Interreg - IPA CBC

Greece - Republic of North Macedonia

EUROPEAN UNION

FLOOD SHIELD

Joint flood risk governance and management in the Axios/Vardar cross border area

B.5.2. Final Report on the vulnerability analysis for the sites located in the Axios River basin

The content of the deliverable is the sole responsibility of the Decentralized Administration of Macedonia and Thrace and can in no way be considered to reflect the views of the European Union, the participating countries and the Managing Authority.

Responsible partner for the deliverable:

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The project is co-funded by the European Union and the national resources of the participating countries.

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Acronyms, Abbreviations and Definitions

Acronyms	Definitions
ALI	Adult Literacy Index
ALR	Adult Literacy Rate
CBC	Cross Border Cooperation
CGDP	Combined Gross Enrollment Index
EI	Education Index
EWS	Early Warning System
FVI	Flood Vulnerability Index
GDP	Gross Domestic Product
GDPpc	GDP per capita at PPP
GEI	Gross Enrollment Index
GIS	Geographic Information Systems
GR	Greece
HDI	Human Development Index
IPA	Instrument for Pre-Accession Assistance
IPCC	International Panel of Climate Change
LEI	Life Expectancy Index
LE	Life Expectancy
RNM	Republic of North Macedonia
CP	Contracting Partner
DAMT	Decentralized Administration of Macedonia and Thrace
GLRO	General Land Reclamation Organization
RB	River Basin
PATHE	Patra-Athens-Thessaloniki-Evzoni
WC	Water Compartment

1 Introduction

1.1 General Project Information

Project title: Joint flood risk governance and management in the Axios/Vardar cross border area

Acronym: FLOODSHIELD

Timetable: 21/07/2022 to 15/12/2023

Project budget: 1.474.450,00€

Corporate Structure:

Decentralized Administration of Macedonia and Thrace – GR (Lead Partner)

General Secretariat of Natural Environment and Water – GR

Ministry of Environment and Physical Planning – RNM

Protection and Rescue Directorate – RNM

The project is implemented under the programme INTERREG IPA CBC "Greece – Republic of North Macedonia 2014 – 2020" in the Priority Axis 2 "Protection of Environment – Transportation", in the Thematic Priority c: Promoting sustainable transport and improving public infrastructure and the specific objective 2.4: "Prevention, mitigation and management of natural disasters, risks and hazards".

1.2 Subject of the Contractor

According to the contract of 6/04/2023 "provision of consulting services for the technical support of the project "Joint flood risk governance and management in the Axios/Vardar cross border area" and acronym "FLOODSHIELD" (MIS 5062181)", implemented in the framework of "INTERREG Greece - Republic of North Macedonia 2014-2020", between the Decentralized Administration of Macedonia and Thrace (D. A.M.T.), Contracting Authority (CA) and the company LEVER - Development Consultants S.A., Contractor is foreseen to implement certain activities as described in the relevant contract and the project contract documents. More specifically, the scope of work to be implemented by the contractor concerns the support of the D.A.M.T. in the implementation of the deliverables of work packages 2, 3, 4 and 5 of the project, ensuring the adherence to the work schedule and the quality of these deliverables. In this context, the Contractor will support DAMT in the following actions (A.1-5.) and deliverables (numbered with two numerical digits A.1.1. - B.5.2.):

A.1. Development, implementation, monitoring and evaluation of the project's Communication Plan

A.1.1.1. Project Communication Plan

A.1.2. Summary reports of the communication actions (2 in total)

A.2. Creation of promotional material and public relations

A.2.1. Two (2) newsletters

A.2.2. Press release

A.2.3. Report on the implementation of the press conference

A.2.4. Project brochure (600 copies in total)

A.2.5. Guideline booklet (600 copies in total)

A.2.6. Popularized Report (250 copies in total)

A.3. Development, updating and maintenance of the official project website and social media

A.3.1. Creation of a Website and a Facebook page

A.3.2. Project website and social media update reports (as a sub-chapter of Deliverable A.2.)

A.4. Organization of the final project event in Thessaloniki

A.4.1. Implementation report of the final event and networking lunch

A.5. Organize two (2) seminars on the operation and use of the flood risk monitoring and response system and conduct paper and structural field exercises

A.5.1. Report on the implementation of the seminars (e-learning and in situ) and exercises on paper and field tests

A.6. Awareness and information activities:

A.6.1. Awareness-raising video of a maximum duration of two (2) minutes

A.6.2. Presentation report of the pages to be posted on the official project website

A.6.3. Report on the implementation of informal training and information of the units for disabled people and elderly people

A.6.4. Report on the implementation of the Event in Thessaloniki

A.7. Encouragement and promotion of volunteering

A.7.1. Report on the encouragement and promotion of volunteering

B.1. Compilation of a report on the civil protection system in Greece

B.1.1. Report on the identification of the civil protection system in Greece

B.2. Preparation, organization of two (2) meetings and participation in the remaining meetings of the Joint Flood Risk Management Group

B.2.1. Reports of participation in the Joint Flood Risk Management Group Meeting (Four Reports)

B.3. Investigation and mapping of existing monitoring systems in the Axios transboundary basin

B.3.1. Report on the investigation and mapping of existing monitoring systems in the Axios transboundary river basin

B.4. Formulation of the transboundary flood response strategy

B.4.1. Report on the transboundary flood response strategy

B.5. Preparation of a Vulnerability Analysis for the Axios river basin

B.5.1. Draft Vulnerability Analysis Report for the sites located in the Axios river basin

B.5.2. Final Vulnerability analysis report for the sites in the Axios river basin

1.3 Subject of the present report

This report is the deliverable "B.5.2 Final Report on the vulnerability analysis for the sites located in the Axios River Basin" of the Activity "B.5 Preparation of a Vulnerability Analysis for the Axios River Basin". The objective is to highlight the vulnerabilities of the areas in order to prioritize flood prevention needs and to facilitate the emergency response mechanism and the reconstruction of the area after a catastrophic flood.

This report presents the current situation of parts of the Axios river basin in terms of their vulnerability. The entire floodplain of the Axios River in Greece was divided into five (5) sub-basins.

The vulnerability analysis of the selected areas was carried out using the Flood Vulnerability Index (FVI), which consists of 4 sub-elements: social, economic, environmental and physical. The basic data used for the sub-indices and the overall index were extracted either from primary data or from available information and data, with the assistance of Geographical Information Systems software.

The most vulnerable area in the Greek part of the Axios River was found to be the area upstream of the Elli dam up to Polykastro.

In this example, the vulnerability calculation method can be used to prioritize resources and means at the level of a Municipality (sub-basins) or Region (sub-basins of different river basins) or even Ministry (different Water Basin Districts) when available resources are limited.

2 Vulnerability

2.1 Definition

Vulnerability is defined as the degree to which climate change can damage or destroy a system and depends not only on its sensitivity but also on its ability to adapt to new climatic conditions (Watson et al., 1996). Vulnerability is related to probability of occurrence, extent (referring to the geographical area and/or size of the affected population), intensity (referring to the magnitude of the change), risk assessment (resulting from the combination of probability, magnitude and intensity of events), potential for avoiding or minimizing impacts, and inter-regional and/or transboundary character.

Picture 1: *Catastrophic flooding with chain-shattering of 2 dams in Derna, Libya, 11/09/2023. Source: https://edition.cnn.com/2023/09/19/world/libya-floods-climate-change-impact/index.html.*

2.2 Vulnerability Background

In 1992, the International Panel on Climate Change (IPCC) defined vulnerability as the degree of inability to cope with the effects of climate change and sea-level rise. Years later, the IPCC, through Watson et al. (1996) defined vulnerability as "the degree to which climate change can harm or damage a system. It depends not only on the sensitivity of a system but also on its ability to adapt to new climate conditions". Blaikie et al. (1994) describe vulnerability as a measure of the exposure of an individual or group to the effects of a natural hazard, including the extent to which they can recover from the impact of that event.

Green (2004) expresses sensitivity as the potential receptor of targets that can be damaged. These last three (quite similar) definitions are contemporary and express vulnerability as potential damage or harm. Kelly & Adger (2000) discuss regarding the consideration of some vulnerability assessments as the end point of any assessment, others as the focus point and others as the starting point. Van der Veen & Logtmeijer (2005) broadened the concept of vulnerability to explain vulnerability to flooding from an economic perspective.

Gheorghe (2005) explains vulnerability as a function of sensitivity, resilience and knowledge state. In 1999, Klein & Nicholls expressed vulnerability for the physical environment as a function of three main components: resistance, resilience and sensitivity. Messner & Meyer (2006) and Merz et al. (2007), limited the definition of vulnerability to elements at risk, exposure (potential for damage) and sensitivity (loss), in contrast Mitchell (2002) expresses vulnerability as a function of exposure, resilience and resistance. Adger (2006) emphasized vulnerability as the state of susceptibility to harm from exposure, to stresses related to environmental and social changes and from the absence of adaptive capacity.

In the case of flooding: the degree to which a system is prone to flooding due to exposure, disturbance, combined with its resilience, coping, recovery or adaptive capacity/ability.

Combining all the above definitions, the general concept of vulnerability can be expressed as:

$$Vulnerability = Exposure + Susceptibility - Resilience$$

All societies are vulnerable to flooding, under different circumstances and situations, which make them somewhat unique.

2.3 Vulnerability approach

Vetere Arellano et al. (2003) and Meyer and Messner (2005) presented different approaches used in European countries to assess flood damage. The differences in approach relate to (a) the objective of the assessment, (b) the damage categories considered, (c) the level of detail, (d) the scale of analysis and (e) the basic principles of assessment. Some risk analyses further relate the expected damage to the probability of flooding so that the risk can be accounted for economically (Merz et al., 2004).

Picture 2: *Flooding on Pinios river of Thessaly, 08/09/2023.*

Expected flood damage will be influenced by, among other factors, land use and the economic value of the human activities involved. White (1964) correlated land use with functions that relate property damage to flood depth. These damage-depth functions have become the standard approach to flood damage or impact assessment (Smith, 1994). Although depth is the most considered variable in damage functions, other flood characteristics such as flood duration and flow velocities are considered (McBean et al. 1998). Smith (1994) and Dutta et al. (2003) estimated flood damage using the risk map with depth-damage functions. In previous applications, the lack of high-resolution data often limited the assessment of damage at broad scales, such as land use zoning in a city.

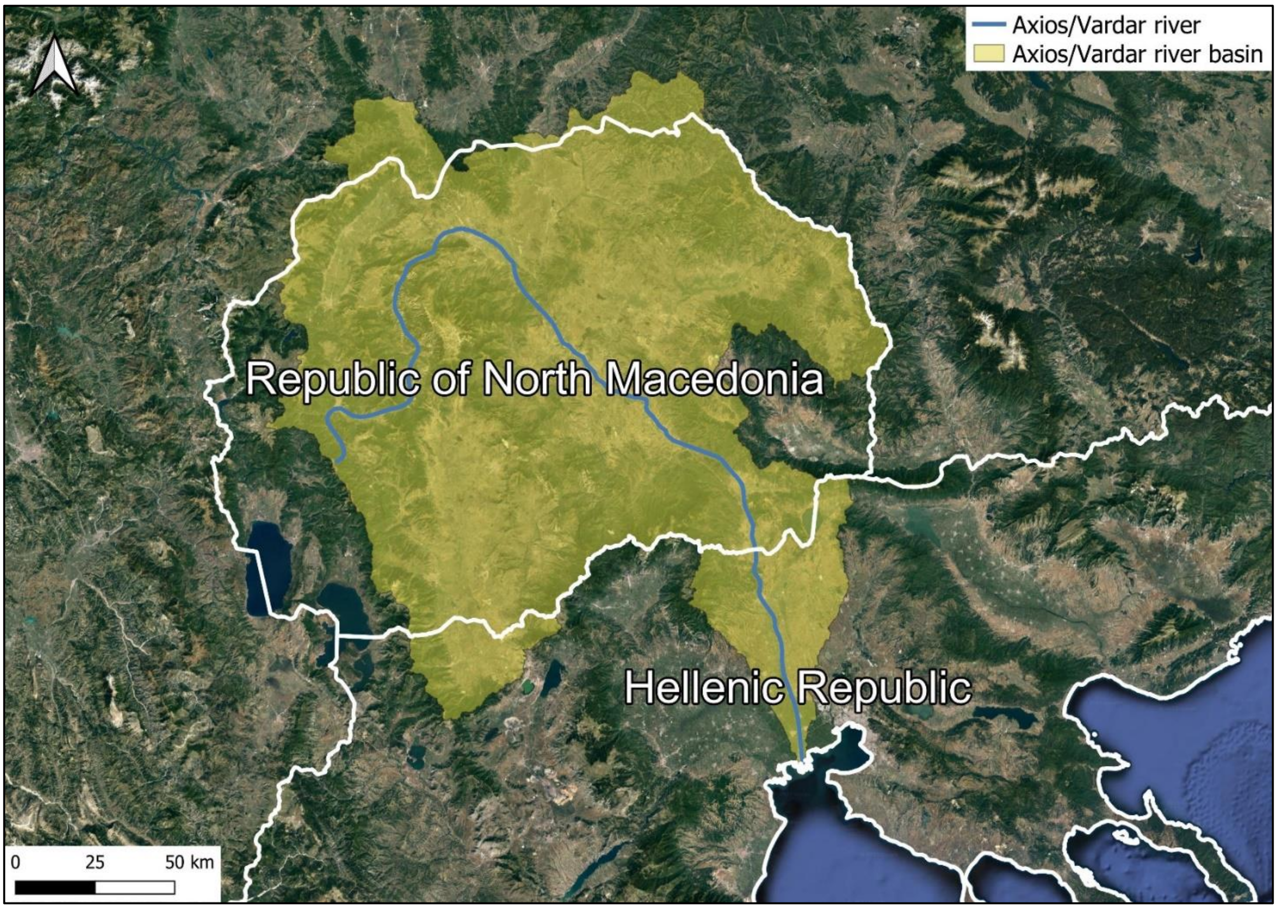
Damage functions can be developed through empirical approaches that use historical data to develop the relationship between flood characteristics and damage. The empirical approach has been used in multiple studies and relies on the availability of reliable historical flood damage data. If such empirical data exist, they should be used, even in conjunction with a synthetic approach. Such damage data can be collected either by official bodies or by insurance companies. There is, however, a lack of reliable, consistent and comparable flood damage data (Elmer et al., 2010).

The other approach is described as synthetic, where expertise is used to create a database of absolute damage curves for different types of buildings. The synthetic approach does not mean that it is artificial (Messner et al. 2007). The creation of damage curves often involves the synthesis of all data, including historical data. Some authors have differed slightly on the meaning of this term. Merz et al. (2010) described this approach as developing by applying "what-if" scenarios and argued that the synthetic and empirical approaches can be combined, while Penning-Rowsell et al. (2010) see it as a synthetic approach, with the empirical and synthetic approaches being mutually exclusive.

The method used herein is Balica's vulnerability index (FVI) (Balica et al., 2009), which is discussed in detail in Chapter 5.

3 Analysis area

The Axios/Vardar River has a catchment area of 24.397 km^2. Parts of its basin are located in Serbia, Kosovo, Greece and North Macedonia. Its estuary is located in Greece, in the Thermaikos Gulf, where it has been moved westwards by an engineering project. The work of diverting the estuary lasted from 1928 to 1934 and was aimed at preventing the port of Thessaloniki from being blocked by the large number of debris carried downstream by the river.



Picture 3: *Map of the catchment area of the cross-border river Axios/Vardar.*

3.1 Basin of the Greek part of the Axios River

The Axios River Basin (EL1003) belongs to the Region of Central Macedonia, Greece. It consists of the catchment areas of the Axios and Loudia rivers. It is located in Central Macedonia Water District (EL10) and extends from the Greek-Northern Macedonia border to the coast of the Region, west of the Thermaikos Gulf. The river basin is characterized by high altitudes (over 1.000m) at its north-western (Mount Paiko) and northern (Mount Kerkini) extremities and a gentle-flat morphology in the rest of its extent. Thus, more than 50% of its extent has an altitude of less than 100m and more than 75% of it less than 200m, while the average altitude of the river basin is about 180m. The total water supply in the Axios L.A.P. is 4,4x10^9m^3, of which 0,8 x10^9m^3 comes from the own resources of the EL10 Water Authority and the remaining 3,6 x10^9m^3 from the inflow of water from the neighboring North Macedonia through the river Axios.

Picture 4: *View of the river Axios at the bridge of Koufalia.*

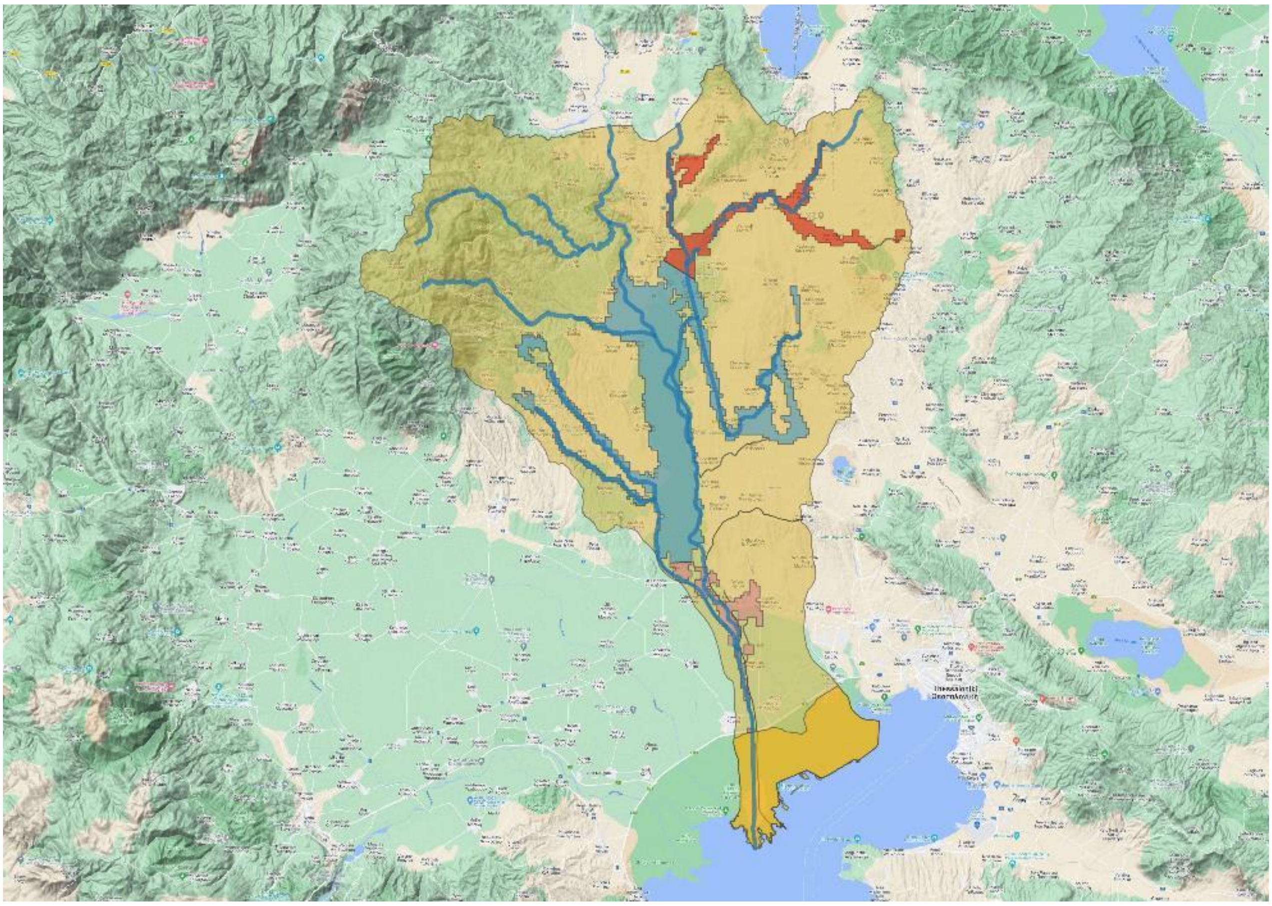
The most important use of water in the Axios river basin is irrigation. Projects for the utilization of surface water resources that have been constructed so far and cover the irrigation needs of the Thessaloniki plain are the water intake of Eleousa from the river Axios (construction started in 1954 and operation started in 1962 - annual withdrawal of 430hm^3, approx. Alyakmonas (WD EL09) through the Unitary Canal of Alyakmonas Axios (its construction started after the operation of the Polyfitos reservoir in 1976 - transferred quantity for the needs of WD EL10 is about 350hm^3 per year, of which about 300hm^3 per year for irrigation). Almost all of the approximately 1.130 km^2 of irrigated crops in the Axios river basin are served by the collective irrigation networks managed by the General Land Reclamation Organization (G.L.R.O.) of the Thessaloniki-Lagada Plain.

Other important works in river basin, which were carried out during the period 1925 - 1936, concern the drainage of the former lake of Giannitsa through the river Loudias and the former lakes of Amatovo and Arjan (where the homonymous reservoir was recently constructed), through the homonymous ditches to the river Axios.

3.2 Distinction of Regions

Five (5) potential regions for the vulnerability analysis were identified within the Axios River basin. The 5 regions were defined by the possibility of blockage of the main channel or key tributaries by debris, with the consequent impact of flooding of upstream regions. Such risk points include the Elli dam, the PATHE bridge and its upstream region, the Arjan-Ayak ditch point in Limnotopos and the upstream point of the Axios Straits (Church of St. Panteleimon of Mikrodasos). The first four (4) regions are already on the flood risk map with a recovery period of T=100 years, of the respective Flood Management Plans (MoF, 2017).

1. The delta of river Axios.
2. From the delta of river Axios to Elli dam.
3. From Elli dam to the region of Polykastro.
4. From Polykastro to the upper eastern parts of the river basin
5. The Evzoni valley on the border with the Republic of North Macedonia



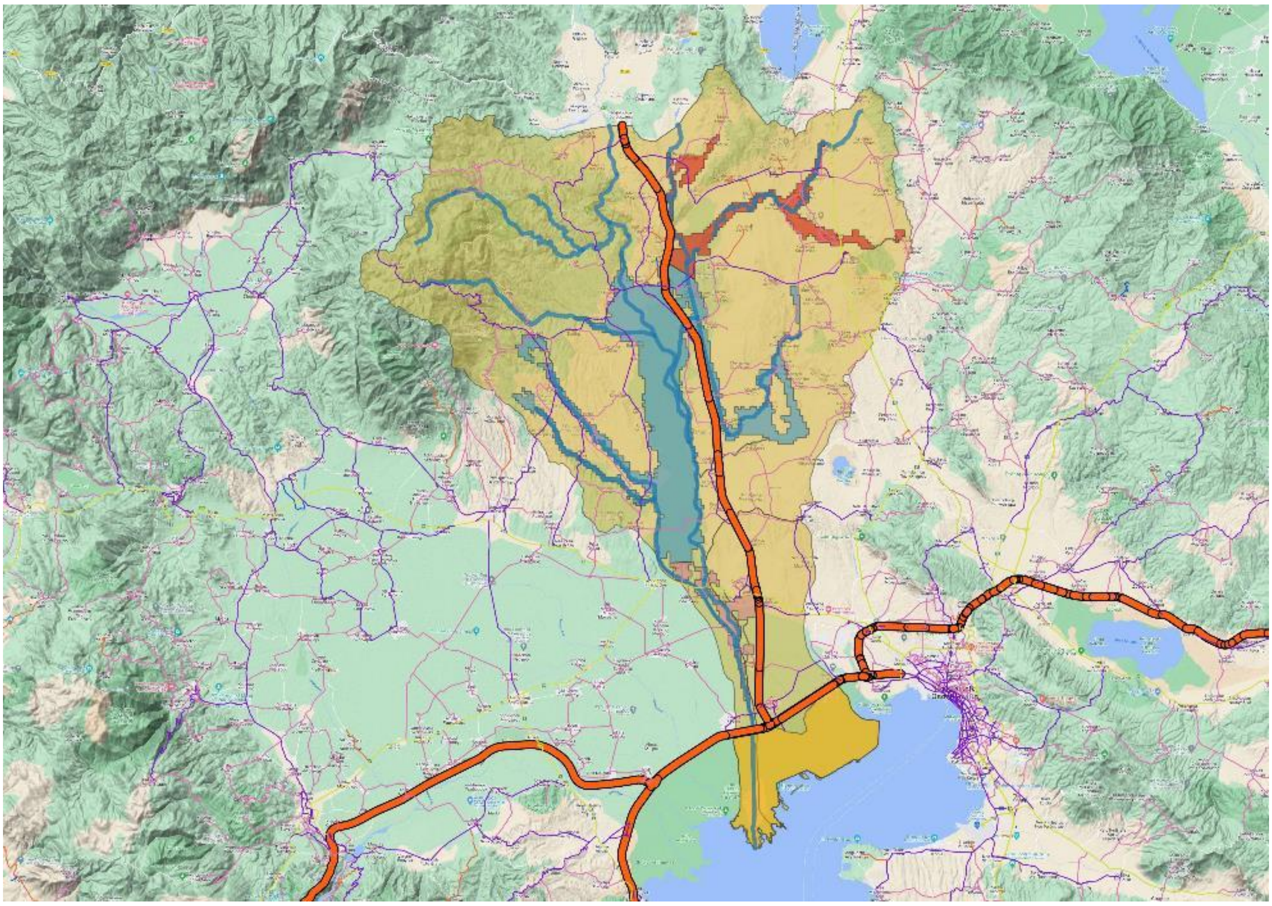
Picture 5: *The Greek part of the Axios catchment region. The different colors correspond to the different sub-basins. The river Axios and its tributaries are distinguished by a strong blue line.*

3.3 Characteristics of the Study Area

Vulnerability analysis concerns data on population, land cover, infrastructure, industry, existence of cultural monuments, etc. The main characteristics of the 5 regions are presented in the table below.

Table 1: *Elements of the selection criteria.*

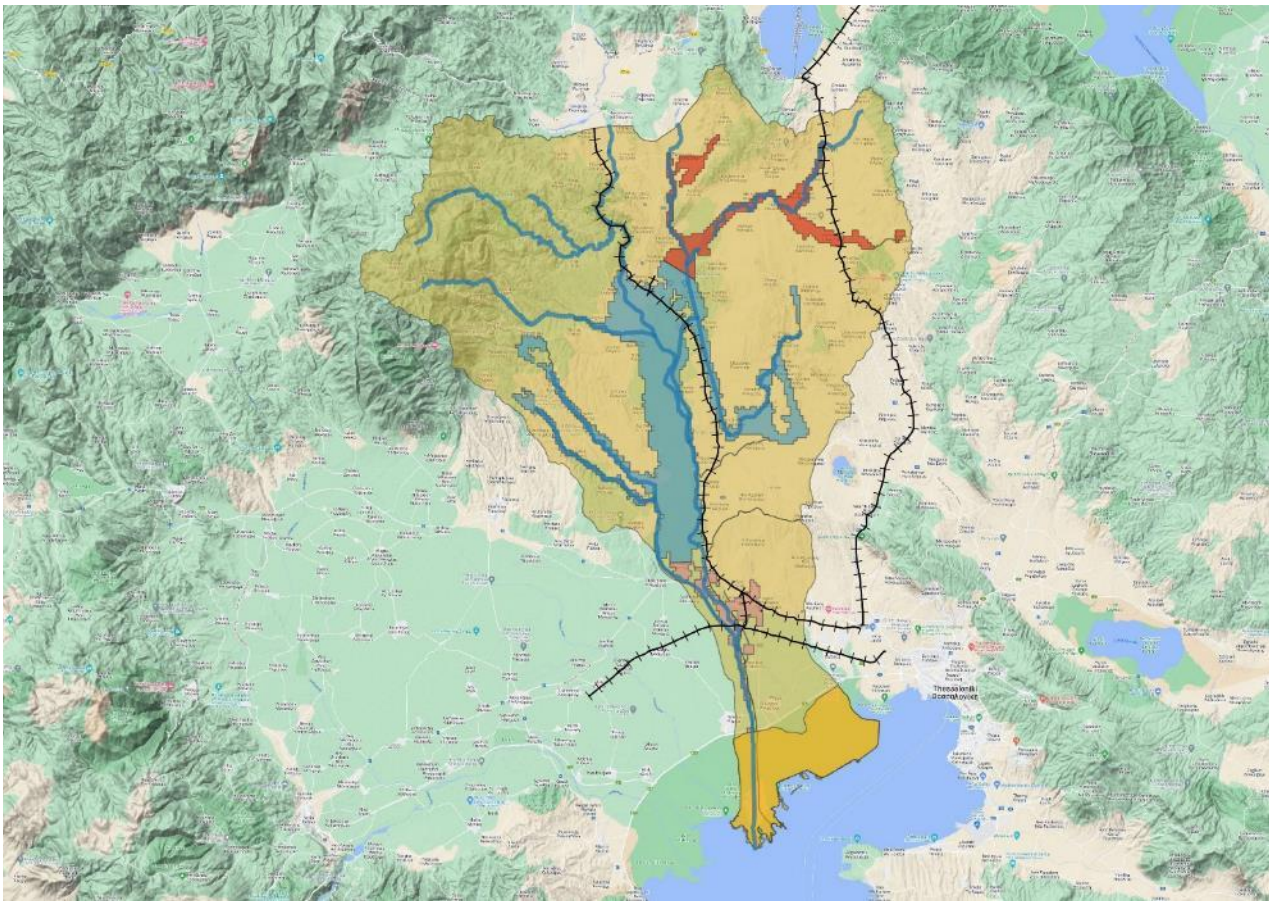
REGION	POPULATION	AREA COVERAGE (ha)			INFRASTRUCTURES	INDUSTRY	CULTURAL MONUMENTS
		FORESTS AND SEMI-FOREST AREAS	AGRICULTURAL AREAS	ARTIFICIAL SURFACES			
DELTA	0	137	9.941	139	NO	NO	NO
DOWNSTREAM OF ELI'S DAM	2.829	0	79.220	293	YES	YES	NO
UPSTREAM OF ELI'S DAM	5.106	65.225	103.049	2.233	YES	YES	YES
BORDER REGION	837	1.159	121.624	1.303	YES	YES	YES
EVZONI	0	97	785	15	YES	NO	NO



Picture 6: *Thematic map of infrastructure related to road network within the study area.*

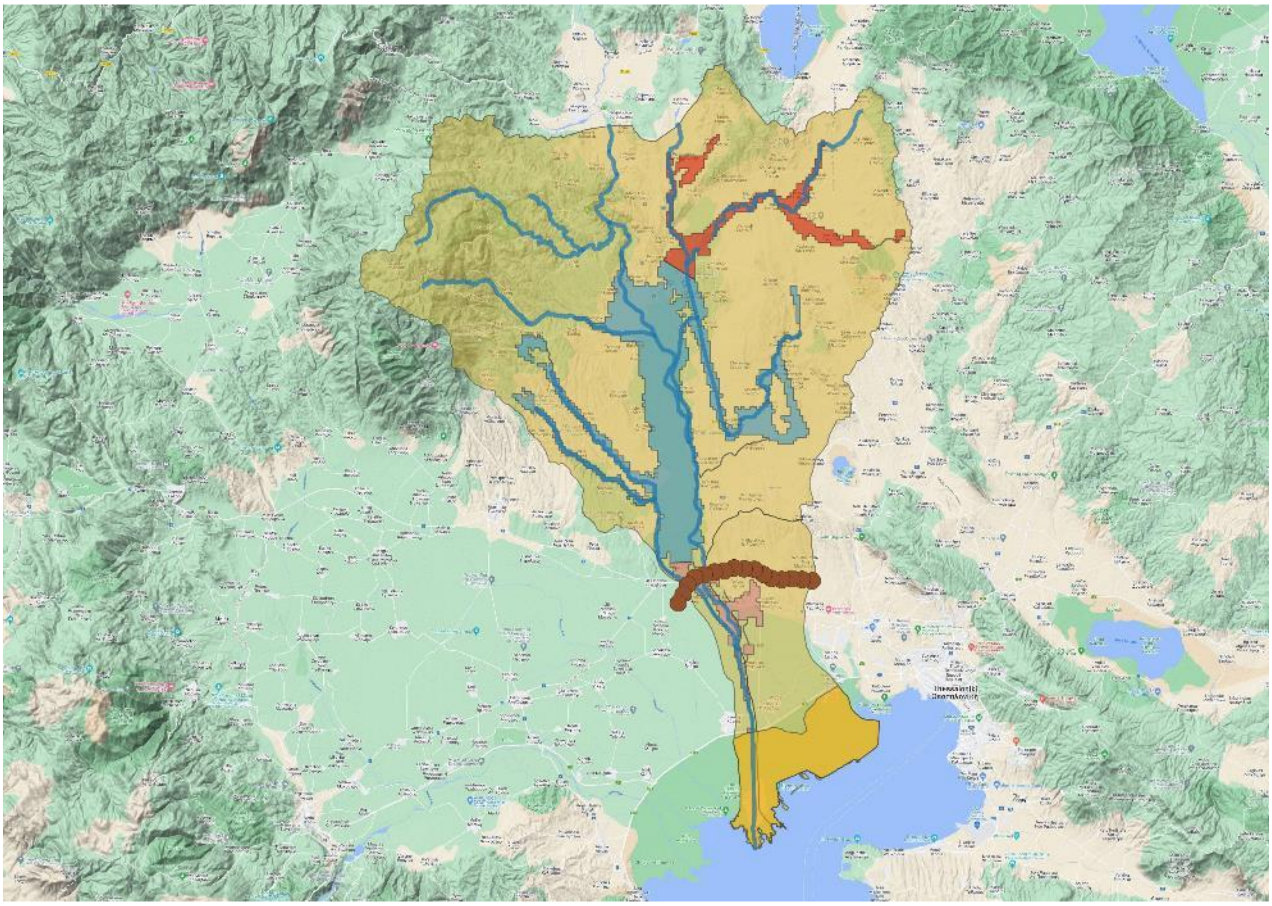
As there are no significant settlements at risk of flooding in the most upstream and most downstream regions (Evzoni, Delta), further analysis concerns the remaining regions.

Regarding the infrastructure related to the road network of the study area, the whole region is crossed by the P.A.TH.E. motorway (Patras-Athens-Thessaloniki-Evzoni), while downstream, in the region of the delta of the river Axios, it is crossed by the Egnatia Highway. In addition, the main roads are located in the central part of the region, upstream and downstream of Elli dam.



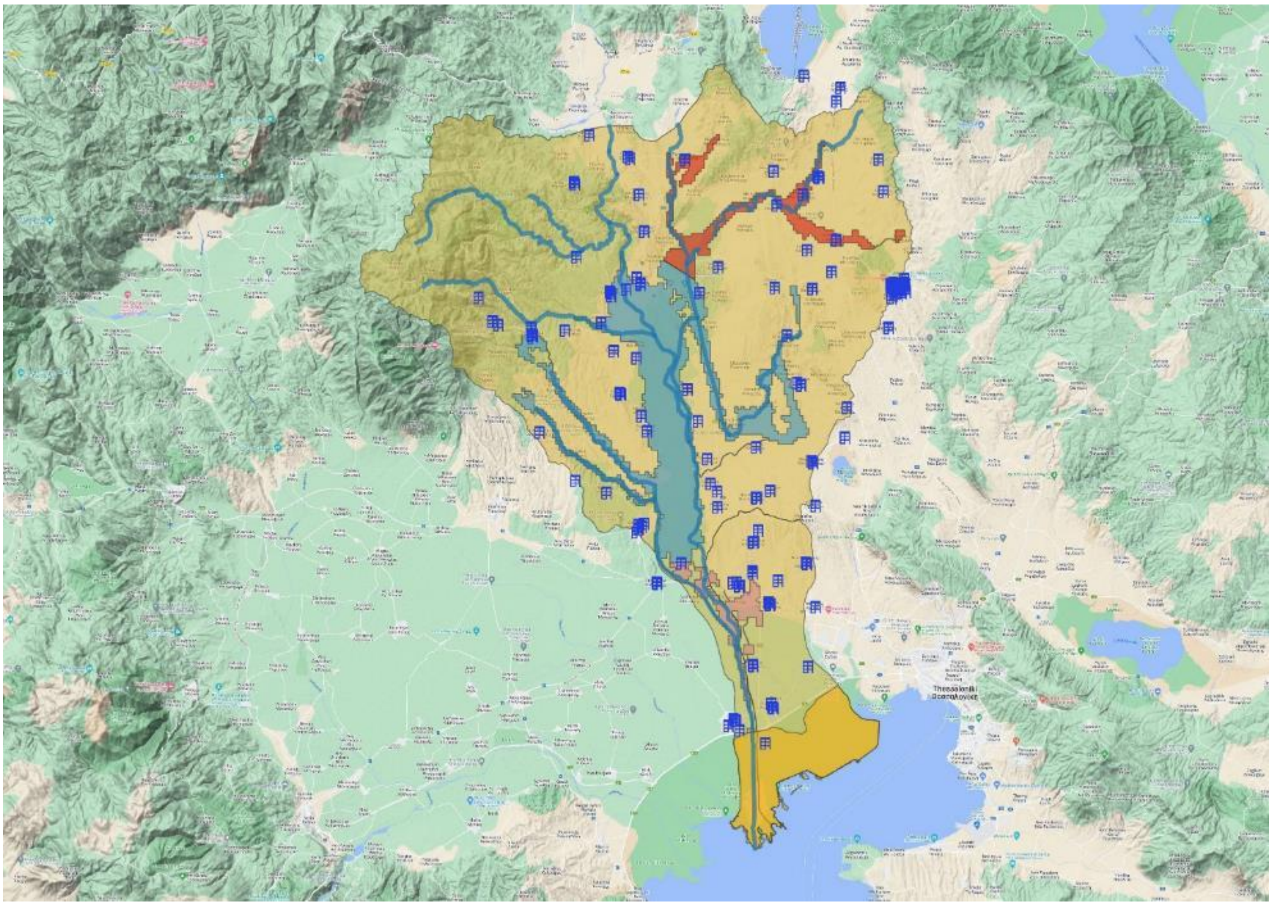
Picture 7: *Thematic map of rail network infrastructure passing through the study area.*

Alongside the P.A.TH.E. motorway, the railway network that crosses the study area can be seen. This network is mainly concentrated in the central part of the region with additional sections near the Elli dam.



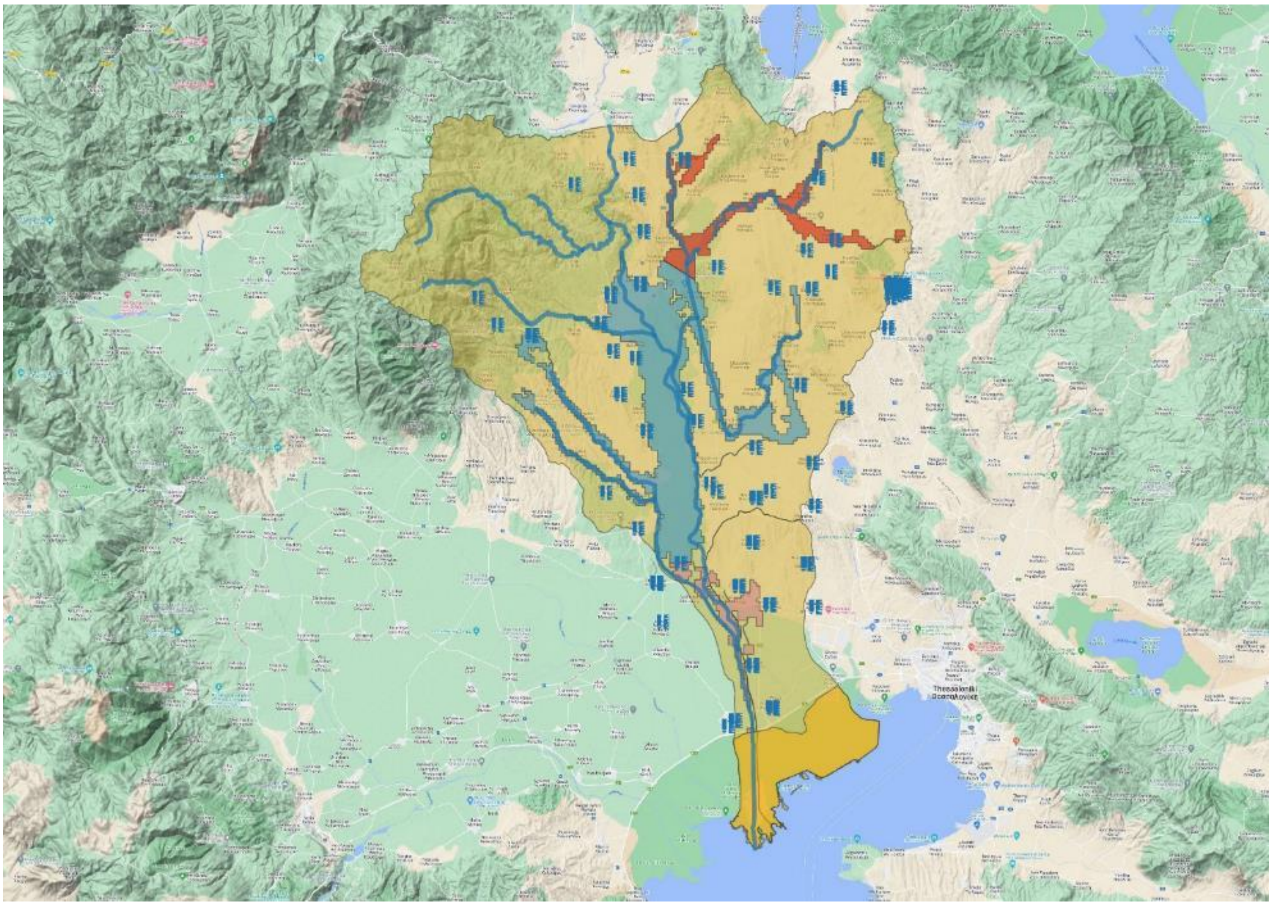
Picture 8: *Thematic map of the section of the Adriatic Gas Pipeline route (brown) passing through the study area.*

The Adriatic Gas Pipeline crosses the study area downstream of Elli dam.



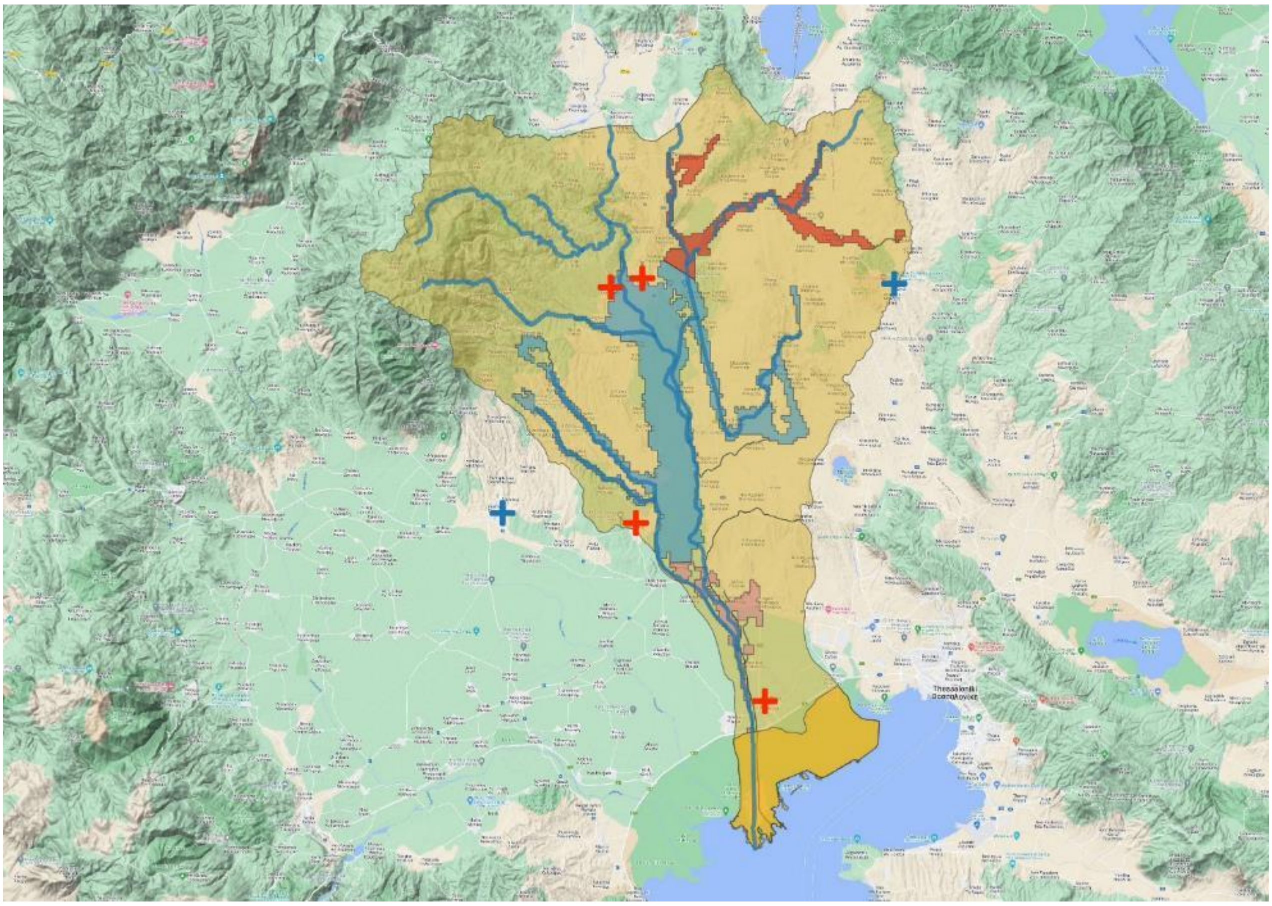
Picture 9: *Thematic map of public buildings within the study area.*

Regarding the public buildings in the study area, they are all located around the perimeter of the flood risk zones, most of them concentrated in the two central regions, namely from the delta of river Axios to Elli d.am and from Elli dam to the region of Polykastro.



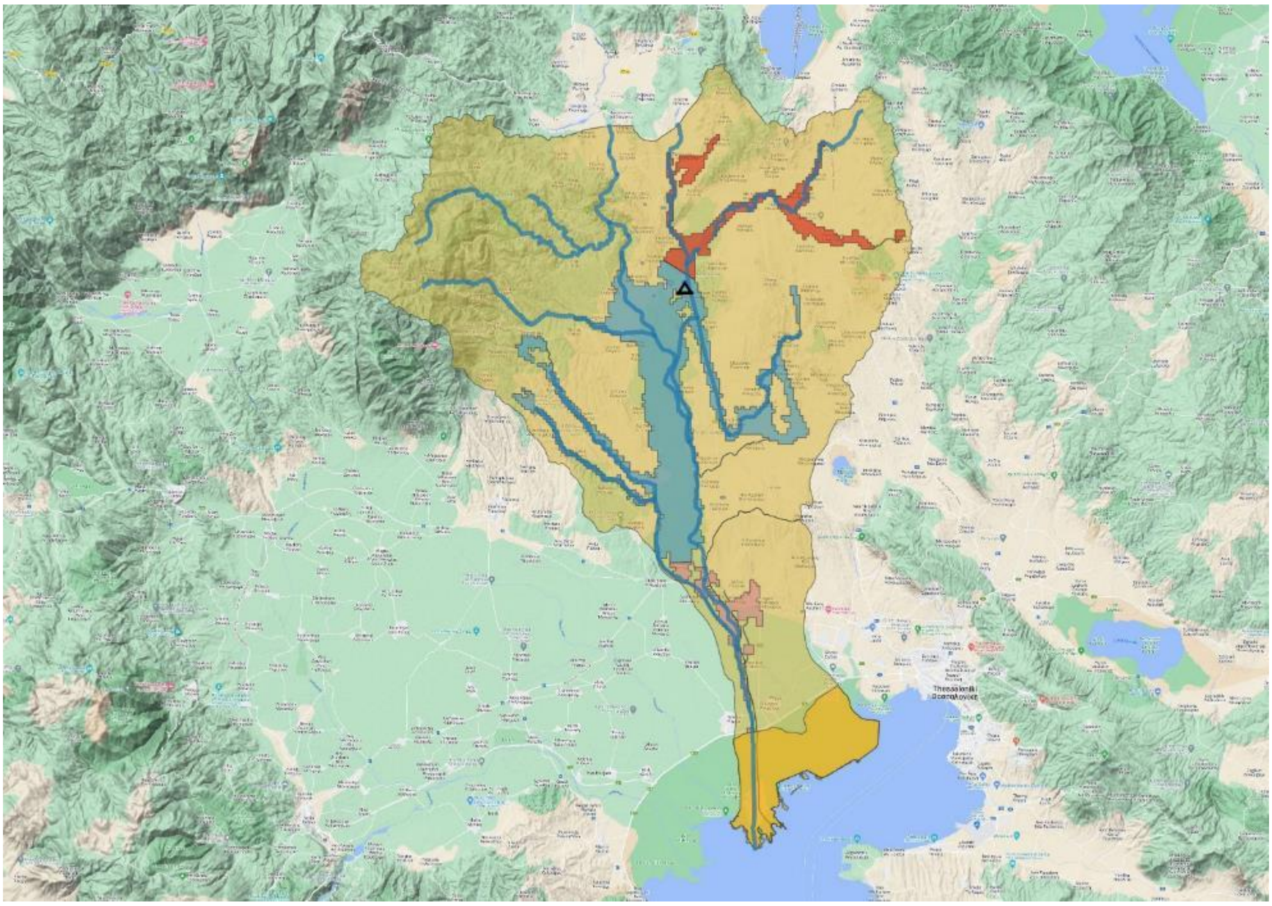
***Picture 10**: Thematic map of schools within the study area.*

Similarly to the above, as far as schools are concerned, they are all located around the perimeter of the flood risk zones, with the majority of them concentrated in the two central regions, namely from the delta of river Axios to Elli dam and from Elli dam to the region of Polykastro.



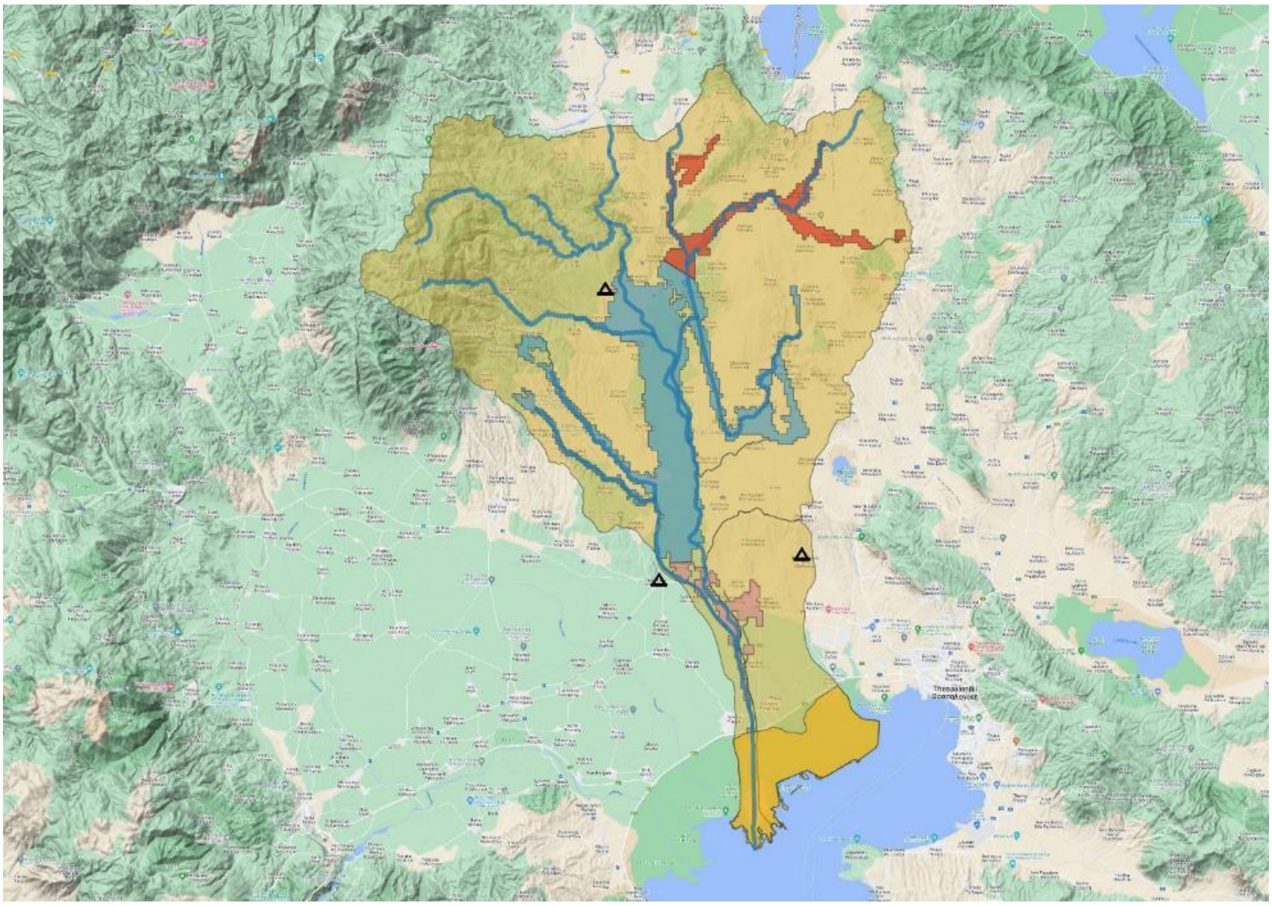
__Picture 11__: Thematic map of health centers (red) and hospitals (blue) in and near the study area.

As far as the health centers in the study area are concerned, they are mainly concentrated in the two central regions, i.e. from the delta of river Axios to Elli dam and from Elli dam to the region of Polykastro. The hospitals identified are located at long distances outside the flood risk zones.



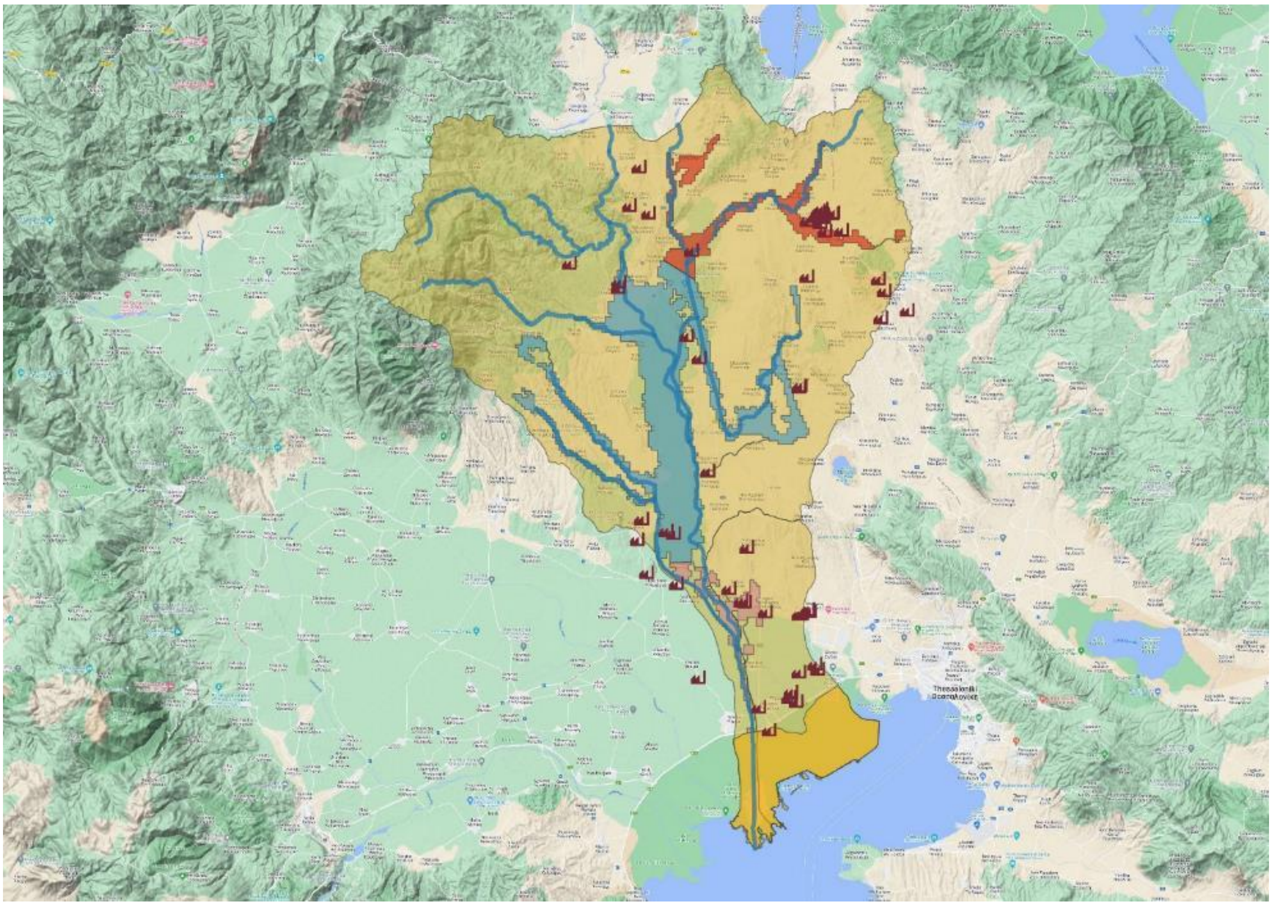
Picture 12: *Thematic map of refugee accommodation structures within the study area.*

Within the study area, one refugee shelter was identified in the region of Polykastro which is located within the candidate region for vulnerability analysis upstream of Elli dam up to the region of Polykastro.



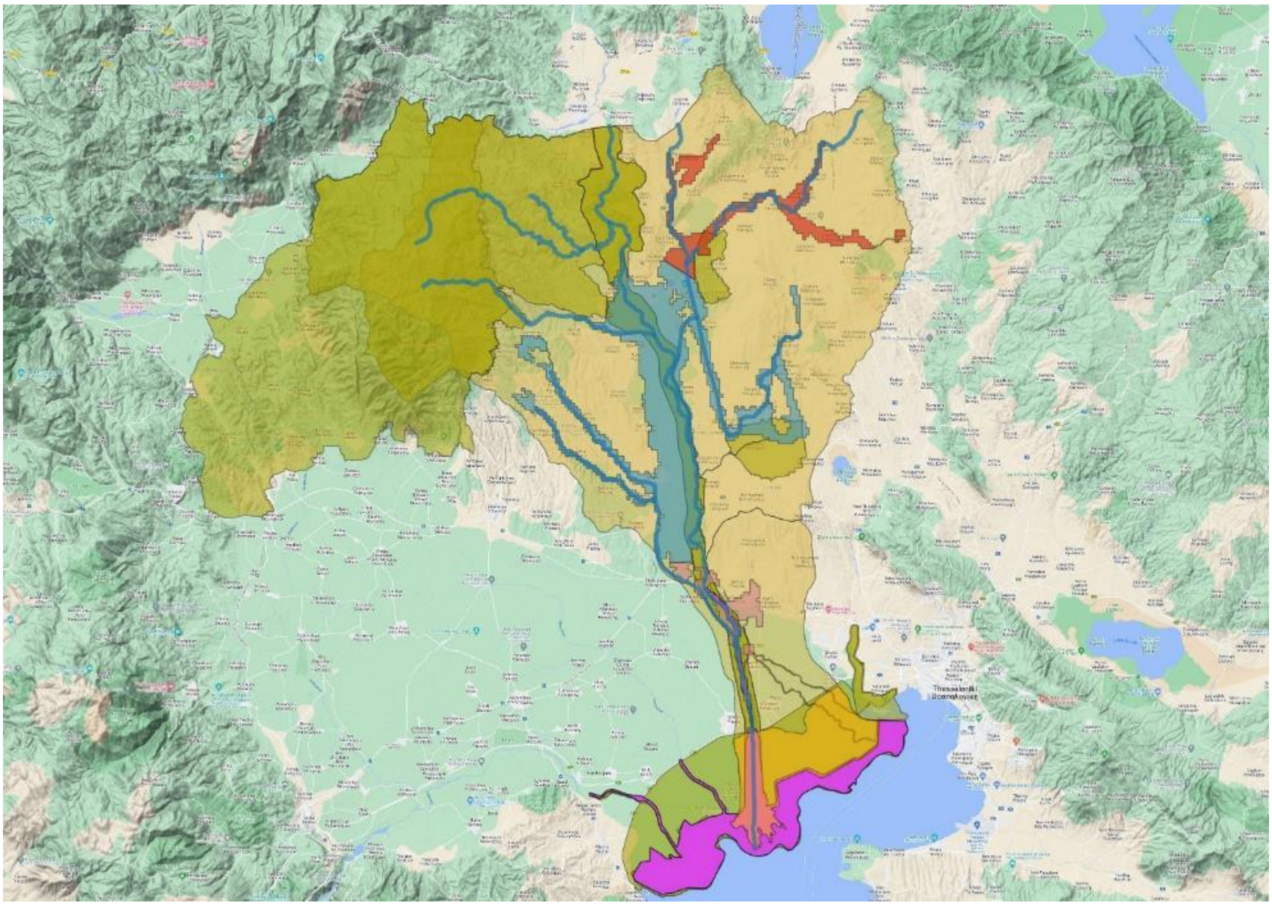
Picture 13: *Thematic map of Roma settlements within the study area.*

In addition, three Roma settlements were identified in the study area, which are concentrated in the central part of the study area, namely from the delta of river Axios to Elli dam and from the dam to the region of Polykastro.



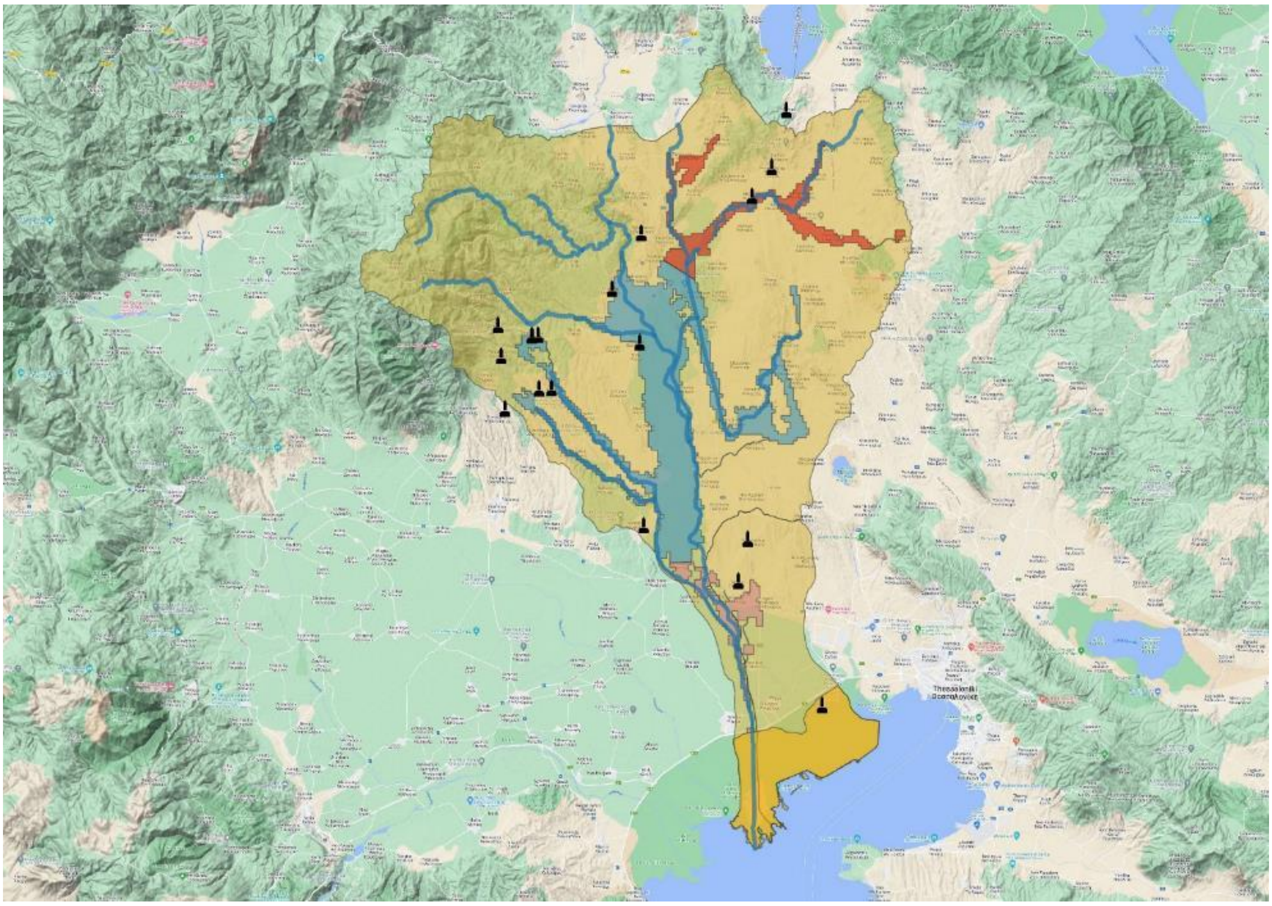
Picture 14: *Thematic map of industries within the study area.*

Regarding the industries within the study area, the highest concentration of these within the flood risk zones is upstream of the Delta region and downstream of Elli dam. In addition, a large concentration of industries is located upstream, in the region between the villages of Eleftherochori and Stavrochori, but these are not within the flood risk zones.



Picture 15: *Map of NATURA 2000 sites (green) and Ramsar sites (purple) within the study area.*

Most of the study area includes all or parts of the protected regions of NATURA 2000 and more specifically GR1220002 (Axios Delta - Loudias - Aliakmonas - Greater Region - Axioupolis), GR1220010 (Axios Delta - Loudias - Aliakmonas - Aliki Kitros), GR1230005 (Artzan Marsh Region), GR1230006 (Anthophytos Region), GR1240003 (Mount Paiko), GR1240009 (Mount Paiko, Apsalos and Moglenitsa Straits). Within the regions GR1220002 (Axios Delta - Loudia - Aliakmonas - Greater region - Axioupolis) and GR1220010 (Axios Delta - Loudia - Aliakmonas - Aliki Kitros), the Ramsar site GR59 (Axios, Loudias, Aliakmon Delta) is included. It is noted that the species concerned in these regions are wetland species as a whole and do not face problems in case of flooding, therefore they will not be taken into consideration in the vulnerability analysis.



***Picture 16**: Thematic map of protected monuments within the study area.*

Finally, regarding the protected monuments within the study area, they are mostly located in the two central regions, namely from the delta of river Axios to Elli dam and from Elli dam to the region of Polykastro.

4 Analysis methodology

4.1 The Vulnerability Index

The Flood Vulnerability Index (FVI) aims to identify hotspots associated with flood risk in different regions of the world so that it can be used as a tool to assist planners and policy makers in prioritizing their areas of intervention and can also be used as a means of providing useful information for awareness raising. The main idea is to identify different characteristics of a system, making it applicable to flooding at different spatial scales.

In the present implementation, an indicator based FVI is calculated to assess the conditions causing flood damage at different spatial scales. The methodology is based on indicator sets for the four (4) different vulnerability factors for river and urban flooding (social, economic, environmental and physical).

The methodology identifies different characteristics for each spatial scale identified, allowing for a more in-depth analysis and interpretation of local indicators. It also allows the selection of actions to reduce the vulnerability of local flooding.

The general equation of FVI is: $FVI = \frac{E \times S}{R}$, whereas E = exposure, S = susceptibility and R = resilience.

This equation links the values of all indicators to flood vulnerability data and factors (exposure, sensitivity and resilience), without balancing or interpolation from a data set. The use of this equation allows comparisons between different geographical scales, as the result of the calculation is dimensionless. Dimensionless results are necessary for comparing FVI for similar data and scales for different case studies.

The dimensionless FVI equations are developed using fractions with indices as part of a numerator or denominator, depending on their effect on flood vulnerability.

Indexes representing exposure and sensitivity increase flood vulnerability and are therefore placed in the numerator. Resilience indicators reduce flood vulnerability and are instead part of the denominator.

4.2 Individual Indexes

The equations below (Balica, 2009) reflect the vulnerability of a selected geographical region, constrained by catchment divisions rather than administrative boundaries.

- Flood vulnerability index for social component at sub-basin scale: $$FVI_S = FVI_S\left[\frac{P_{FA}, R_{Pop}, \%_{disable}, C_m}{P_E, A/P\,, C_{PR}, W_S, E_R, HDI}\right]$$

- Flood vulnerability index for economic component at sub-basin scale:

$$FVI_{Ec} = FVI_{Ec}\left[\frac{L_U, U_M, I_{neq}, U_A}{L_{EI}, F_I, AmInv, \frac{S_C}{V_{year}}, E_{CR}}\right]$$

- Flood vulnerability index for environmental component at sub-basin scale:

$$FVI_{En} = FVI_{En}\left[\frac{R_{ainfall}, D_A, U_G}{L_U, E_V, N_R, U_{npop}}\right]$$

- Flood vulnerability index for physical elements at sub-basin scale:

$$FVI_{Ph} = FVI_{Ph}\left[\frac{T}{\frac{E_V}{R_{ainfall}}, \frac{S_C}{V_{year}}, D\_L}\right]$$

The indexes take values from 0 to 1. The overall use of the indicators is summarized in the following table.

Table 2: *Flood vulnerability interpretation (Balica, 2012).*

Index Value	Description
< 0,01	Very small vulnerability to floods
0,01 – 0,25	Small vulnerability to floods
0,25 – 0,50	Vulnerable to floods
0,50 – 0,75	High vulnerability to floods
0,75 – 1,00	Very high vulnerability to floods

The individual parts of the FVI index indicate, in a comparison, the sensitive/weak points of each geographical region corresponding to the points to be selected. In this way, guidelines can be attempted to prevent and mitigate the effects of a catastrophic flood in order to minimize damage.

4.3 Data and Assumptions

The above equations require feeding the following data:

- Population in regions of potential flooding (P_{FA}): It refers to the number of residents in the potential flood regions. A larger population is associated with an increase in vulnerability.
- Rural population (R_{Pop}): It refers to the number of people working outside the urban area in regions of potential flooding. A larger population is associated with an increase in vulnerability.
- Percentage of disabled people ($\%_{disable}$): It refers to the percentage of the population permanently residing in the potential flood regions and having a disability. This indicator includes the population aged less than 12 years and

more than 65 years. A higher proportion of the population is associated with an increase in vulnerability.

- Early warning system (W_S): This refers to the existence or not of an Early Warning System (EWS) and is set to 1 if there is no EWS or 10 if there is an EWS. The existence of such a system implies a reduction in vulnerability.
- Human Development Index (HDI): The Human Development Index represents the average of the following indicators:
  - Life Expectancy Index: $LEI = \frac{LE-25}{85-25}$
  - Education Index: $EI = \frac{2}{3}ALI + \frac{1}{3}GEI$
    - Adult Literacy Index: $ALI = \frac{ALR}{100}$
    - Gross Enrollment Index: $GEI = \frac{CGEI}{100}$
  - GDP Index: $GI = \frac{\log(GDPpc) - \log(100)}{\log(40000) - \log(100)}$
  - *Explanatory notes:*
    CGEI (Combined gross enrolment index): Combined gross enrollment index. Note that this indicator may exceed 100% due to the inclusion of pupils of older or younger age who enter school early or late and/or repeat classes in school
    GDPpc (GDP per capita at PPP in $): Gross domestic product per capita at purchasing power parity.
- Awareness/Preparedness (A/P): It takes values from 1 to 10, with 10 being the lowest vulnerability, according to the table below:

Table 3: *Scale for awareness & preparedness indicator.*

Score	Indication
1	The population has no concern with floods
2	The population has not experienced floods in recent times
3	The population has little experience with floods; they have not created institutions for flood mitigation. Population does not realize the effects of their actions towards flood protection
4	The population has little experience with floods; institutions have neglected their responsibilities. Population does not realize the effects of their actions towards flood protection and are not prepared for emergency situations
5	The population has experienced floods a long time ago, so that institutions still exist, population is not aware of these institutions; budget is enough, there is no flood insurance
6	The population has experienced floods; they have recently created institutions to mitigate the harms of floods, budget is scarce, awareness and preparedness

Score	Indication
	is in process of being raised
7	The population has experienced floods for a long time; they have created and have little trust in institutions to mitigate the harms of floods, population has limited concern over their actions towards flood protection and are not quite prepared for emergency situations
8	The population has experienced floods for a long time; they have created and have some trust in institutions to mitigate the harms of floods, there is no flood insurance, population understand the consequences and restrictions of their actions, they are prepared for certain emergency situations
9	The population has experienced floods for a long time; they have created and trust in institutions to mitigate the harms of floods, limited flood insurance, population understand the consequences and restrictions of their actions, they are prepared for emergency situations
10	The population has experienced floods for a long time (know the potential for floods in the area); they have created and have high trust in institutions to mitigate the harms of floods, they have flood insurances, they understand the consequences and restrictions of their actions towards flood protection, they are prepared for emergency situations

- Past experience (P_E): It refers to the number of people affected by flooding in the last 10 years. A higher population value implies a reduction in vulnerability.
- Infant mortality index (C_m): It refers to the number of deaths of children under one (1) year of age per 1000 births. A higher rate implies an increase in vulnerability.
- Evacuation roads (E_R): It refers to the percentage of paved roads. Higher road quality implies a reduction in vulnerability.
- Communication penetration rate (C_{PR}): It refers to the percentage of households with direct access to information sources. A higher percentage implies a reduction in vulnerability.
- Land use (L_U): Refers to the percentage of land uses categorized as industrial, agricultural or any type of economic activity. In this case, a higher percentage implies an increase in vulnerability. In addition, this data also refers to the percentage of land use classified as forest land. In this case, a higher percentage implies a reduction in vulnerability.
- Unemployment rate (U_M): It refers to the percentage of people not working in the regions of potential flooding. A higher percentage implies an increase in vulnerability.
- Inequality index (I_{neq}): It refers to the Gini coefficient, which represents a measure of statistical dispersion intended to represent the distribution of

income or wealth of a nation's inhabitants. It takes a value from 0 to 1, where a value of 1 means low vulnerability.

- Percentage of urbanized area (U_A): It concerns the percentage of urbanized land. A higher percentage implies an increase in vulnerability.
- Flood insurance (F_I): It concerns the number of flood insurance policies. A higher number implies a reduction in vulnerability. In case there is no recorded insurance, it is assigned the value 1.
- Amount invested in flood protection works (AmInv): Percentage of investment in flood protection projects to total Gross Domestic Product. A higher share of investment implies a reduction in vulnerability.
- Storage capacity over yearly discharge (S_C/V_{year}): It refers to the storage capacity of the dams to the annual runoff volume. Greater storage capacity implies a reduction in vulnerability.
- Economic recovery index (E_{CR}): It takes values from 10 to 100, incremented by 10, with 100 being the lowest vulnerability, according to the table below:

Table 4: *Economic recovery scale.*

Score	Indication
10	All economic activities are strongly damaged and they may not recover for years
20	The most representative economic activity is strongly damaged but will recover after a long period of time (years)
30	The most representative economic activity is damaged but will recover after some time (months)
40	The most representative economic activity is slightly damaged but will recover after a short period of time (weeks)
50	Some economic activities are strongly damaged, they will recover after a large period of time (years)
60	Some economic activities are damaged, they will recover after some time (months)
70	Some economic activities are slightly damaged, they will recover after a short period (weeks)
80	Some small non-representative economic activities are very damaged, because of this they may recover only after a long time
90	The economy us damaged slightly in some non-representative economic activities, which will recover in little time
100	The economic activities of the region; agriculture, industry, commerce, etc., are almost not affected by floods, neither on the short term or on the long term

- Urban growth (U_G): It refers to the rate of urban growth over the last 10 years. Rapid urban growth is likely to lead to low-quality buildings and therefore to an increase in vulnerability.

- Degraded areas (D_A): It concerns the percentage of deprived (arid) areas. A higher percentage implies an increase in vulnerability.
- Evaporation rate (E_V): It refers to the annual rate of water evaporation. A higher percentage implies an increase in vulnerability.
- Natural reservation (N_R): It concerns the percentage of natural reserves (Natura 2000 sites, Ramsar sites, wildlife refuges, etc.). A higher percentage implies a reduction in vulnerability.
- Uninhabited land area (U_{npop}): It refers to the percentage of areas with a population density of less than 10 inhabitants per km^2. A higher percentage implies an increase in vulnerability.
- Topography (T): It refers to the average slope of the relief. Steeper slopes are associated with an increase in vulnerability.
- Dikes / Levees (D_L): It refers to the total length of embankments along the river. A longer total length implies a reduction in vulnerability.
- Rainfall ($R_{ainfall}$): It refers to the total mm of rainfall recorded annually. A higher rainfall record is associated with an increase in vulnerability.

5 Vulnerability Analysis

5.1 Data quotation and calculation

This chapter sets out the data necessary for the vulnerability analysis explained in chapter 5.3, lists the values to be used for the calculation of the indicators and sets out the methodology for calculating those that were not available.

Population in areas of potential flooding (P_{FA}):

This data relates to the number of residents in the potential flood regions. A higher population number implies an increase in vulnerability.

The region is part of the municipalities of Delta, Kilkis, Paionia, Pella and Chalkidonos. According to the Hellenic Statistical Authority (ELSTAT) and the population census conducted in 2021, the permanent residents of the above municipalities, as a whole, are presented in the table below.

Table 5: *Permanent residents of municipalities in the study area (ELSTAT).*

MUNICIPALITY	POPULATION
DELTA	44.935
KLKIS	45.308
PAIONIA	25.169
PELLA	57.039
CHALKIDONOS	30.030
TOTAL	**202.481**

Using GIS software, an approximate percentage of the above population residing in the potential flood regions was calculated. After the calculations, the total number of residents in the selected regions is equal to 8.772 people (4,3%) or 2.829 people in Region 2, 5.106 people in Region 3 and 837 people in Region 4 (percentages of 1,4%, 2,5% and 0,4% respectively).

Rural population (R_{Pop}):

This data relates to the proportion of people working outside the urban area in regions of potential flooding. A larger population is associated with an increase in vulnerability.

According to the Hellenic Statistical Authority (ELSTAT), the population exclusively engaged in agriculture in the area of interest was equal to 83.230 people in 2020, which implies a percentage of 41,11% of the total population (202.481).

Percentage of disabled people ($\%_{disable}$):

This data relates to the percentage of the population permanently residing in the potential flood regions that have a disability. The population aged less than 12 years and more than 65 years is included in this indicator. A higher percentage of the population is associated with an increase in vulnerability. Following direct contact with the municipalities in the area of interest, the following data were collected:

Table 6: *Population in need of support (people with disabilities, older age groups, etc.) in the areas of interest.*

MUNICIPALITY	POPULATION
DELTA	450
KLKIS	470
PAIONIA	200
PELLA	550
CHALKIDONOS	450
TOTAL	**2.120**

The above total refers to the total population of the municipalities, therefore, applying the percentage relating to the population located within the potential flood regions (4.3%), the total is equal to 91 people.

In addition, according to ELSTAT, in the age groups 10-19 years old and 60-69 years old, a population of 195.074 and 195,720 people respectively was recorded in 2011 in the Region of Central Macedonia. Considering that the people are equally distributed in the age groups, the information of 58.522 and 97.860 people respectively is obtained. Adding the population recorded in the 0-9 and 70+ age groups to a final total, the population recorded in the 0-12 age group was 247.267, while in the 65+ age group 378.924 people were recorded.

According to ELSTAT, the population of the Region of Central Macedonia recorded a decrease of 4,6% in the 2021 registration, compared to the 2011 registration. Thus, by reducing the above quantities, 236.393 and 362.260 people are obtained respectively. As mentioned above, the total number of people residing in the municipalities of the area of interest is equal to 202.481 people, which corresponds to 11% of the total of the Region of Central Macedonia (1.795.669).

Applying this percentage to the calculated age groups, 26.003 and 39.849 people are obtained respectively, which is the consideration of the age groups of interest residing in the municipalities containing the study area. Finally, applying to the above values the percentage of people residing in the potential flood regions (4,3%), 1.118 and 1.714 people are obtained respectively.

Following the above, the total population permanently residing in the potential flood regions and having a disability, together with the age groups 0-12 and 65+ years is equal to 2.923 people or 943 people for region 2, 1.701 people for region 3 and 279 people for region 4, which corresponds to 33,32% of the total population permanently residing in the potential flood regions or 10,75% for region 2, 19,40% for region 3 and 3,18% for region 4.

Infant mortality index **(C_m):**

This data refers to the number of deaths of children under one (1) year of age per 1.000 births. A higher rate implies an increase in vulnerability.

According to the Hellenic Statistical Authority (ELSTAT), the infant mortality rate in Greece, for the year 2021, was equal to 3,5.

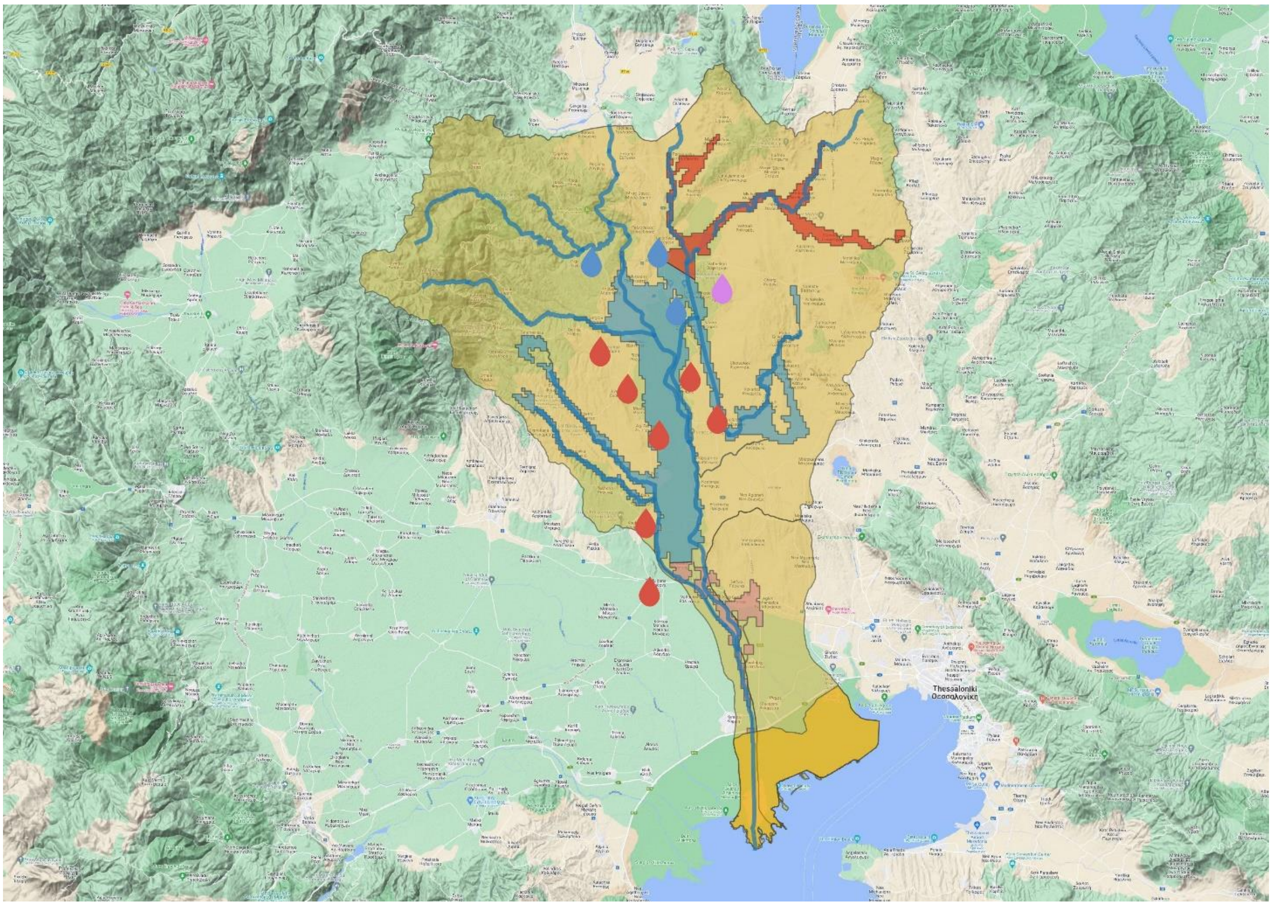
Past experience **(P_E):**

This data refers to the number of people affected by flooding in the last 10 years. A higher population value implies a decrease in vulnerability.

During the period 2013-2017, flood events were recorded in and near potential flood regions, which are depicted in the figure below using GIS software and presented in the table below. In total, 25.739 people or 2.905 people in Region 2, 15.650 people in Region 3 and 7.184 people in Region 4 were affected.

Table 7: *Locations, dates of past flood events and population.*

LOCATION OF FLOODING INCIDENT	INCIDENTS	DATE	POPULATION (2021)
Municipal Community of Axioupoli	2	04/12/2014 16/11/2017	2.834
Municipal Community of Koufalia	2	06/09/2016 16/11/2017	7.522
Municipal Community of Polykastro	2	04/12/2014 16/11/2017	6.609
Municipal Community of Chalkidona	2	05/12/2014 16/11/2017	2.905
Local Community of Agios Petros	2	05/12/2014 16/11/2017	1.291
Local Community of Axiochori	2	04/12/2014 16/11/2017	220
Local Community of Aspros	2	05/12/2014 16/11/2017	575
Local Community of Vafiochori	3	04/12/2014 23/09/2014 16/11/2017	597
Local Community of Europos	2	04/12/2014 16/11/2017	1.413
Local Community of Limnotopos	3	04/12/2014 23/09/2014 16/11/2017	1.267
Local Community of Toumba	2	16/11/2017 12/05/2015	506
		TOTAL	**25.739**



Picture 17: *Illustration of the flooding events that took place during the period 2013-2017 in and around the potential flood regions.*

Awareness/Preparedness (A/P):

This datum takes values from 1 to 10, with 10 being a lower vulnerability, according to Table 3 in Chapter 5.3.

In this case, the population has experienced flooding for a long time and institutions have been established to protect against it. There is relevant information on flooding. But it is questionable whether the population is concerned about their actions to protect themselves from floods. Also, no data on flood insurance was found. This data is therefore assigned a value of 7.

Communication penetration rate (C_{PR}):

This data refers to the percentage of households with direct access to information sources. A higher percentage implies a reduction in vulnerability.

According to the Hellenic Statistical Authority (ELSTAT), the percentage of the population using a computer and having access to the internet in Greece, for the year 2022, was equal to 83,2%.

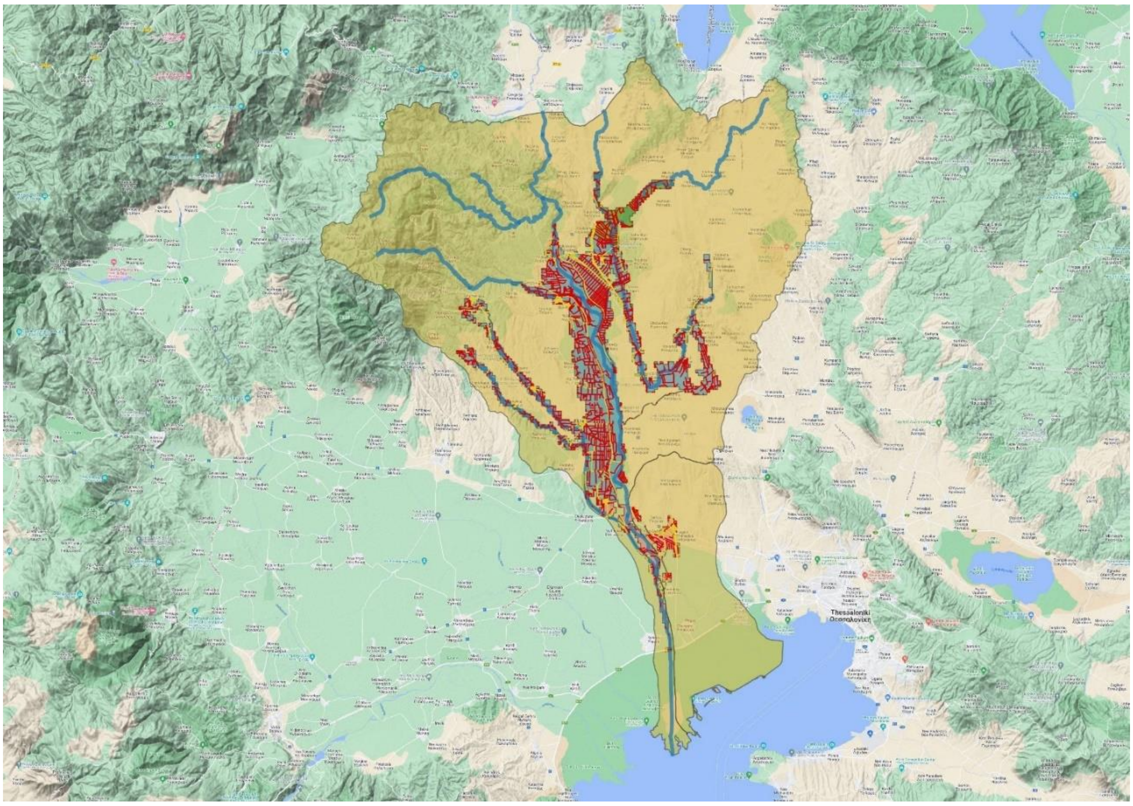
Early warning system **(W_S):**

This data refers to the existence or not of an Early Warning System (EWS) and is set to 1 if there is no EWS or 10 if there is an EWS. The existence of such a system implies a reduction in vulnerability.

The Planning and Prevention Department of the Civil Protection Directorate of the Decentralized Administration of Macedonia-Thrace provided information that there is no Early Warning System in the area of interest, therefore this data is assigned a value of 1.

Evacuation roads **(E_R):**

This data relates to the percentage of paved roads. Higher road quality implies a reduction in vulnerability.



Picture 18: *Thematic map of infrastructure related to road network within the study area. Paved roads are shown in yellow, while unpaved roads are shown in red.*

Using GIS software, the total length of road network within the potential flooding regions was recorded, which was found to be equal to 100.508,70 m for Region 2, 854.673,30 m for Region 3 and 73.576,89 m for Region 4. Of these, 50.374,38, 196.391,81 and 7.139,46 m respectively relate to paved roads. The above results in a percentage of paved roads equal to 50,12% for Region 2, 22,98% for Region 3 and 9,70% for Region 4.

Human development index (HDI):

This data relates to the Human Development Index which represents the average of the following indicators (see chapter 5.3 for explanations):

- Life expectancy index: $LEI = \frac{LE-25}{85-25} = \frac{80{,}1-25}{85-25} = 0{,}918$
- Education index: $EI = \frac{2}{3}ALI + \frac{1}{3}GEI = \frac{2}{3}0{,}980 + \frac{1}{3}1{,}01 = 0{,}990$
    - Adult literacy index: $ALI = \frac{ALR}{100} = \frac{98}{100} = 0{,}980$
    - Gross enrolment index: $GEI = \frac{CGEI}{100} = \frac{101}{100} = 1{,}01$
- Gross domestic product index: $GI = \frac{\log(GDPpc)-\log(100)}{\log(40000)-\log(100)} = \frac{\log(39478)-\log(100)}{\log(40000)-\log(100)} = 0{,}9978 \approx 0{,}998$

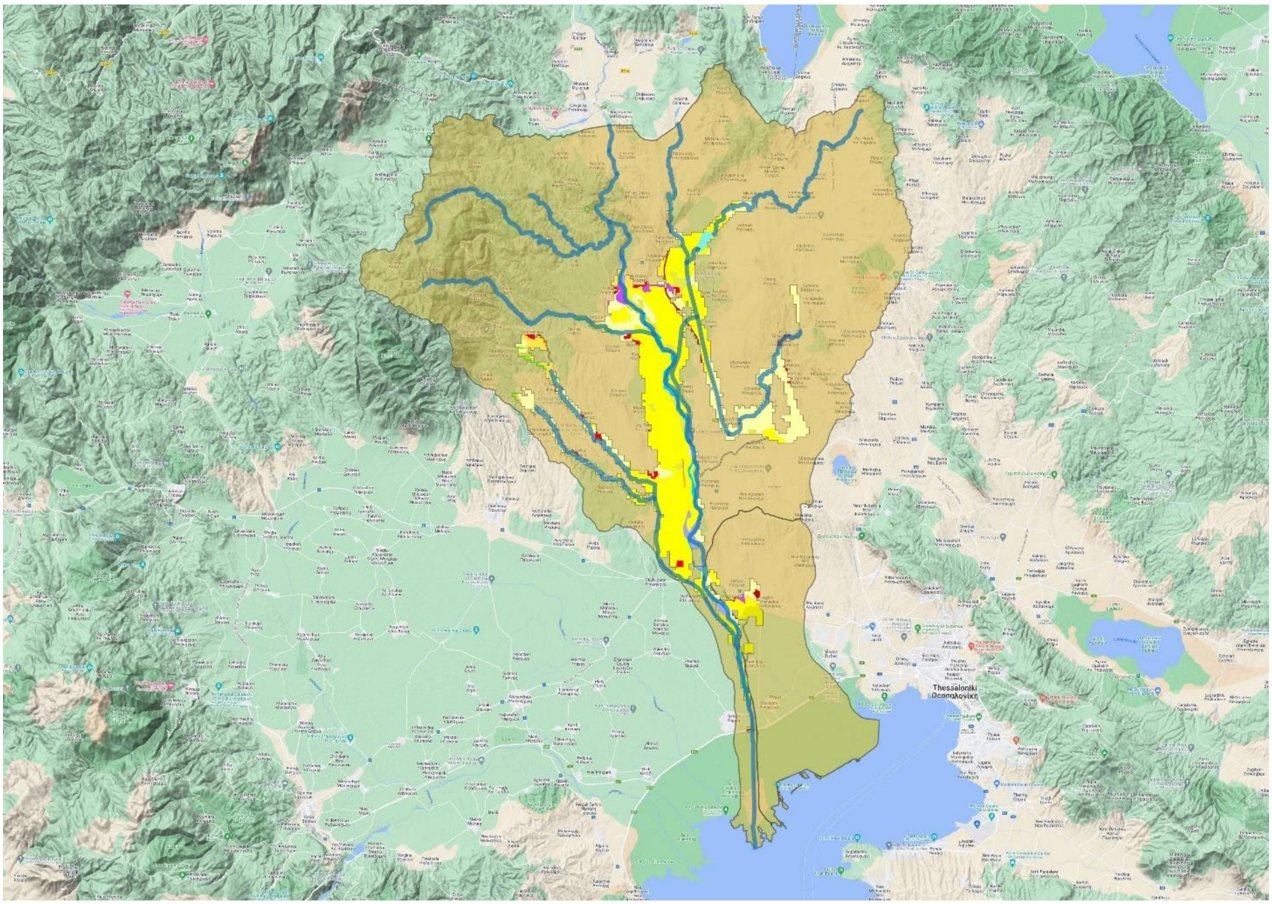
$$HDI = \frac{LEI + EI + GI}{3} = \frac{0{,}918 + 0{,}990 + 0{,}998}{3} = \frac{2{,}906}{3} = \mathbf{0{,}969}$$

In the above calculations, the following data were used:

- Life expectancy: 80,1 years (2021) (https://ec.europa.eu/eurostat/databrowser/view/tps00205/default/table?lang=en)
- Adult literacy rate: 98% (2018) (https://data.worldbank.org/indicator/SE.ADT.LITR.ZS?locations=GR)
- Combined Gross enrolment index: 101 (2020) (https://data.worldbank.org/indicator/SE.PRM.ENRR?locations=GR)
- Gross Domestic Product per capita: 39.478$ (2023) (https://en.wikipedia.org/wiki/List_of_countries_by_GDP_(PPP)_per_capita)

Land use (L_U):

This data relates to the percentage of land use classified as industrial, agricultural or any type of economic activity. In this case, a higher percentage implies an increase in vulnerability. In addition, this data also relates to the percentage of land use classified as forest land. In this case, a higher percentage implies a reduction in vulnerability.



Picture 19: *Satellite view of land use in the selected regions of interest. It can be seen that the main land use is agricultural (yellow).*

Using GIS software, a calculation of the area of the regions categorized as industrial, agricultural or any kind of economic exploitation was carried out and found equal to 2.024,42 ha for region 2, 18.692,27 ha for region 3 and 1.631,33 ha for region 4, which correspond to percentages of 80,13%, 91,08% and 88,66% respectively of the total regions (2.526,31 ha, 20.523,20 ha and 1.839,96 ha respectively).

Similarly, using the same methodology, the area of the regions classified as forest was calculated and found to be equal to 0,00 ha for region 2, 180,98 ha for region 3 and 35,34 ha for region 4. The percentage for region 3 is 0,88%, the percentage for region 4 is 1,92%, while the percentage for region 2 will be considered as 0,001% in order to minimize the impact on the indicator to which this data relates.

Unemployment rate (U_M):

This data relates to the percentage of people not working in the potential flood regions. A higher percentage implies an increase in vulnerability.

According to the Hellenic Statistical Authority (ELSTAT), the unemployment rate in Central Macedonia, for the first quarter of the year 2023, was equal to 15,3%.

Inequality index (I_{neq}):

This data refers to the Gini coefficient, which represents a measure of statistical dispersion intended to represent the distribution of income or wealth of a nation's inhabitants. It takes a value from 0 to 1, where a value of 1 means low vulnerability.

Greece's Gini coefficient according to the European Statistical Office (Eurostat) has been calculated, for the year 2022, to be equal to 31,4.

Percentage of urbanised area (U_A):

This data relates to the percentage of urbanised land. A higher percentage implies an increase in vulnerability. The total land use in the area of interest is shown in Figure 15.

Using GIS software, a calculation of the area of urbanized areas was carried out and found equal to 38,38 ha for region 2, 311,20 ha for region 3 and 0,00 ha for region 4, which correspond to percentages of 1,519% and 1,516% respectively of the total regions (2.526,31 ha and 20.523,20 ha respectively), while the percentage of region 4 will be considered 1% in order to affect as little as possible the indicator to which this data relates.

Flood insurance (F_I):

This data relates to the number of flood insurance policies. A higher number implies a reduction in vulnerability. In case there is no recorded insurance, it shall be assigned the value 1.

Following telephone calls to insurance companies, it has been impossible to collect information concerning flood insurance, as it is considered a secondary insurance compared to e.g., fire insurance, therefore also from a security point of view, this data item is assigned a value of 1.

Amount invested in flood protection projects (AmInv):

This data refers to the percentage of investments made in flood protection projects as a proportion of the total Gross Domestic Product. A higher share of investment implies a reduction in vulnerability.

The amount spent on flood protection works in the area of interest was estimated at around €100,000,000. The Gross Domestic Product of the country was in 2021 equal to 196,769 billion €.

Therefore, the rate of investment in flood protection works in the area of interest equals to $\frac{100.000.000}{196.769.000.000} = 0{,}0005$ or **0,05%**.

Storage capacity over yearly discharge (S_C/V_{year}):

This data relates to the storage capacity of the dams to the annual runoff volume. Higher storage capacity implies a reduction in vulnerability.

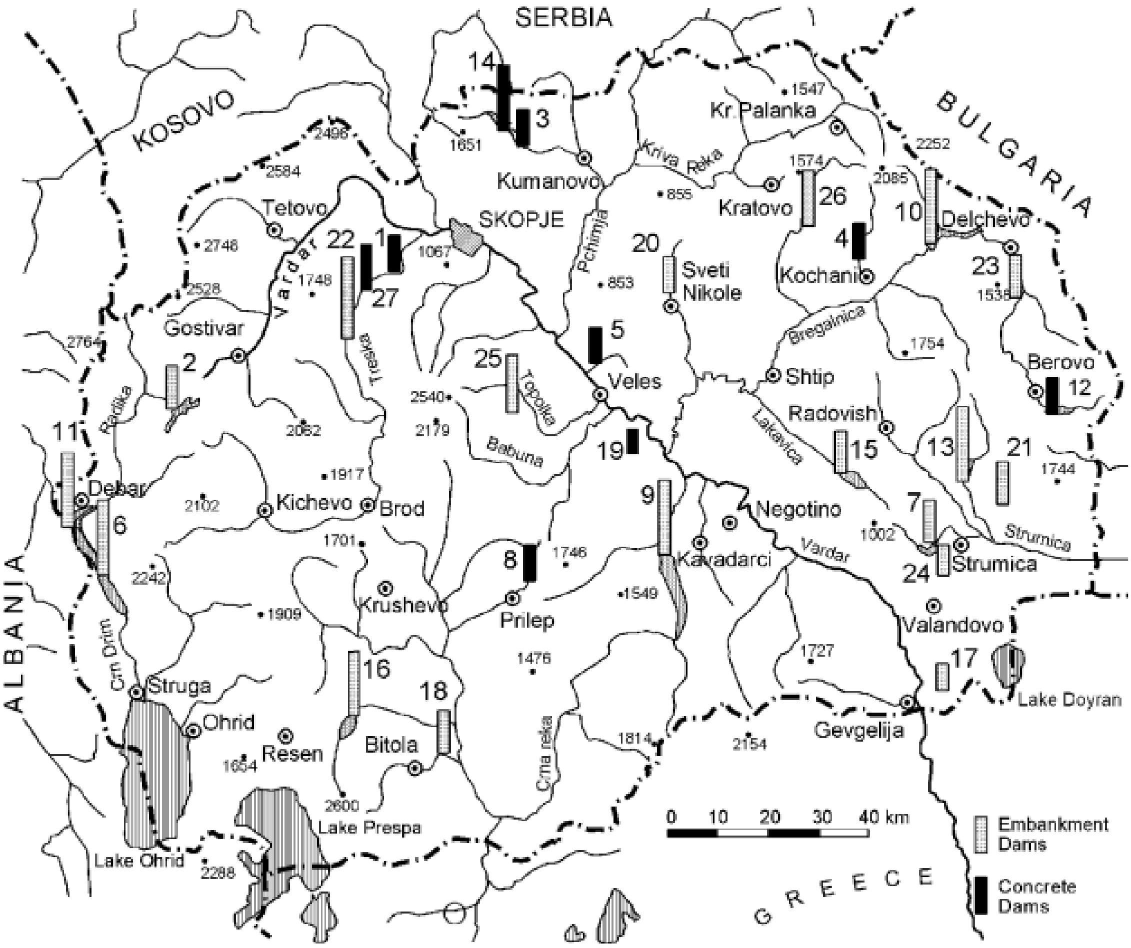
A hydroelectric dam does not have a very large water storage capacity, as to perform its purpose, the dam must have at least some water volume. Similarly, irrigation dams operate for about 6 months of the year, starting with very low available water supplies in October and reaching the end of winter with usually high reservoir fullness. Therefore, to assume that in spring the irrigation dams have the capacity to store flood volumes of water would not be correct. On the contrary, water supply dams are likely to have larger daily fluctuations than seasonal ones.

Other problems with the ability of dams to retain flood water volumes have to do with the specific characteristics of the dams, in addition to their functionality. For example, the obsolete Elli dam, located in the area of interest, is filled with debris (see Figure 16).

Picture 20: *Satellite view of the effective surface of the Elli dam.*

In the case of the Arjan-Amatovo reservoir, according to the Ministry of Rural Development and Food (MAFF), the useful volume is equal to 8.600.000 m^3 and the annual flood water storage capacity was estimated at 3.440.000 m^3.

Finally, the volume of the dams of neighboring North Macedonia was searched, which was found to be equal to 2,29 km^3 or 2.290.000.000 m^3 (https://knoema.com/atlas/North-Macedonia/topics/Water/Dam-Capacity/Total-dam-capacity, 2020). The total number of dams and their characteristics up to 2012 is presented in the figure and table below. The total available volume of floodwater they can store, depending on their purpose, was estimated at 343.500.000 m^3.



[Picture 21](#): *Large dams in the Republic of North Macedonia (up to 2012).*

[Table 8](#): Large dams in the Republic of North Macedonia (up to 2012).

NAME	RIVER	YEAR OF CONSTRUCTION	TYPE	HEIGH ABOVE GROUND (m)	STRUCTURAL HEIGH (m)	LENGTH OF DAM CREST (m)	DAM VOLUME (m^3 x10^3)	MAXIMUM RESERVOIR CAPACITY (m^3 x10^6)	USAGE
Matka	Treska	1938	AR	29,5	38	64	3	3,55	HEP
Mavrovo	Mavrovska	1952	EAR	54	62	210	777	357	HEP, IR
Lipkovo	Lipkovska	1958	AR	29,5	40	203	13	2,25	IR, WS
Gratche	Kochanska	1959	AR	29	43	150	12	2,4	WS, IR
Mladost	Otovica	1962	AR	27	34	73	2,56	8	IR
Globochica	CrnDrim	1965	E-R	82,5	90	196	998	58	HEP
Vodocha	Vodocha	1965	E-R	4	48,7	185	316,8	26,7	IR, WS
Prilep	Oreovechka	1966	MA	35	38,5	408,5	25,5	6	IR
Tikvesh	Crna Reka	1968	E-R	104	113,5	338	2722	475	IR, HEP
Kalimanci	Bregalnica	1969	E-R	85	92	240	1389	127	IR, HEP
Shpilje	Crn Drim	1969	E-R	101	112	330	2699	520	HEP
Ratevska	Ratevska	1972	AR	49	53	194	21,7	10,5	WS, IR
Turiya	Turiya	1972	E-R	77,5	93	417,3	1978	48	IR,

NAME	RIVER	YEAR OF CONSTRUCTION	TYPE	HEIGH ABOVE GROUND (m)	STRUCTURAL HEIGH (m)	LENGTH OF DAM CREST (m)	DAM VOLUME (m^3 $x10^3$)	MAXIMUM RESERVOIR CAPACITY (m^3 $x10^6$)	USAGE
									WS, HP
Glazhnja	Lipkovska	1972	AR	71,5	80	344	168	22	IR, HEP
Mantovo	Lakavica	1975	E-R	37,5	49	138	261	47,5	IR, WS
Strezhevo	Shemnica	1982	E-R	76	84,6	632	4300	112	IR, WS, HEP
Paljurci	Luda Mara	1982	EAR	21,1	21,5	310	185	2,9	IR
Suvodol	Suvodolska	1982	EAR	33,9	38,3	941	1740	7,88	R, WS
Podles	Vodnik	1985	AR	18	22,5	92	6,7	0,31	IR
Mavrovica	Mavrovica	1999	EAR	24	29	360	400	2,8	WS, IR
Ilovica	Ilovichka	2004	E-R	27,8	29,8	274	131	0,5	WS, IR
Kozyak	Treska	2005	E-R	114	126	300	3340	550	R, HEP, WS
Loshana	Loshana	2006	R-F	41	45,2	165	260	1,08	WS
Markova R.	Markova R.	2006	E-R	26	30	72,5	64,6	0,66	WS
Lisiche	Topolka	2008	ERT	66	76,9	579,6	3295	23	WS, IR
Knezhevo	Zletovska	2011	E-R	75	83	290	1550	23,5	WS, IR, HEP
Saint Petka	Treska	2012	AR	41	66	115	32,5	9,1	HEP

Notes: EAR– earth fill dam; E-R–earth rock dam; R-F–rock-fill dam; AR–arch dam; MA–multiarch; WS–water supply; IR–irrigation; HEP–hydroelectric power; R–retention.

Drawing data from the River Basin Management Plans (RBMPs) of Water Region 10 (Central Macedonia), regarding the runoff of the Axios River, the following table is formed.

Table 9: *Instantaneous River runoff volume at regions 2, 3 and 4. The average of measurements taken for one year is used.*

	RUNOFF (m^3/s)		
STATION	**2018**	**2019**	**2020**
PSAR_DW (REGION 4)	0,46	0,43	0,20
A25 (REGION 3)	101.99	77,96	76,29
AXIOS_PATHE (REGION 2)	-	54,79	46,54

Therefore, the total annual mean runoff volume in the selected region 2 was 1.597.771.440m^3, in the selected region 3 was 2.693.594.880m^3 and in region 4 was 11.458.080m^3.

In summary, the theoretical maximum index $\mathbf{S_C/V_{year}}$ for the selected region 2 is calculated as follows: $\frac{S_C}{V_{year}} = \frac{3.440.000+343.500.000}{1.597.771.440} = \frac{346.940.000}{1.597.771.440} \approx \mathbf{0,217}$, the corresponding for the selected region 3 is: $\frac{S_c}{V_{year}} = \frac{3.440.000+343.500.000}{2.693.594.880} = \frac{346.940.000}{2.693.594.880} \approx \mathbf{0,129}$, while for region 4 is: $\frac{S_c}{V_{year}} = \frac{3.440.000+343.500.000}{11.458.080} = \frac{346.940.000}{11.458.080} \approx \mathbf{30,28}$.

Economic recovery index (E_{CR}):

This datum is assigned values from 10 to 100 with increments of 10, with 100 being the lowest vulnerability, according to Table 4 in Chapter 4.3.

The land use data shows that the majority of economic activity in the region of potential flooding is agricultural. With the majority of past flood events occurring in the fourth quarter of 2014, drawing on data from ELSTAT, it is observed that the total number of farms with irrigated and irrigated land for the year 2013 (before the flood events) was, for the Region of Central Macedonia, 100.451. The corresponding total for the year 2016 (after the flood events) was 96.482, which is a decrease of 3,95%. Considering the fact that the above figures refer to the period of the economic crisis 2009-2018, this rate of decrease is considered relatively small. It is concluded that the economic recovery of the region is quite high, therefore this data can be taken, on the safety side, to be 60.

Urban growth (U_G):

This data relates to the rate of urban growth over the last 10 years. Rapid urban growth is likely to lead to low-quality buildings and therefore to an increase in vulnerability.

The area of interest contains mainly small, rural areas rather than large, urban centers. In addition, during the last decade, due to the economic crisis, urban redevelopment has been considerably curtailed. This implies little urbanization of the area. Therefore, the urbanization rate will be considered equal to 10%.

Degraded areas (D_A):

This data relates to the percentage of deprived (arid) areas. A higher percentage implies an increase in vulnerability. The total land use in the area of interest is shown in Figure 15.

Using GIS software, the area of degraded areas was calculated and found to be equal to 0,00 ha for regions 2 and 4 and 50.91 ha for region 3. The percentage of region 3 is 0,25%, while the percentage of regions 2 and 4 will be considered 0,1%, in order to affect as little as possible the indicator to which this data relates.

Evaporation rate (E_V):

This data refers to the annual rate of water evaporation. A higher rate implies an increase in vulnerability.

Drawing data from the River Basin Management Plans (RBMPs) of Water Region 10 (Central Macedonia), on evaporation that took place in the period 2001-2021, the following tables are formed.

Table 10: *Annual evaporation in the selected region 2 by sub-basin in mm in Water Unit 10. 20-year evaporation averages are used (2001-2021).*

SUB-BASIN	EVAPORATION (mm)
EL1003R0F0201004H	355,27619
EL1003R0F0202014A	389,552381
EL1003R0F0202015N	384,561905
EL1003R0F0202116N	384,728571
EL1003R0F0203006N	403,452381
EL1003R0F020305N	371,457143
EL1003R0F0204017A	405,838095
EL1003R0F0204018A	401,852381
EL1003R0F0204019N	410,661905
EL1003R0F0204120A	412,142857
EL1003R0F0204121N	411,557143
EL1003R0F0204222N	414,77619
EL1003R0F0204223N	428,480952
EL1003R0F0205007N	396,8
EL1003R0F0206024N	413,566667
EL1003R0F0206025N	427,804762
EL1003R0F0206026N	410,761905
EL1003R0F0207008N	397,92381
EL1003R0F0207009N	392,219048
EL1003R0F0207010N	401,828571
EL1003R0F0208027N	390,842857
EL1003R0F0208028N	431,666667
EL1003R0F0208029N	420,190476
EL1003R0F0208130N	429,552381
EL1003R0F0209011N	398,157143
EL1003R0F0209012N	389,942857
EL1003R0F0209013N	391,271429

Table 11: *Annual evaporation in the selected region 3 by sub-basin in mm in Water Unit 10. 20-year evaporation averages are used (2001-2021).*

SUB-BASIN	EVAPORATION (mm)
EL1003R0F0202014A	389,5524
EL1003R0F0203006N	403,4524
EL1003R0F0204017A	405,8381
EL1003R0F0204018A	401,8524
EL1003R0F0204019N	410,6619
EL1003R0F0204120A	412,1429
EL1003R0F0204121N	411,5571
EL1003R0F0204222N	414,7762
EL1003R0F0204223N	428,481
EL1003R0F0205007N	396,8
EL1003R0F0206024N	413,5667
EL1003R0F0206025N	427,8048
EL1003R0F0206026N	410,7619
EL1003R0F0207008N	397,9238
EL1003R0F0207009N	392,219
EL1003R0F0207010N	401,8286
EL1003R0F0208027N	390,8429
EL1003R0F0208028N	431,6667
EL1003R0F0208029N	420,1905
EL1003R0F0208130N	429,5524
EL1003R0F0209011N	398,1571
EL1003R0F0209012N	389,9429
EL1003R0F0209013N	391,2714

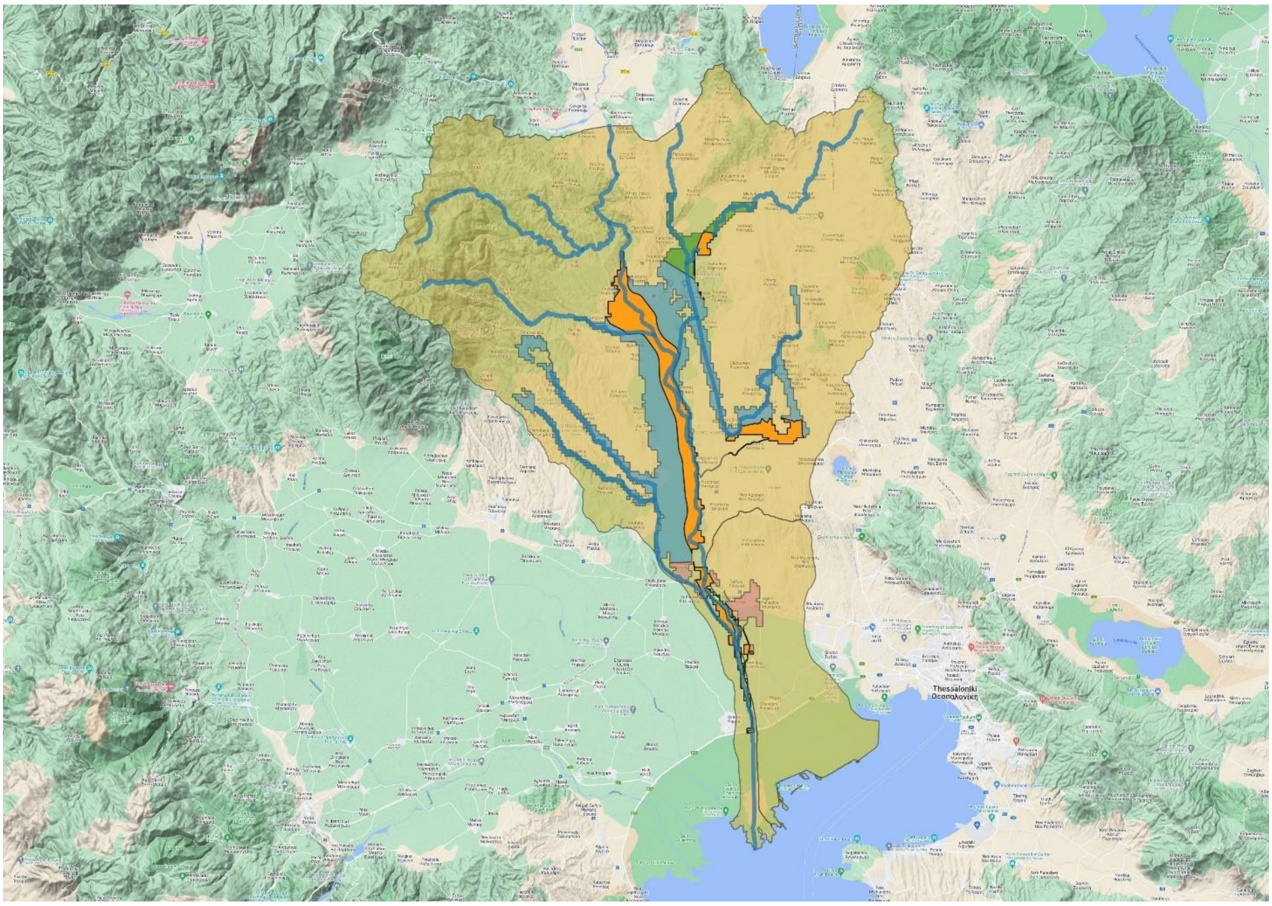
__Table 12:__ Annual evaporation in the selected region 4 by sub-basin in mm in Water Unit 10. 20-year evaporation averages are used (2001-2021).

SUB-BASIN	EVAPORATION (mm)
EL1003R0F0204018A	401,8524
EL1003R0F0204019N	410,6619
EL1003R0F0204222N	414,7762
EL1003R0F0204223N	428,481
EL1003R0F0207008N	397,9238

The above values were multiplied by the region of each sub-basin and then divided by the total region of the sub-basins. These calculations resulted in 390,46 mm of evaporation for region 2, 395,63 mm of evaporation for region 3 and 420,32 mm of evaporation for region 4.

__Natural reservation__ (N_R):

This data relates to the percentage of natural reserves (NATURA 2000 sites, Ramsar sites, wildlife refuges, etc.). A higher percentage implies a reduction in vulnerability.



***Picture 22**: Thematic map of natural reserves in the area of interest. NATURA 2000 sites are shown in orange and Ramsar sites, the area of which lies within the boundaries of NATURA 2000 sites, are shown in yellow.*

Using GIS software, the area of natural reserves was calculated and found to be equal to 2.513,36 ha for Region 2, 10.645,15 ha for region 3 and 271,54 ha for region 4 which correspond to percentages **99,49%, 51,87% and 14,76%** on the corresponding total surface regions (2.526,31 ha, 20.523,20 ha and 1.839,99 ha).

Unpopulated areas (U_{npop}):

This data refers to the percentage of areas with a population density of less than 10 inhabitants per km2. A higher percentage implies an increase in vulnerability. The total land use in the area of interest is shown in Figure 15.

Using GIS software, a calculation of the area of degraded regions and agricultural regions was carried out and found equal to 1.916,45 ha for region 2, 18.398,98 ha for region 3 and 1.666,67 ha for region 4, which correspond to percentages of 75.86%, 89.65% and 90.58% respectively of the total regions (2.526,31 ha, 20.523,20 ha and 1.839,99 ha respectively).

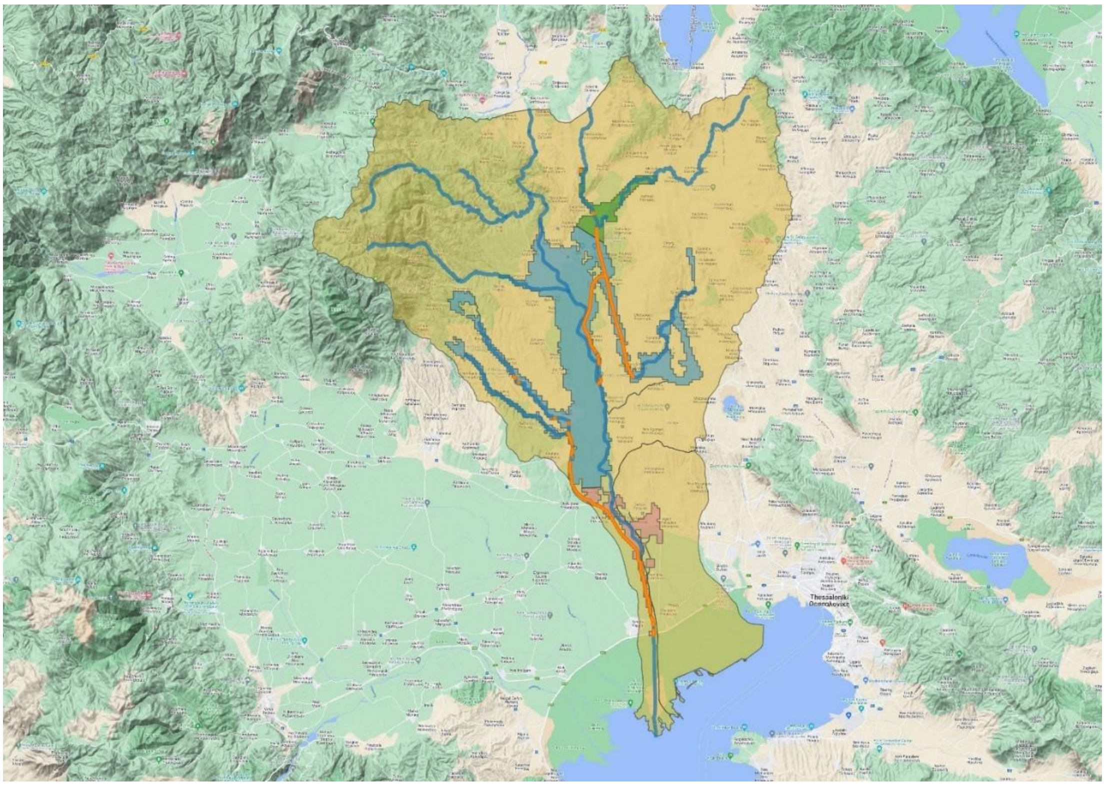
Topography (T):

This data refers to the average slope of the topography. Steeper slopes are associated with an increase in vulnerability.

By using GIS software and importing a digital elevation model (DEM), the average slope of the topography of the area of interest can be obtained. More specifically, the selected region 2 has an average relief slope equal to 0,917°, the selected region 3 has an average relief slope equal to 1,195°, while region 4 has an average relief slope equal to 1,97°. Using the formula $inclination(\%) = [tangent(angle)] * 100$, the above angles are converted into slopes in per cent, which are **1,601%, 2,086% and 3,439%** respectively.

Dikes / Levees (D_L):

This data refers to the total length of levees along the river to the length of the river. A longer total length is associated with a reduction in vulnerability.



Picture 23: Satellite view of the embankments in the area of interest (orange).

Using GIS software, the total length of the embankments along the river was calculated, which was found to be 55.871,81 m or 18.528,35 m in region 2, 32.020,80 m in region 3 and 5.322,66 m in region 4. In addition, the lengths of the river Axios and its tributaries in these regions were calculated and found to be equal to 28.027,81 m in Region 2, 124.344,59 m in Region 3 and 53.297,35 m in Region 4.

Following on from the above, in region 2 the percentage of embankments to river length was found equal to 0,661, in region 3 it was found equal to 0,258 and in region 4 it was found equal to 0,099.

Rainfall ($R_{ainfall}$):

This data refers to the total mm of rainfall recorded annually. A higher rainfall record implies an increase in vulnerability.

Drawing on data from the River Basin Management Plans (RBMPs) of Water Unit 10 (Central Macedonia) on the rainfall that occurred in the period 2001-2021, the following table is formed.

Table 13: *Annual precipitation in the selected region 2 by sub-basin in mm in Water Division 10. 20-year rainfall averages are used (2001-2021).*

SUB-BASIN	RAINFALL (mm)
EL1003R0F0201004H	355,27619
EL1003R0F0202014A	389,552381
EL1003R0F0202015N	384,561905
EL1003R0F0202116N	384,728571
EL1003R0F0203006N	403,452381
EL1003R0F020305N	371,457143
EL1003R0F0204017A	405,838095
EL1003R0F0204018A	401,852381
EL1003R0F0204019N	410,661905
EL1003R0F0204120A	412,142857
EL1003R0F0204121N	411,557143
EL1003R0F0204222N	414,77619
EL1003R0F0204223N	428,480952
EL1003R0F0205007N	396,8
EL1003R0F0206024N	413,566667
EL1003R0F0206025N	427,804762
EL1003R0F0206026N	410,761905
EL1003R0F0207008N	397,92381
EL1003R0F0207009N	392,219048
EL1003R0F0207010N	401,828571
EL1003R0F0208027N	390,842857
EL1003R0F0208028N	431,666667
EL1003R0F0208029N	420,190476
EL1003R0F0208130N	429,552381
EL1003R0F0209011N	398,157143
EL1003R0F0209012N	389,942857
EL1003R0F0209013N	391,271429

Table 14: *Annual precipitation in the selected region 3 by sub-basin in mm in Water Division 10. 20-year rainfall averages are used (2001-2021).*

SUB-BASIN	RAINFALL (mm)
EL1003R0F0202014A	389,5524
EL1003R0F0203006N	403,4524
EL1003R0F0204017A	405,8381
EL1003R0F0204018A	401,8524
EL1003R0F0204019N	410,6619
EL1003R0F0204120A	412,1429
EL1003R0F0204121N	411,5571
EL1003R0F0204222N	414,7762
EL1003R0F0204223N	428,481

SUB-BASIN	RAINFALL (mm)
EL1003R0F0205007N	396,8
EL1003R0F0206024N	413,5667
EL1003R0F0206025N	427,8048
EL1003R0F0206026N	410,7619
EL1003R0F0207008N	397,9238
EL1003R0F0207009N	392,219
EL1003R0F0207010N	401,8286
EL1003R0F0208027N	390,8429
EL1003R0F0208028N	431,6667
EL1003R0F0208029N	420,1905
EL1003R0F0208130N	429,5524
EL1003R0F0209011N	398,1571
EL1003R0F0209012N	389,9429
EL1003R0F0209013N	391,2714

Table 15: *Annual precipitation in the selected region 4 by sub-basin in mm in Water Division 10. 20-year rainfall averages are used (2001-2021).*

SUB-BASIN	RAINFALL (mm)
EL1003R0F0204018A	401,8524
EL1003R0F0204019N	410,6619
EL1003R0F0204222N	414,7762
EL1003R0F0204223N	428,481
EL1003R0F0207008N	397,9238

The above values were multiplied by the area of each sub-basin and then divided by the total area of the sub-basins. These calculations resulted in 592,85 mm of rainfall for region 2, 613,12 mm of rainfall for region 3 and 613,53 mm of rainfall for region 4.

5.2 Calculation of Vulnerability Indexes

Following the provision of the necessary data, the individual vulnerability indicators, i.e., social, economic, environmental and physical, can be calculated for each selected region. The average of the above coefficients is the final vulnerability index for each region.

5.2.1. Selected region 2 (From the Axios River Delta to the Elli dam)

Flood Vulnerability Index for social component

The calculation of the flood vulnerability index for the social component is calculated as follows:

$$FVI_S = FVI_S\left[\frac{P_{FA}, R_{Pop}, \%_{disable}, C_m}{P_E, A/P\,, C_{PR}, W_S, E_R, HDI}\right] = FVI_S\left[\frac{2.829 \times 0{,}4111 \times 0{,}11 \times 3{,}5}{2.905 \times 7 \times 0{,}832 \times 1 \times 0{,}501 \times 0{,}969}\right] = \mathbf{0,053}$$

Flood Vulnerability Index for economic component

The calculation of the flood vulnerability index for the economic component is calculated as follows:

$$FVI_{Ec} = FVI_{Ec}\left[\frac{L_U, U_M, I_{neq}, U_A}{L_{EI}, F_I, AmInv, \frac{S_C}{V_{year}}, E_{CR}}\right] = FVI_{Ec}\left[\frac{0{,}8013 \times 0{,}153 \times 31{,}4 \times 0{,}01519}{0{,}918 \times 1 \times 0{,}0005 \times 0{,}217 \times 60}\right] = \mathbf{0,098}$$

Flood Vulnerability Index for environmental component

The calculation of the flood vulnerability index for the environmental component is calculated as follows:

$$FVI_{En} = FVI_{En}\left[\frac{R_{ainfall}, D_A, U_G}{L_U, E_V, N_R, U_{npop}}\right] = FVI_{En}\left[\frac{592{,}85 \times 0{,}001 \times 0{,}1}{0{,}001 \times 390{,}46 \times 0{,}9949 \times 0{,}8965}\right] = \mathbf{0,170}$$

Flood Vulnerability Index for physical component

The calculation of the flood vulnerability index for a physical element component is calculated as follows:

$$FVI_{Ph} = FVI_{Ph}\left[\frac{T}{\frac{E_V}{R_{ainfall}}, \frac{S_C}{V_{year}}, D\_L}\right] = FVI_{Ph}\left[\frac{0{,}01601}{0{,}659 \times 0{,}217 \times 0{,}661}\right] = \mathbf{0,169}$$

5.2.2. Selected region 3 (From the Elli dam to the region of Polykastro)

Flood Vulnerability Index for social component

The calculation of the flood vulnerability index for the social component is calculated as follows:

$$FVI_S = FVI_S\left[\frac{P_{FA}, R_{Pop}, \%_{disable}, C_m}{P_E, A/P\ , C_{PR}, W_S, E_R, HDI}\right] = FVI_S\left[\frac{5.106 \times 0{,}4111 \times 0{,}194 \times 3{,}5}{15.560 \times 7 \times 0{,}832 \times 1 \times 0{,}230 \times 0{,}969}\right] = \mathbf{0,070}$$

Flood Vulnerability Index for economic component

The calculation of the flood vulnerability index for the economic component is calculated as follows:

$$FVI_{Ec} = FVI_{Ec}\left[\frac{L_U, U_M, I_{neq}, U_A}{L_{EI}, F_I, AmInv, \frac{S_C}{V_{year}}, E_{CR}}\right] = FVI_{Ec}\left[\frac{0{,}9108 \times 0{,}153 \times 31{,}4 \times 0{,}01516}{0{,}918 \times 1 \times 0{,}0005 \times 0{,}129 \times 60}\right] = \mathbf{0,187}$$

Flood Vulnerability Index for environmental component

The calculation of the flood vulnerability index for the environmental component is calculated as follows:

$$FVI_{En} = FVI_{En}\left[\frac{R_{ainfall}, D_A, U_G}{L_U, E_V, N_R, U_{npop}}\right] = FVI_{En}\left[\frac{613{,}12 \times 0{,}0025 \times 0{,}1}{0{,}0088 \times 395{,}63 \times 0{,}5187 \times 0{,}8827}\right] = \mathbf{0,096}$$

Flood Vulnerability Index for physical component

The calculation of the flood vulnerability index for a physical element component is calculated as follows:

$$FVI_{Ph} = FVI_{Ph}\left[\frac{T}{\frac{E_V}{R_{ainfall}}, \frac{S_C}{V_{year}}, D\_L}\right] = FVI_{Ph}\left[\frac{0{,}021}{0{,}645 \times 0{,}129 \times 0{,}258}\right] = \mathbf{0,972}$$

5.2.3. Selected region (The narrow region upstream of Polykastro)

Flood Vulnerability Index for social component

The calculation of the flood vulnerability index for the social component is calculated as follows:

$$FVI_S = FVI_S\left[\frac{P_{FA}, R_{Pop}, \%_{disable}, C_m}{P_E, A/P\,, C_{PR}, W_S, E_R, HDI}\right] = FVI_S\left[\frac{837 \times 0{,}4111 \times 0{,}032 \times 3{,}5}{7.184 \times 7 \times 0{,}832 \times 1 \times 0{,}097 \times 0{,}969}\right] = \mathbf{0,009}$$

Flood Vulnerability Index for economic component

The calculation of the flood vulnerability index for the economic component is calculated as follows:

$$FVI_{Ec} = FVI_{Ec}\left[\frac{L_U, U_M, I_{neq}, U_A}{L_{EI}, F_I, AmInv, \frac{S_C}{V_{year}}, E_{CR}}\right] = FVI_{Ec}\left[\frac{0{,}8866 \times 0{,}153 \times 31{,}4 \times 0{,}01000}{0{,}918 \times 1 \times 0{,}0005 \times 30{,}28 \times 60}\right] = \mathbf{0,0005}$$

Flood Vulnerability Index for environmental component

The calculation of the flood vulnerability index for the environmental component is calculated as follows:

$$FVI_{En} = FVI_{En}\left[\frac{R_{ainfall}, D_A, U_G}{L_U, E_V, N_R, U_{npop}}\right] = FVI_{En}\left[\frac{613{,}53 \times 0{,}001 \times 0{,}1}{0{,}0192 \times 420{,}32 \times 0{,}1476 \times 0{,}9058}\right] = \mathbf{0,057}$$

Flood Vulnerability Index for physical component

The calculation of the flood vulnerability index for a physical element component is calculated as follows:

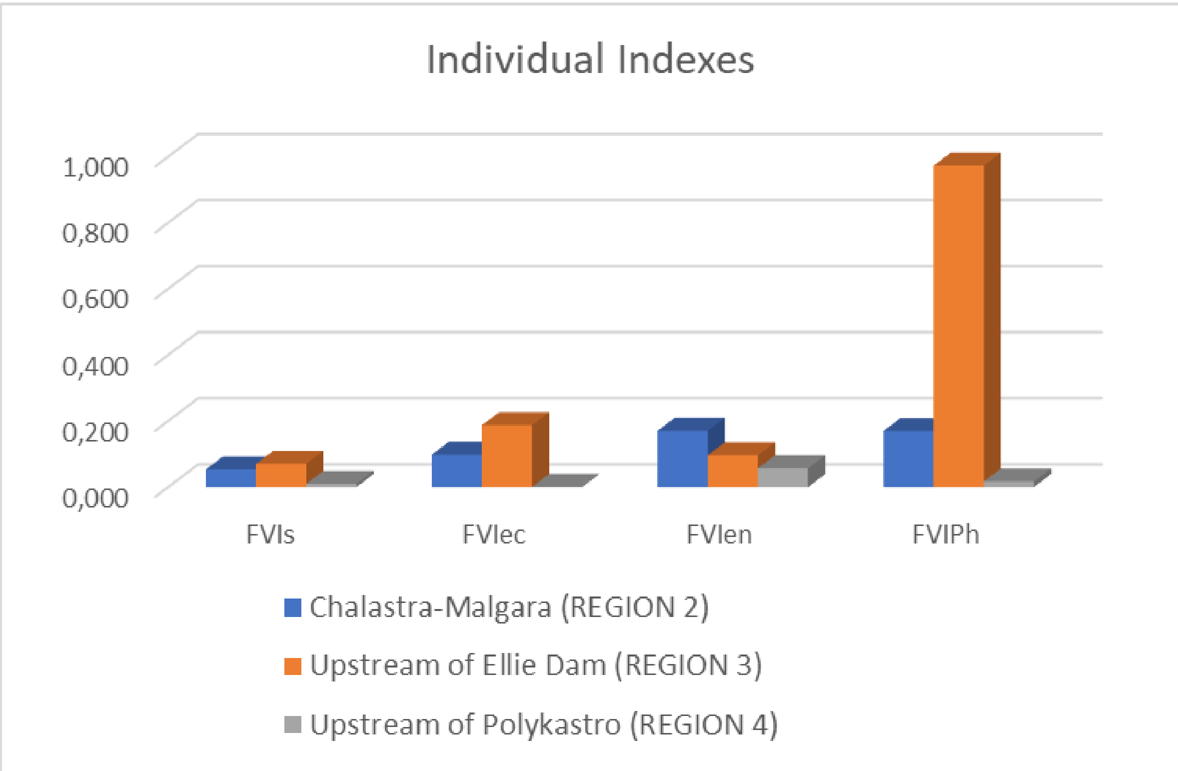
$$FVI_{Ph} = FVI_{Ph}\left[\frac{T}{\frac{E_V}{R_{ainfall}}, \frac{S_C}{V_{year}}, D\_L}\right] = FVI_{Ph}\left[\frac{0{,}034}{0{,}685 \times 30{,}28 \times 0{,}099}\right] = \mathbf{0,017}$$

5.2.4. Comparison of regions

The above individual indicators, together with the indicators derived from this report, can be used in combination and standardized using the equation $FVI = \frac{FVI_S}{FVI_{S\_max}} + \frac{FVI_{Ec}}{FVI_{Ec\_max}} + \frac{FVI_{En}}{FVI_{En\_max}} + \frac{FVI_{Ph}}{FVI_{Ph\_max}}$ to calculate the FVI index and the results are shown in the table below.

Table 16: *Individual vulnerability indicators of the selected regions and the overall vulnerability index.*

REGION	FVI_s	FVI_{ec}	FVI_{en}	FVI_{Ph}	FVI
Chalastra-Malgara (REGION 2)	0,053	0,098	0,170	0,169	2,455
Upstream of Ellie Dam (REGION 3)	0,070	0,187	0,096	0,973	3,565
Upstream of Polykastro (REGION 4)	0,010	0,001	0,057	0,017	0,493



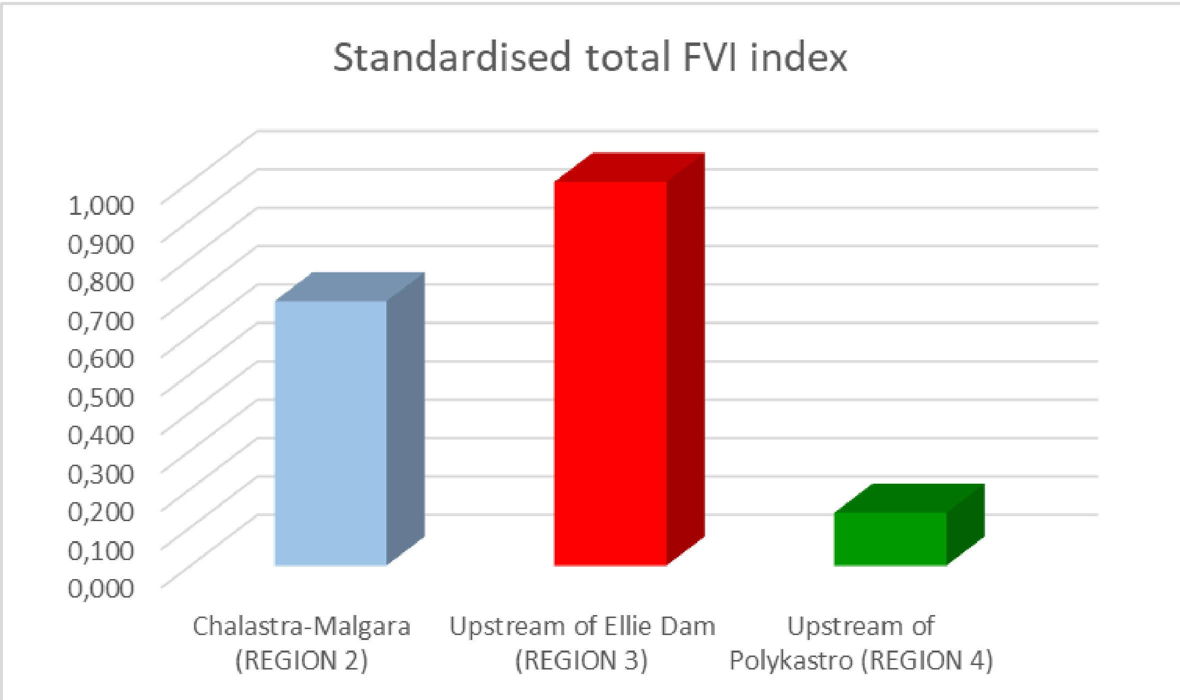
Picture 24: *The individual FVI indexes (s: social, ec: economic, en: environmental, Ph: physical) in the three regions of the Axios River.*

As shown in the figure above, the differences between the two regions relate to a lesser extent to social inequalities (exposure of vulnerable groups to risk) and to a greater extent to physical particularities. Taking into account the components of the physical indicator FVI_{Ph} (Section 4.2), and considering the proximity of the regions to each other, it can be mainly influenced by flood protection works (embankments, retention of flood flows in dams, etc.). In other words, the upstream region of the Elli dam up to Polykastro is the least shielded by flood protection, as the obsolete dam is now filled with debris and its maintenance requires additional resources.

Using the formula $sFVI = \frac{FVI_{subbasin} - FVI_{min}}{FVI_{max} - FVI_{min}}$, standardization of the indicator values is carried out in order to assign them to values in the range 0 to 1 and to evaluate them with the score table (Table 2) presented in chapter 5.2.

Table 17: *The original and standardized vulnerability indicators of selected regions.*

REGION	FVI	stFVI
Chalastra-Malgara (REGION 2)	2,455	0,689
Upstream of Ellie Dam (REGION 3)	3,565	1,000
Upstream of Polykastro (REGION 4)	0,493	0,138



Picture 25: *The values of the FVI score from the 3 regions of Axios (values 0 – 1).*

In the region of the Greek section of Axios/Vardar River, where the following sections were compared: a) Halastra-Malgaron, b) the region from the Elli dam to Polykastro and c) the upstream region of the former Arjan-Ajak-Amatovo marsh, the region with the highest vulnerability was the second.

6 Conclusions

The method of determining vulnerability using indicators is still under development. However, the present example has shown that the method is useful at sub-basin or whole river basin level, when limited available resources are at stake and priorities need to be set. For example, with a finite set of means of response, prevention or rehabilitation to a flood, the aid target at municipal, regional or national level will be different when prioritizing the vulnerability of the regions under the responsibility of the agency. The method can be used to compare vulnerability between whole river basins or even Water Boards, so that the proportionality of resource allocation is subject to rational criteria related to which Water Boards or which river basins or which sub-basins, even at municipality level, make sense to be funded more or immediately and which less or later.

In terms of flood prevention, the abundance of dams, especially on the North Macedonia side, can help. As long as there is volume available in the dams to hold back flood flows when rainfall conditions (duration and/or intensity) are of concern. In order to make this possible, it is necessary for the dam operator to know how much available volume for water retention the dam has. As the initial available volume of a dam decreases year by year due to the accumulation of sediment at the bottom, older dams (e.g., Elli dam near Chalkidona) have lost the flood protection capacity they once had.

However, apart from clarifying how much each dam can help in flood protection, a number of necessary steps need to be taken between the two countries, such as:

- In prevention, cooperation for on-line provision of data and information:
    - by hydrometric and meteorological stations,
    - from dam levels,
    - from the evolution of dangerous meteorological phenomena.
- Assistance, cooperation in rescue matters for the protection of human lives, property and infrastructure.
- Damage restoration guarantees to support each other's funding requests and technical assistance.

In the current analysis of flood vulnerability the most vulnerable area in the Greek part of Axios/Vardar River Basin was the one upstream of Ellis Dam and up to Polykastro.

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Interreg - IPA CBC

Greece - Republic of North Macedonia

FLOOD SHIELD

INTERREG IPA Cross Border Cooperation Programme "Greece - Republic of North Macedonia 2014-2020"

The project FLOOD SHIELD aims to minimize the cross-border flood risks and disasters by strengthening the cross-border cooperation, organizationally, technologically, and socially.

FLOOD SHIELD implementation will result in more effective joint actions and coordination activities against floods, in terms of:

- *Management: Establishment of a Joint management group in the field of flood risks, definition of the procedures needed to overcome the barriers in the cross-border cooperation and elaboration of a cross border flood reaction strategy.*

- *Response: staff training of the authorities, services volunteer groups participating in the interventions during floods, mapping of flood risks and vulnerable sites, identification, and accessibility modeling of means and equipment in the neighboring areas and operation of an Incident Management and Collaboration Platform for local Civil protection and other stakeholders to train, prepare and respond in case of flooding.*

- *Prevention: Introduction of an early warning system and implementation of awareness raising and information activities for citizen to protect themselves from flood hazards*

- *Mitigation: Measures for mitigation of flood risks will be included in the flood reaction strategy*

In addition to the main objective, the project combines different aspects to achieve the following sub-objectives:

- *1. Strengthening the flood risk governance at the Cross-border area to better assess, plan, monitor, prevent & react against floods.*

- *2. Improving the technical capacity for effective cross-border flood risk assessment, monitoring, preparedness & response.*

- *3. Promoting the role of citizens and voluntarism groups in the civil protection actions in case of flood disasters to protect themselves and actively involved in prevention and reaction activities.*

The Project is co-funded by the European Union and national funds of the participating countries.