banks (WB) sources which can be accessed from the related websites were used for some of the missing data under the country profile. Average values were used for the years where no data existed. In order to calculate the index more accurately, it is necessary to develop provincial updated database, which contains detailed data accessible by every user. Unfortunately, data scarcity and data compilation problem is still valid for the developing countries like Turkey. .

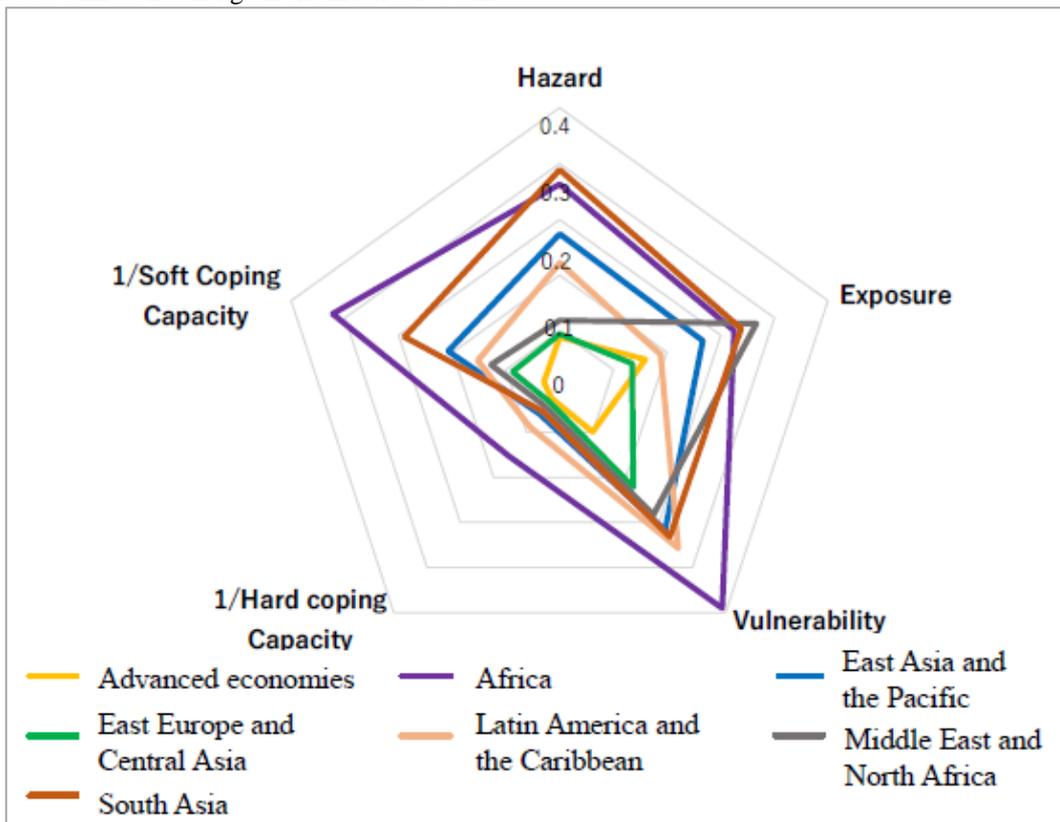


Fig. 6. Five indicators calculated by region (146 countries) (Imamura and Sasaki, 2018).

There is no satisfactory assessment of flood vulnerability parameters in Turkey. Hazard and risk assessments generally focus on economic damage and structural defence measures. The uniqueness of the recently developed FRI is that not only the hazard parameters that directly affect flood formation, but also, the vulnerability parameters that reflect the socio-economic characteristics of a region can be quantified. Furthermore, the FRI, can also be applied as an objective tool for evaluating flood

adaptation policies. For example, the change in expected flood damage due to the change in land use can be predicted by FRI, and then, the results can be addressed as guidelines for future urban planning. Another example is the socio-economic change of the basin (e.g. it will allow to predict the relationship between population and economic growth) that contributed to flood damage, and to predict the expected damage of future floods. This would enable more accurate cost-benefit analysis and

more appropriate budget allocation. Economic damages after flood events should be calculated in order to conduct annual expected average damage-benefit cost analyses for flood-related planning and risk reduction attempts.

Fano (2010) suggested a proposal to formulate the Philippine flood risk index (P-Fric) based on the (PAR) model consisting of five key indices, including hazard, exposure, vulnerability, soft and hard coping capacity similar to this study practiced to Yeşilirmak Basin. It was stated that the results of the comparison were generally correct, but some years did not match. This situation was explained by the fact that while the P-Fric referred to current flood risk, the damage data used for comparison was a compilation of 40 years data.

Imamura and Sasaki (2018) proposed a country-by-country FRI resulting from both natural and socio-economic factors that contributed to reducing flood damage. The developed method had been applied to 33

Asian-Pacific countries and it was seen that the countries were categorised as high, medium and low flood risk and that the economic development affected flood risk. The same study also applied the methodology to 146 countries in the world. Figure 6 shows the resulting chart.

Based on the findings, one can state that the majority of African countries bear high flood risks, and some other tropical countries have high- to- medium flood risk. The African countries need to control rapid population growth and change poor educational and living conditions to cope with this natural hazard. It is obvious that highly developed countries and regions experience the least risk. It is also an interesting outcome that despite the high GDP per capita values, some oil-producing countries show slightly high flood risk because of high exposure and vulnerability values.

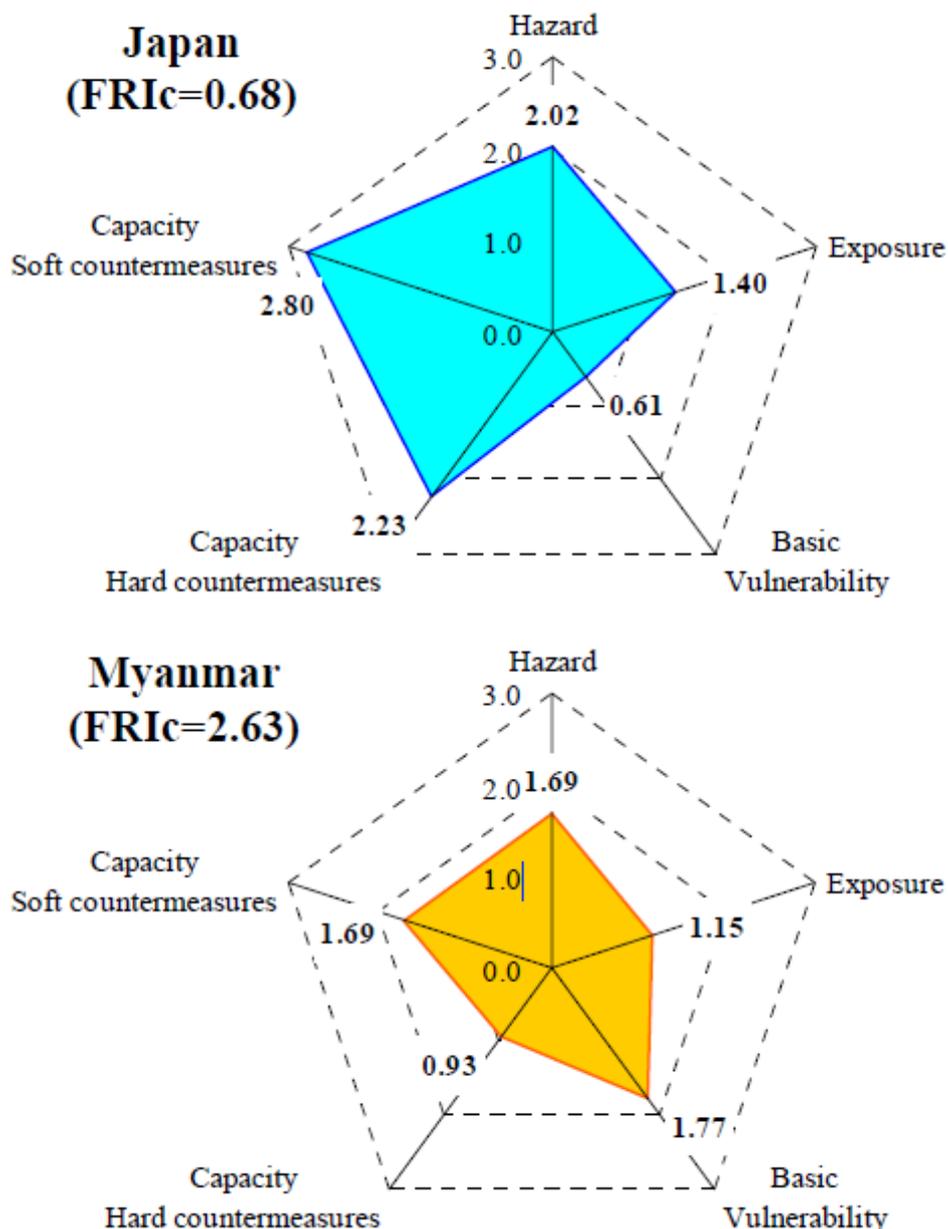


Fig. 7. The structure of the Myanmar and Japan FRIc (Kannami, 2008).

Kannami (2008) tried to evaluate flood risk on a country basis (FRIC) based on the PAR model. The methodology used in the FRIC enabled the analysis as high or low flood risk. The calculated FRIC were compared with the historical flood damage data. FRIC was calculated for 235 countries and regions. Japan's danger and exposure was found comparatively higher than Myanmar's, but Japan's flood risk was assessed as low due to high countermeasures and low vulnerability. This means that Japan must constantly strive to develop countermeasures; otherwise, the risk of flooding may easily increase. Figure 7 illustrates the structures of FRIC for Japan and Myanmar. Myanmar and Japan had number of deaths during the past two decades from flood events, but FRIC of Myanmar is 2.63 whereas that of Japan is only 0.68. Hazard and exposure of Japan were higher than those of Myanmar; but, Flood risk of Japan was assessed as low due to high capacity and low vulnerability. Flood risk of Myanmar was assessed as high due to high vulnerability and low capacity. This implies that Japan should make an effort to build capacity continuously; otherwise, flood risk can easily increase.

### Conclusions and Recommendations

Calculation and/or estimation of flood risks in developing countries like Turkey still lacks. However, coastal countries and in countries where there plenty of rivers frequently experience flood events. Nowadays, as climate change effects have started to be faced all around the world, the risk calculations have gained even more interest than previous years. This study aimed to apply an index-based model to Yeşilirmak Basin of Turkey with the key idea of finding missing data to accomplish the model structure with maximum reliable data. This first attempt resulted with success despite data scarcity. Lack of provincial database in which necessary data would be stored to provide the necessary data for better expressing the indicators was the main handicap of the study. To fill in the missing data, average global values were utilized. It is important to note that similar studies cited in literature accomplished country-based FRIC, which is of utmost importance. Therefore, it recommended that each of the countries should attempt to calculate the FRI including Turkey.

### References

Adams, J. (1995). *Risk*. University College London Press, London, 228p.

Aghayev, A., Mahmudov, R. (2019). Analysis of the Kura River flooding in Azerbaijan territory in 2010 based on Hydrometeorological Observation and Remote Sensing, *International Journal of Environment and Geoinformatics* 6 (2), 205-212.

Badalova, A., Ismatova, K., Guliyeva, S. (2019). Influence of Riverbed Change on a Possibility of Flooding During Water Level Rise of the River Kura, *International Journal of Environment and Geoinformatics (IJEGEO)* 6 (1), 148-152.

Blöschl, G., Sivapalan, M. (1995). Scale issues in hydrological modelling: a review, *Hydrological processes*, 9(3-4), 251-290.

BPAP (2010). *Report on the Yeşilirmak Basin Protection Action Plan*, The Scientific and Technological Research Council of Turkey (TUBITAK) Marmara Research Centre (MRC), Former Ministry of Environment and Urbanization.

Coates, L. (1999). Flood fatalities in Australia, 1788–1996. *Australian Geographer*. 30(3), 391–408.

Crichton, D. (1999). The risk triangle, a new way to think about risk from an insurance perspective, *The Hazards Forum Newsletter*, London, 36, 12-13.

Downing, T.E., Butterfield, R., Cohen, S., Huq, S., Moss, R., Rahman, A., Sokona, Y., Stephen, L. (2001). *Climate Change Vulnerability: Linking Impacts and Adaptation*. Report to the Governing Council of the United Nations Programme. United Nations Environmental Programme, Environmental Change Institute, Nairobi, Kenya.

Etkin D. (1999). Risk transference and related trends: driving forces towards more mega-disasters. *Environmental Hazards*, 1, 69-75.

Fano, A., F., (2010). *Establishment of Philippine Flood Risk Index by Province Based on Natural and Social Factors*. 111p.

Farhan, M. Moazzam, UI., Vansarochana, A., Rahman, AU. (2018). Analysis of flood susceptibility and zonation for risk management using frequency ratio model in District Charsadda, Pakistan, *International Journal of Environment and Geoinformatics (IJEGEO)* 5 (2), 140-153

Ferrier, N., Haque, C.E. (2003). Hazards risk assessment methodology for emergency managers: a standardized framework for application. *Natural Hazards*, 28, 271-290.

French, J., R. Von Allmen, S., Wood, R. (1983). Mortality from flash floods: a review of national weather service reports, 1969–81. *Public Health Reports*, 98(6), 584–588.

Gazioglu, C. (2018). Biodiversity, Coastal Protection, Promotion and Applicability Investigation of the Ocean Health Index for Turkish Seas. *International Journal of Environment and Geoinformatics (IJEGEO)*, 5(3), 353- 367.

Han, D., Kwong, T., Li, S. (2007). Uncertainties in real-time flood forecasting with neural networks. *Hydrol. Processes*, 21(2), 223–228.

Imamura, Y., Sasaki, S. (2018). *Assessing Flood Risks Globally Using an Improved Country-Based Index*. Yamaguchi University, Advanced Science and Innovational Research Center, 2-16-1, Tokiwadai, Ube, Yamaguchi 755-8611.

Kale, M. M., Ataoğlu, M., Tekkanat, S. I. (2019). Assessment of the changes in shoreline using digital shoreline analysis system: a case study of Kızılırmak Delta in northern Turkey from 1951 to 2017. *Environmental Earth Sciences*, 78, 579.

Kannami, Y. (2008). *Establishment of country-based flood risk index*. (Unpublished master's thesis). International Centre for Water Hazard and Risk Management, Tsukuba.

- Kaya, H., Orakçı, V., Yücel, ZY., Gazioğlu, C. (2008). Yerel Yönetimlerde Afet Risk Yönetimi, Ulusal Jeomorfoloji Sempozyumu, 294-301
- Kron, W., Thumerer, T. (2002). *Water-related disasters: loss trends and possible countermeasures from a (re) insurers viewpoint.*
- Mentes, E.N. (2019). *Sel Risk Endeksinin Belirlenmesi: Yeşilirmak Havzası Örneği, Yüksek Lisans Tezi*, ITU Fenbilimleri Enstitüsü, Haziran 2019.
- Mooney, L.E. (1983). Applications and Implications of Fatality Statistics to the Flash Flood Problems. In *Proceedings of the 5th Conference on Hydrometeorology, Tulsa, USA, 17–19 October 1983*, 127–129.
- Random House. (1966). *The Random House Dictionary of the English Language*, Stein, J. (ed.), Random House, New York.
- Sattler, D. N., Kaiser, C. F., Hittner, J. B. (2000). Disaster preparedness: relationships among prior experience, personal characteristics, and distress. *Journal of Applied Social Psychology*, 30(7), 1396-1420.
- Şeker, DZ., Tanık, A., Cital, E., Öztürk, İ., Övez, S. & Baycan, T. (2016). Importance and Vulnerability Analyses for Functional Zoning in a Coastal District of Turkey, *International Journal of Environment and Geoinformatics (IJEGEO)*, 3 (3), 76-91.
- Simav, Ö., Şeker, D.Z., Tanık, A., Gazioğlu, C. (2015). Determining the endangered fields of Turkish coasts with coastal vulnerability index. *Journal of Map*, 153: 1- 8.
- Smith, K. (1996). *Environmental Hazards*. Routledge, London, 389 p.
- Sood,A., Smakhtin, V., Eriyagama, N., Villholth, KG., Liyanage, N., Wada, Y., Ebrahim, G., Dickens, C. (2017). *Global Environmental Flow Information for the Sustainable Development Goals*, International Water Management Institute (IWMI), 168p.
- Trenberth, K. E. (2011). Changes in precipitation with climate change. *Climate Research*, 47(1/2), 123-138.
- Ülker, D., Ergüven, O., Gazioğlu, C. (2018). Socioeconomic impacts in a Changing Climate: Case Study Syria. *International Journal of Environment and Geoinformatics (IJEGEO)*, 5(1), 84-93.
- Wilby, R. L., Keenan, R. (2012). Adapting to flood risk under climate change. *Progress in Physical Geography*, 36(3), 348-378.
- Wisner, B., Blaikie, P., Cannon, T., Davis, I. (2004). *At Risk: natural hazards, people's vulnerability and disasters*, 2nd edn. New York, Routledge.