Deliverable C.3: Report on water related impact and adaptation assessment

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Executive summary

In the current report, a climate change impact and adaptation assessment is conducted for the municipalities of Peristeri (Attica region, Greece), Reggio Emilia (Emilia-Romagna region, Italy) as well as for the neighboring municipalities of Strovolos and Lakatamia (Lefkosia district, Cyprus), in the frame of the LIFE UrbanProof project. The scope of the assessment refers to the impacts of water availability, droughts and floods, which are examined with respect to the future periods of 2031-2060 and 2071-2100. The data on climate change projections used in the assessment are based on the emission scenarios RCP4.5 and RCP8.5. A methodology was developed for the assessment of water related climate change impacts on the urban environment, according to which the impacts are conceived as a function of the climate change hazards and the vulnerability of the exposed population, with the latter depending on the exposure and sensitivity of systems. A composite social vulnerability index was built combining those social indicators considered more relevant for the assessment of the water and flood impact assessments. These indicators refer to population age, chronic illnesses, poverty rate, educational level and hospital beds per inhabitant.

For the impact assessment of water availability under climate change a number of commonly accepted indicators was used, such as the Water Exploitation Index (WEI) and the Standardized Precipitation Evapotranspiration Index (SPEI). Water availability in the frame of the current assessment is assessed at the wider river basin management level where the main domestic water supply sources of the project municipalities are located. The results for the case of the reservoirs supplying the municipality of Peristeri, indicate a reduction of 20-24% the period 2031-2060 in water inflow according to RCP8.5 and a reduction of 46-49% for the period 2071-2100, while according to RCP4.5 the maximum expected reduction is 11% for the period 2071-2100. For the case of the reservoirs supplying the Cypriot municipalities, significant reductions are expected for both climate change scenarios. In particular, according to RCP4.5 a reduction of 24-48% and 35-59% is expected during the periods 2031-2060 and 2071-2100, respectively. Based on RCP8.5 the reduction is higher for the period 2071-2100 ranging from 63 to 76%. For the case of the aquifer supplying Reggio Emilia municipality, no significant changes in groundwater recharge are expected for any of the climate change scenarios and periods examined.

Following, the WEI was calculated based on the available data for annual inflow, abstractions and storage. Future abstractions were calculated on an annual basis based on the average water abstractions per capita for the baseline period which is multiplied with the projected population for a given year in the future. In that sense, water demand patterns are considered constant for the future periods while total abstractions change proportionally to population changes. The results for the case of Lefkosia district show that the WEI for the baseline period is already high (91-94%) for all relevant reservoirs, meaning that available water resources barely satisfy water demand. As water storage is relatively low in all relevant reservoirs, the foreseen decrease in annual inflow due to climate change and the increase in withdrawals due to

population increase will result in the depletion of water stored in the reservoirs and to inability to satisfy a significant part of water demand. For the case of Attica region the WEI for the baseline period is also high (94-96%) for both reservoirs, while according to RCP4.5 the WEI for both future periods will decrease to 36-72%. According to RCP8.5, the WEI for the case of Evinos reservoir will increase up to 118% while for the case of Mornos reservoir it will slightly decrease. For the case of the Reggio Emilia province and the Enza aquifer, the WEI for the baseline period is 60%, while for the period 2031-2060 it will increase up to 109% and for the 2071-2100 period it will further increase up to 164%, while the increase is mainly attributed to the high rate of abstractions and not to climate change impacts.

With respect to droughts, one may observe that overall drought intensity has an increasing trend with the exception of Cyprus and Greece during the period 2071-2100 where drought intensity slightly decreases compared to the period 2031-2060. Overall drought frequency has an increasing trend in all examined water bodies throughout the time periods. The change of drought risk in the future periods compared to the baseline period, is very high for the case of the South Conveyor system of Cyprus where drought risk is almost double for both future periods (92-95% increase). Furthermore, a significant increase is also observed during the period 2071-2100 for the case of Enza aquifer in Italy (57%) while lower increases are also observed for all other cases.

Overall, the highest impact on water resources is expected for the case of Cypriot municipalities as they gather the highest score in all future periods and scenarios. The climate change impact on water resources for Peristeri municipality is expected to be “moderate to high” in all examined cases apart from the period 2031-2060 and RCP8.5 where the impact is expected to be “moderate”. The impact for Reggio Emilia municipality is expected to be “moderate to high” in all cases apart from the period 2071-2100 and RCP4.5 where the impact is estimated to be “high”.

With respect to the flood impact assessment, flood hazard maps produced by the competent national authorities in compliance with the Floods Directive 2007/60/EC were used for identifying the location and extent of the area potentially affected by flooding (flood hazard zone) in each municipality. The hazard indicator is enhanced with an extra weight where low-lying areas (inclination: <1^{o}) are located next to rivers. Exposure to floods takes into account both population and critical infrastructure within the flood hazard zone. The exposure is also estimated with respect to the critical infrastructure exposed to floods, such as hospitals, schools, commercial and industrial areas, public facilities, cultural units and transport infrastructure. The effect of green space in reducing the flood impact is also estimated, with the quantification of the adaptation effect by means of runoff coefficients. The assessment results show that the municipality of Peristeri is expected to face the most significant flood impacts with the flood zone covering 29% of its total area, and an overall impact score of the flood zone area classified as “high”, which is translated to a “medium to high” overall impact score for the municipality. Next are the municipalities of Strovolos and Lakatamia with a “medium” overall flood impact score for the municipality and the municipality of Reggio Emilia with a “low to medium” overall flood impact score for the municipality.

For the adaptation assessment, a review of the available adaptation measures for addressing water availability and flood climate change impacts took place. Following, a questionnaire was developed for the evaluation of the adaptation measures based on a set of criteria (Multi-Criteria Analysis, MCA). Potential adaptation measures evaluation was based on four criteria related to efficiency, environmental friendliness, economic viability and job growth. The measures were evaluated against these criteria by a number of experts & stakeholders (national, regional, local authorities; neighbouring municipalities and Unions; NGOs & CSOs; companies; academic bodies & research institutes) from Italy, Greece and Cyprus. The total score attained was used for the prioritization of the adaptation measures in their inclusion to the adaptation strategies of the project municipalities. Furthermore, the effect of the adaptation measures in moderating the impacts of water availability and floods (impact after adaptation) is assessed.

1. Introduction

In the current report, a climate change impact and adaptation assessment is conducted for the municipalities of Peristeri (Attica region, Greece), Reggio Emilia (Emilia-Romagna region, Italy) as well as for the neighboring municipalities of Strovolos and Lakatamia (Lefkosia district, Cyprus). The scope of the assessment refers to the impacts of water availability, droughts and floods, which are examined with respect to the future periods of 2031-2060 and 2071-2100. The data on climate change projections used in the assessment are based on the emission scenarios RCP4.5 and RCP8.5. The adaptation assessment includes the multi-criteria evaluation of selected adaptation measures as well as the assessment of the effect from the implementation of the adaptation measures. The impact and adaptation assessment is carried out in the frame of Action C.3 of the project LIFE UrbanProof “Climate Proofing Urban Municipalities” while the assessment results will be used for the development of the adaptation strategies of the municipalities in the frame of Action C.7 of the project.

In the second chapter of the report, the overall methodology for the impact and adaptation assessment used is laid down, including the definitions of the frequently used terms, the functional relationship of the relevant indicators and the methodological steps followed. In the third chapter of the report, the individual social vulnerability indicators comprising the social vulnerability index are presented as well as the methodology for the classification of their values. In the fourth chapter of the report the assessment for the water availability and drought impacts takes place. At first the relevant methodology is presented, following the assessment is broken down in the individual assessments of surface and groundwater resources availability, the water exploitation index and the standardized precipitation-evapotranspiration index, while at the end of the chapter the overall results are presented. In the fifth chapter of the report, the flood impact assessment methodology is laid down and the individual indicators used are presented while at the end the overall results are presented. In the sixth and last chapter of the report, the methodology for the evaluation of the adaptation measures is presented, while next the results of their evaluation and their effect from their implementation are presented in the form of maps.

2. Impact and adaptation assessment methodology

In the frame of the LIFE UrbanProof project, a methodology was developed for the assessment of water and heat related climate change impacts on the urban environment. The impacts are assessed with respect to the current as well as the projected changes in climate for the emission scenarios RCP4.5 and RCP8.5. At this point, it is considered crucial to present the definitions after IPCC (2014) of certain terms that will be widely used in this report.

Impacts *The term impacts is used primarily to refer to the effects on natural and human systems of extreme weather and climate events and of climate change. Impacts generally refer to effects on lives, livelihoods, health, ecosystems, economies, societies, cultures, services and infrastructure due to the interaction of climate changes or hazardous climate events occurring within a specific time period and the vulnerability of an exposed society or system.*

Hazard *The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources.*

Exposure *The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.*

Vulnerability *The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.*

Adaptation *The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.*

In brief, according to the methodology developed for the assessment of climate change impacts on urban municipalities, the impacts are conceived as a function of the climate change hazards and the vulnerability of the exposed population. The concept is expressed through *Equations 1* and 2 presented below:

$$\boldsymbol{I = (H * V)^{1/2}} \qquad \textbf{(Eq. 1)}$$

and

$$\boldsymbol{V = aV_s * E} \qquad \textbf{(Eq. 2)}$$

Where ***I*** is the impact examined, ***H*** is the hazard, ***V*** is the total vulnerability of the exposed population, ***E*** is the exposure, V_S the social vulnerability and ***α*** the weight of social vulnerability. Each variable of Equations 1 and 2 is an independent indicator consisting of one or more sub-indicators. The hazard indicators are used to reflect the climate dependent information for each impact, the exposure indicators are used to reflect the exposure of population and/or infrastructure to an impact while the social vulnerability indicators are used to reflect population groups sensitive to climate change impacts and the adaptive capacity of the society and its structures. The hazard indicators were calculated with the use of climatic information for the reference period as well as for the projected changes in climate based on the emission scenarios RCP4.5 and RCP8.5.The data were provided by the National Observatory of Athens within the framework of Action C.2 entitled "Simulation of current climate and projection of future changes in climate". Exposure is estimated with the use of spatial data on population (i.e. population density) and on the critical infrastructure (where relevant) while social vulnerability is estimated with the use of relevant statistical data on sensitivity and adaptive capacity indicators. The social vulnerability indicators are combined to form the composite social vulnerability index (for more information see Section 3). Adaptation is considered to reduce the level of impact and therefore the following equation is applied:

$$I_{with\ adaptation} = I_{w/o\ adaptation} - A \qquad \textbf{\textit{(Eq. 3)}}$$

In general, the methodology includes the stages of normalization, weighting and aggregation. In the normalization stage, the values of indicators expressed in different measurement units are adjusted to a common scale, in order to be comparable. The normalization scale for the impact indicators is set within the numerical range 0-5 with the different values expressing five different levels, from low to high as shown in Table 1. The social vulnerability indicator values were normalized based on their position with regard to the respective European average value (above/below average values), an approach which was also applied in Defra (2006). The weighting stage includes the assignment of weights to the variables in order to express the contribution and the relevant importance of each sub-indicator in a composite index. In particular, a weight of 0.4 is assigned to social vulnerability (Vs) in order to reflect its contribution to the overall impact assessment.

Table 1: Rating scale of impact indicators

Qualitative scale	Numerical scale
Low	**$0 < I \leq 1$**
Low to Medium	**$1 < I \leq 2$**
Medium	**$2 < I \leq 3$**

Medium to High	**3 < I ≤ 4**
High	**4 < I ≤ 5**

In Sections 4 and 5 the impacts of water availability, droughts and floods are assessed while in Section 6 the impacts are re-assessed after the implementation of selected adaptation measures.

3. Social vulnerability index

In the frame of the current impact assessment, a composite social vulnerability index was built combining those social indicators considered more relevant for the assessment of the water and flood impact assessments. These indicators refer to population age, chronic illnesses, poverty rate, educational level and hospital beds per inhabitant. The specific indicators are selected because they are considered to reflect the sensitive groups within the population such the elderly and the very young, the low-income people, the illiterate and the people with illnesses, or, to reflect the response capacity through the adequacy of the medical infrastructure within the region (hospital beds). The sensitivity indicators are proportionally related to vulnerability, as the higher the sensitivity the higher the vulnerability, while the adaptive capacity indicators are inversely related to vulnerability, as the higher the adaptive capacity, the lower the vulnerability. The equation used for the calculation of the Social vulnerability index (V_{social}) is as follows:

$$\boldsymbol{V_{social} = \frac{\sum_1^n S}{n}} \qquad \textbf{\textit{(Eq. 4)}}$$

Where *S* is the social indicator and *n* is the number of individual social indicators. The correlation of these indicators with social vulnerability to water and floods is presented following.

3.1. Age

The climate change impacts on water availability may affect the very old people in the case of extremes, e.g. of a prolonged and severe drought where the water supply system is interrupted. A potential reduced physical ability of these people due to aging, is possible to deter them from finding alternative water sources to satisfy their needs (Swart et al., 2012).

With respect to floods, the very young and older people are considered to be less capable of dealing with the impetuous flood forces. In particular, children are particularly vulnerable because they are physically smaller and weaker than adults and are especially susceptible to hypothermia and shock while the very old are more vulnerable to the effects of immersion (Defra, 2006). The elderly and the children are particularly vulnerable to the direct and the indirect health consequences of floods (Hajat et al., 2005). Confused elderly people may be frightened and bewildered by flood warnings (Thrush, 2005) and thus less capable of protecting themselves. The age threshold for the older people was considered to be 70, which may be considered as an average of 65 and 75 age thresholds referred to in Swart et al. (2012) and Defra (2006) respectively. In the case of the very young people, the threshold of 9 years old was used.

The developed indicator refers to the percentage of people over 70 years old plus the percentage of people under 9 years old and is used to account for the increased sensitivity of these groups to the climate change impacts under study. The data are available at municipal level and are sourced from the National Statistical Services of Italy (ISTAT, 2017), Greece (ELSTAT, 2011a) and Cyprus (CYSTAT, 2012) as well as from Eurostat (2017). The percentage values for each municipality were normalized in the scale 0-5 based on their position with regard to the respective European average value (above/below average values), as shown in Table 2.

3.2. Illiteracy

The literacy rate is included as a measure of the adaptive capacity of individuals (World Bank, 1998). Education increases the skills and knowledge to understand risks and increases the ability to protect (Katic, 2017). People with more education have better position to negotiate equitable solutions (Granados, 2012). On the other hand, it may be more difficult for people who cannot read or write to learn and claim, for example, flood government reimbursements for damages to their property. Illiteracy may prevent people from understanding information provided by authorities on the risk of flooding, emergency procedures or preventative/recovery actions (Kazmierczak, 2015).

The indicator created to reflect this population group is actually the percentage of people with educational level lower than primary school, such as illiterate/literate with lack of an official educational level or those who gave up school. The data are available at municipal level and are sourced from the National Statistical Services of Italy (ISTAT, 2011), Greece (ELSTAT, 2011b) and Cyprus (CYSTAT, 2011) as well as from Eurostat (2017). The percentage values for each municipality were normalized in the scale 0-5 based on their position with regard to the respective European average value (above/below average values), as shown in Table 2.

3.3. Low-income

In the cases where water is not affordable for all and especially in times of water shortages when water may become more expensive, the water budget in low-income households may constitute a significant part of the total household budget. Therefore the low-income groups are considered sensitive to water scarcity (Swart et al., 2012).

Low-income people are also particularly vulnerable to the direct and the indirect health consequences of floods (Hajat et al., 2005). Low-income people may be more sensitive to floods because of poorer-quality housing while higher income people may afford to implement flood protection measures and/or may recover more quickly from flood impacts (Katic, 2017).

The indicator created to reflect this population group is actually the percentage of population exposed to poverty risk. This information is available from Eurostat (2016) at national level only and therefore the values assigned to each partner municipality are the respective national ones. The percentage values for each municipality were normalized in the scale 0-5 based on their position with regard to the respective European average value (above/below average values), as shown in Table 2.

3.4. Chronic diseases

The climate change impacts on water availability in the case of extremes, e.g. of a prolonged and severe drought where the water supply system is interrupted, can be particularly stressful for sensitive population groups such as the infirm people and the people with physical disabilities (Swart et al., 2012).

Pre-existing health problems may also negatively affect the capacity of people to react in the event of extreme weather events, such as floods (Rygel et al., 2006). People suffering from chronic health diseases are most prone to post-flood mortality and to flood-related diseases. Finally, flooding may limit access to medicine or to prompt medical care (Swart et al., 2012).

The indicator refers to the percentage of people with chronic diseases (asthma, chronic lower respiratory-excluding asthma, high blood pressure, stroke or chronic stroke disease, diabetes, chronic depression). This information is available from Eurostat (2014) at national level only and therefore the values assigned to each partner municipality are the respective national ones. The percentage values were normalized in the scale 0-5 based on their position with regard to the respective European average value (above/below average values), as shown in Table 2.

3.5. Hospital beds

Flooding events stress hospital capacity as they are suddenly overwhelmed by patients with injuries caused by floods as well with other mental illnesses caused by traumatic experiences from floods (Fernandez et al., 2002). The number of hospital beds may reflect the capacity of a city to treat an increased number of patients due to extreme weather events such as floods (Swart et al., 2012; Katic, 2017). The higher the hospital capacity, the higher the response capacity to emergency events.

The indicator refers to the available hospital beds per capita and is available from Eurostat (2015) at regional level. Therefore the values assigned to each partner municipality are the respective regional ones.

Unlike the previous indicators, this is an adaptive capacity indicator and therefore its normalization is based on an inverse scale, as the greater the number of hospital beds per capita, the lower the vulnerability. In particular, the indicator values were normalized in the scale 5-0 based on their position with regard to the respective European average value (above/below average values), as shown in Table 2.

Table 2: Normalization of social indicator values

$\frac{\text{Municipal/regional/national value}}{\text{European average value}}$	Normalized scale for sensitivity indicators	Normalized scale for adaptive capacity indicators
0.0 – 0.4	0 - 1	5 - 4
0.4 – 0.8	1 - 2	4 - 3
0.8 – 1.2	2 - 3	3 - 2
1.2 – 1.6	3 - 4	2 - 1
1.6 - above	4 - 5	1 - 0

The normalized values for each of the abovementioned indicators are presented below.

Table 3: Normalized values of social indicators

Social indicator	Study area A	Study area B	Study area C
Age (<9 & >70) – municipal level	2.9 (Reggio Emilia)	2.8 (Peristeri)	2 (Strovolos)/ 1.9 (Lakatamia)
Illiteracy level – municipal level	0.9 (Reggio Emilia)	1.8 (Peristeri)	0.7 (Strovolos & Lakatamia)
Poverty risk – national level	3.8 (Italy)	3.9 (Greece)	3 (Cyprus)
Chronic diseases – national level	2.8 (Italy)	2.8 (Greece)	2 (Cyprus)
Hospital beds per inhabitant – NUTS2 level	4 (Emilia-Romagna)	2 (Attica)	3.9 (Cyprus)

4. Water availability & drought impact assessment

For the impact assessment of water availability under climate change a number of commonly accepted indicators was used, such as the Water Exploitation Index (WEI) and the Standardized Precipitation Evapotranspiration Index (SPEI). These indicators are generally used for the presentation of the current situation with respect to water availability but for the purpose of this study, climatic projections on precipitation are used to depict future water availability. In particular, projections on precipitation were used for two different time periods (2031-2060 & 2071-2100) and climate change scenarios (RCP4.5 & RCP8.5), produced in the frame of Action C2 "Simulation of current climate and projection of future changes in climate" of the LIFE UrbanProof project.

Urban municipalities are not usually supplied with water sourced within the municipalities' boundaries mainly because the water is not enough to meet the demand. Therefore water availability in the frame of the current assessment is assessed at the wider river basin management level where the main domestic water supply sources of the project municipalities are located. The results of the assessment refer to the municipalities as a whole, since water supply is managed at central level and may be used by the competent authorities for investigating whether there will be need for adaptation action, e.g. for promoting water saving measures and/or for augmenting water supply. The hazard and risk indicators used for describing the climate change effect on water resources are presented following:

- **Water Availability**: This indicator quantifies water stress caused by the limited availability of freshwater resources. It is calculated as the sum of surface water and groundwater resources used for potable water supply (see Chapter 4.1). Surface water resources were calculated through the estimation of annual water inflow to reservoirs (see Chapter 4.1.1) and groundwater resources were calculated through the estimation of annual groundwater recharge (see Chapter 4.1.2).

- **Water Exploitation**: The Water Exploitation Index (WEI) relates water availability and water use and compares annual water withdrawal/demand from ground and surface water to the total renewable freshwater resources (see Chapter 4.2). Considering that the calculation of this indicator is based on water availability, it was decided that only WEI will be used for the impact assessment, to avoid double counting.

- **Droughts**: Drought in the frame of this study is measured with the use of the Standardized Precipitation Evapotranspiration Index (SPEI), which constitutes a slight modification of the Standardized Precipitation Index (SPI). The SPI quantifies the precipitation deficit to reflect the impact of drought on the availability of water resources while SPEI takes into account potential evapotranspiration apart from precipitation and therefore is considered more suitable for the assessment of climate change impacts on water resources (see Chapter 4.3).

The assessment of overall water impact was based on the synthesis of the abovementioned hazard and risk indicators with the vulnerability index. The formula used for the assessment of the overall water impact is presented following:

$$\boldsymbol{I_{water}} = [\left(\frac{\sum_{1}^{n} \boldsymbol{W}}{\boldsymbol{n}}\right) * \boldsymbol{V}]^{\boldsymbol{1}/\boldsymbol{2}} \qquad \textbf{\textit{(Eq. 5)}}$$

Where I_{water} : Water impact

W: water indicator

n: number of individual water indicators

Impact (I) is calculated according to Equation 2, with the exception that exposure is not taken into account since there is no spatial differentiation to population/infrastructure exposure within the project municipalities, i.e. the whole population of the municipalities is considered to be equally exposed as water supply is managed centrally. The social vulnerability indicators used for the calculation of the composite social vulnerability index in the water impact formula are the age, poverty and health problems (see Section 3). In the sections that follow, detailed information on the calculation of the individual hazard and risk indicators for each study area is presented.

4.1. Water availability

This section refers to the climate change impact assessment of water availability from the freshwater bodies supplying with potable water the partner municipalities. Water availability is dealt separately for surface water and groundwater resources in the following two sections.

4.1.1. Surface water resources

In this section, the quantity of surface water resources under climate change in the future is estimated based on the calculation of annual water inflow to reservoirs. The assessment takes place for the project municipalities that are supplied with drinking water from surface water resources, i.e. the municipalities of Peristeri, Strovolos and Lakatamia. In particular, the main reservoirs supplying Peristeri municipality are Mornos and Evinos located in the hydrological basin of Central Greece (SSW, 2014), while Lakatamia and Strovolos municipalities are mainly supplied from the reservoirs of Kouris, Arminou, Dhypotamou and Lefkaron which are connected to the South Conveyor Water System (WDD, 2014).

In particular, for the estimation of water inflow to reservoirs, data on mean annual precipitation for the reference period and the two future periods under examination (2031-2060, 2071-2100) were used in combination with the reservoir upstream area (watershed area) and the runoff coefficients of each reservoir (see Table 4). The precipitation data for the reference period are from observations of meteorological stations while for the future periods are from outputs of climatic model simulations provided by the National Observatory of Athens. Runoff coefficient formulas were used for the projection of water inflow in the future periods based on the projections on precipitation. The runoff coefficient formulas for each reservoir were developed from the correlation of precipitation measurements with measurements of water inflow to reservoirs for the reference period. The estimation of water inflow is based on the following equation:

$$\boldsymbol{Water\ inflow} = \boldsymbol{Runoff\ coefficient} \times \boldsymbol{Watershed\ area}\ (\boldsymbol{m^2}) \times \boldsymbol{Mean\ annual\ precipitation}\ (\boldsymbol{mm}) \tag*{(Eq. 6)}$$

Table 4: Precipitation projections, runoff coefficients and watershed area information of main reservoirs

	Reservoirs	Runoff coefficient (1970-2000)	Watershed (km^2) *	Mean annual Precipitation (mm)				
				1970-2000	2031-2060		2071-2100	
					RCP4.5	RCP 8.5	RCP4.5	RCP8.5
GR	Evinou	0.63	352	1197	1202	1035	1125	860
	Mornou	0.38	587	967	976	851	937	711
CY	Kouri	0.18	308	479	416	410	392	294
	Arminou	0.16	116	791	664	643	605	466
	Dhypotamou	0.13	79	482	372	380	343	266
	Lefkaron	0.05	36	577	444	454	410	319

* (WDD, 2009; SSW, 2014)

The results for the area of Greece and Cyprus are presented in Table 5 and Table 6, respectively. In particular for the case of Evinos and Mornos reservoirs, the results of water inflow according to RCP8.5 indicate a reduction of 20-24% the period 2031-2060 and a reduction of 46-49% for the period 2071-2100, while according to RCP4.5 the maximum expected reduction is 11% for the period 2071-2100.

Table 5: Annual water inflow to reservoirs due to rainfall – Central Greece basin

Period	Reservoir	Water Inflow (hm^3)			Change	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1970-2000	Evinos	269				
	Mornos	252				
	Total	**521**				
2031-2060	Evinos		273	205	1.5%	-24.0%
	Mornos		263	202	4.5%	-19.7%
	Total		**536**	**407**	**2.9%**	**-21.9%**
2071-2100	Evinos		241	138	-10.6%	-48.8%

Period	Reservoir	Water Inflow (hm^3)			Change	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
	Mornos		243	137	-3.4%	-45.7%
	Total		**484**	**275**	**-7.1%**	**-47.3%**

For the case of Cyprus' reservoirs, significant reductions are expected for both climate change scenarios. In particular, according to RCP4.5 a reduction of 24-48% and 35-59% is expected during the periods 2031-2060 and 2071-2100, respectively. Based on RCP8.5 the reduction is higher for the period 2071-2100 ranging from 63 to 76%. In all cases, the higher reduction is expected for the case of Lefkara reservoir.

Table 6: Mean annual inflow to reservoirs due to rainfall – South Conveyor System, Cyprus

Period	Reservoir	Mean annual water inflow (hm3)			Change	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1970-2000	Kouri	31.9				
	Arminou	17.1				
	Dhypotamou	5.1				
	Lefkaron	1.5				
	Total	**55.6**				
2031-2060	Kouri		24.3	24.2	-23.8%	-24.1%
	Arminou		11.3	10.3	-34.0%	-39.6%
	Dhypotamou		2.8	3.0	-45.2%	-41.2%
	Lefkaron		0.8	0.9	-47.8%	-43.3%
	Total		**39.2**	**38.4**	**-29.5%**	**-31.0%**
2071-2100	Kouri		20.6	11.8	-35.3%	-63.0%
	Arminou		8.4	4.5	-51.1%	-73.5%
	Dhypotamou		2.3	1.4	-55.7%	-72.9%
	Lefkaron		0.6	0.4	-58.6%	-75.5%
	Total		**32.6**	**18.5**	**-42.6%**	**-67.5%**

If the actual contribution of each reservoir in drinking water supply for the wider case study areas (Attica region, Lefkosia district) is taken into consideration according to the current water management system (Table 7), the annual surface water availability for drinking water in the study areas is estimated, as may be seen in Table 8 and Table 9.

Table 7: Contribution of water bodies in drinking water for the case study areas

	Reservoirs	Contribution (%)
Central Greece basin, Greece **(supply to Greater Metropolitan area of Athens)**	Evinos	**81**
	Mornos	**83**
South Conveyor System, Cyprus **(supply to Lefkosia district)**	Kouris	**30**
	Arminou	**30***
	Dipotamou	**86**
	Lefkaron	**85**

** Water from Arminou reservoir is transferred to Kouris reservoir through Diarizos diversion and then distributed for consumption, therefore the same rates are applied*

In particular, for the case of central Greece basin which supplies the Greater Metropolitan area of Athens with drinking water, a reduction of 22% and 47% in drinking water availability is estimated according to RCP8.5 for the periods 2031-2060 and 2071-2100 respectively, while according to RCP4.5 no significant changes are observed.

Table 8: Mean annual surface water availability for drinking water – Central Greece basin

Period	Mean annual drinking water availability (hm^3)		Change in drinking water availability (%)	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
1970-2000	429			
2031-2060	442	335	2.9%	-21.9%
2071-2100	399	226	-7.1%	-47.3%

For the case of the South Conveyor System reservoirs which supply the district of Lefkosia with drinking water, a reduction in drinking water availability of 32-33% is estimated for the period 2031-2060 for both scenarios while for the period 2071-2100 the reduction rises up to 45% according to RCP4.5 and to 69% according to RCP8.5, resulting in a water availability quantity approximately one third of that estimated for the baseline situation.

Table 9: Mean annual surface water availability for drinking water - South Conveyor System, Cyprus

Period	**Mean annual drinking water availability (hm3)**		**Change in drinking water availability**	
	RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
1970-2000	20.5		-	
2031-2060	13.8	13.7	-32.4%	-32.9%
2071-2100	11.2	6.4	-45.1%	-68.5%

4.1.2. Groundwater resources

In this section, the future quantity of groundwater resources under climate change is estimated based on the calculation of annual groundwater recharge. The assessment takes place for the project municipalities that are supplied with drinking water mainly from groundwater resources, i.e. the municipality of Reggio Emilia in Italy. Groundwater reserves in the area are quite extensive and natural recharge depends on a number of hydrogeological systems located in the wider area of Emilia-Romagna region. The natural recharge of these systems is connected with the hydrogeological balance of other large and complex systems located in the Apennine and River Po basin. To limit the boundaries of the current analysis, the aquifer of Enza river was selected for further examination as it is the aquifer where the most of the wells are located. In particular, six of the seven main wells providing Reggio Emilia's aqueduct with water are located in aquifer of river Enza, as shown in Figure 1.

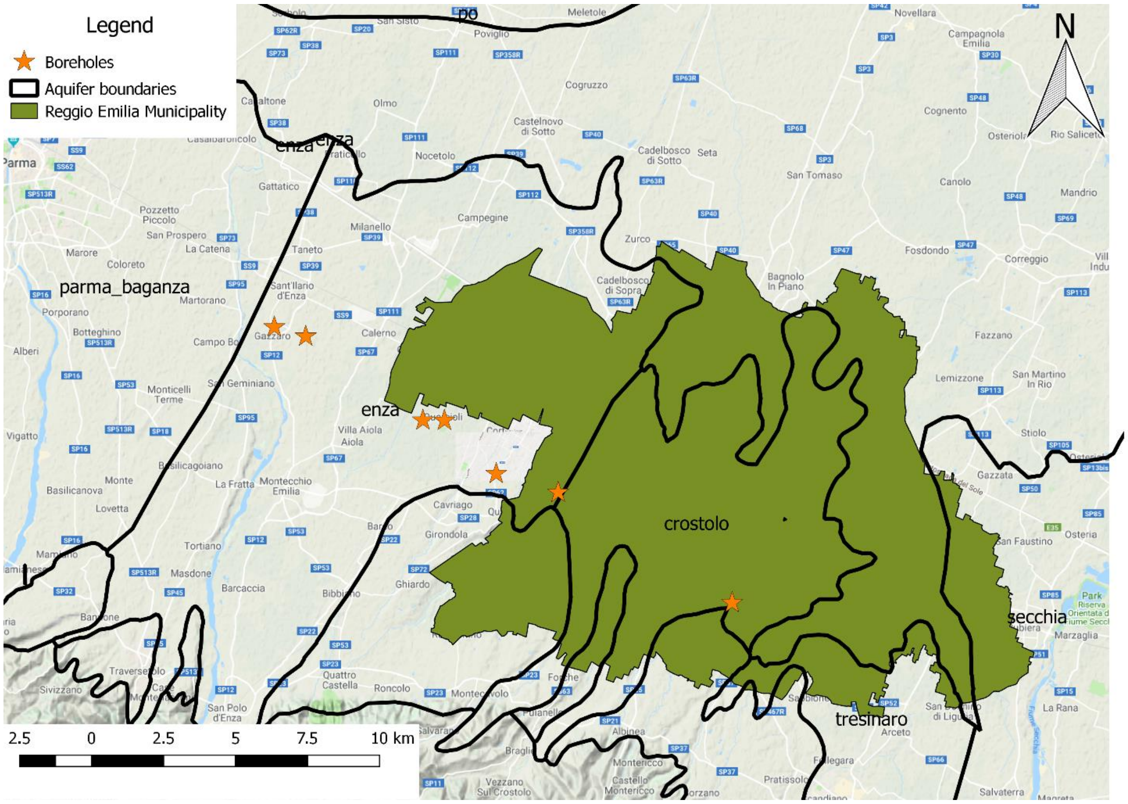

Figure 1: Wells location in Enza river aquifer

Two types of groundwater recharge are examined, recharge by infiltration and recharge by river bed seepage (stretch S.Polo-S.Ilario). There is also another groundwater recharge type, that of recharge by irrigation, but it was not examined in the current study because it is not climate dependent.

Recharge by infiltration was estimated with the use of an infiltration coefficient of 22% (Marletto et al., 1993) based on precipitation data for an area of 131km^2 which corresponds to the total area of the Enza river alluvial fan (Barbieri and Martinelli, 2007). Recharge by river bed seepage was calculated with the use of a coefficient of 23% which was calculated based on river flow timeseries and on an average groundwater recharge quantity due to river bed seepage of 15.7*10^6 m3/y provided by Barbieri and Martinelli (2007). River flow timeseries for the examined future periods were estimated with the use of precipitation timeseries for the future periods and the rainfall-river flow relationship built on available data from the baseline period. The total annual groundwater recharge is calculated with the following equations:

$$\boldsymbol{Annual\ groundwater\ recharge = Recharge\ by\ infiltration + Recharge\ by\ river\ bed\ seepage} \qquad \textbf{\textit{(Eq. 7)}}$$

$$\boldsymbol{Recharge\ by\ infiltration = infiltration\ coefficient\ \times mean\ annual\ rainfal\ (mm) \times aquifer\ area\ (m^2)} \qquad \textbf{(Eq. 8)}$$

$$\boldsymbol{Recharge\ by\ river\ bed\ seepage\ =\ seepage\ coefficient \times river\ flow\ (m^3/s) \times 3.15E+06\ (s/y)} \qquad \textbf{(Eq. 9)}$$

According to Table 10 where the results of the analysis are presented, no significant changes in groundwater recharge are expected for the case of river Enza aquifer for any of the climate change scenarios and periods examined. In particular, the greater change is expected for the period 2071-2100 and it refers to a reduction of 8% in annual groundwater recharge according to the scenario RCP4.5.

Table 10: Annual groundwater recharge of Enza r. aquifer – Reggio Emilia (in hm3)

	1970-2000	2031-2060		2071-2100	
		RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Infiltration	26.4	26.2	26.5	24.5	25.6
River bed seepage	15.7	15.6	15.8	14.4	15.2
Total	42.1	41.8	42.3	38.9	40.7
Change compared to 1970-2000	-	-1%	1%	-8%	-3%

4.2. Water Exploitation

The Water Exploitation Index (WEI) relates water availability and water use and compares annual water withdrawal/demand from ground and surface water resources to the total renewable water resources. In particular, WEI is defined as the ratio of annual water withdrawal to the total freshwater resources. Total freshwater resources are calculated in the frame of this study as the average annual storage of water in the water bodies examined plus the total annual inflow to the water bodies, according to the following equation:

$$\boldsymbol{WEI = \frac{Total\ annual\ withdrawals}{Average\ annual\ storage + Total\ annual\ inflow}} \qquad \textit{(Eq. 10)}$$

The baseline WEI is calculated based on the available data for annual inflow, abstractions and storage. Future abstractions are calculated on an annual basis based on the average water abstractions per capita for the baseline period which is multiplied with the projected population for a given year in the future. In that sense, water demand patterns are considered constant for the future periods while total abstractions change proportionally to population changes.

$$\boldsymbol{Future\ annual\ withdrawals = Average\ annual\ withdrawals\ per\ capita \times Projected\ future\ population} \qquad \textit{(Eq. 11)}$$

The population taken into account for each area is the population served by the drinking water supply system examined, i.e. the population of Lefkosia district for the reservoirs of the Southern Conveyor system in Cyprus, the population of Attica region for the Central Greece basin system and the population of the Reggio Emilia province for the case of the Enza aquifer water supply system. The population projections are sourced from Eurostat (2018) and are developed based on specific assumptions for fertility, mortality and net migration with the use of the "cohort-component" method. Considering that Eurostat provides population projections at national level only, the national population projection trends for the three countries are applied at the respective regional populations under examination. The population data used in the current study are presented in brief in the following table.

Table 11: Population data for the examined areas and periods (averages)

Area		**1985-2015**	**2031-2060***	**2071-2100***
Lefkosia district	Absolute number	301,490	378,377	388,265
	% change	-	26%	29%

Attica region	Absolute number	3,855,471	2,914,653	2,484,663
	% change	-	-24%	-36%
Reggio Emilia province	Absolute number	457,934	517,583	465,957
	% change	-	13%	2%

** Based on population projections available at national level*

As it may be observed from the table above, the population of Lefkosia district is expected to increase in the future by 26-29% compared to the baseline period and the population of Reggio Emilia province is also expected to increase in the near future (2031-2060) by 13% while for the long-term future (2071-2100) there will be no significant change compared to the current period. On the other hand, the population of the Attica region is expected to decrease by 24% in the near future and by 36% in the long-term future.

Future annual inflow to the examined water bodies is estimated in Section 4.1: Water availability. Future storage is calculated on an annual basis based on the data for the latest year available where the annual water balance is added. The latter is calculated as the annual inflow minus the annual abstractions. The relevant equations are presented next:

$$\boldsymbol{Storage_n = Storage_{n-1} + Annual\ balance_n} \tag{Eq. 12}$$

$$\boldsymbol{Annual\ water\ balance = Annual\ inflow - Annual\ withdrawals} \tag{Eq. 13}$$

where n is the year for which water storage is calculated. In the case that the calculation of water storage becomes negative, either due to a decrease in inflow and/or to an increase in the withdrawals, storage is considered equal to zero and water demand is considered to be satisfied only by annual inflow. In the tables that follow, the results of the analysis for each water body and in total are presented separately for each area.

In particular, for the case of Lefkosia district (Table 12) the WEI for the baseline period is already high (91-94%) for all relevant reservoirs, meaning that available water resources barely satisfy water demand. As water storage is relatively low in all relevant reservoirs, the foreseen decrease in annual inflow due to climate change and the increase in withdrawals due to population increase will result in the depletion of water stored in the reservoirs and to inability to satisfy a significant part of water demand. In specific, the WEI of the 2031-2060 period ranges between 150-200% while the WEI of the 2071-2100 period reaches up to 406% for the scenario RCP8.5, meaning that the water demand will be more than four times greater than the available water resources. However, it should be noted here that Cyprus also depends on a great extent on desalination for satisfying demand in drinking water and therefore a reduction in freshwater availability is currently overcome with an increase in desalination water supply. In any case, the projected increase in WEI calls for direct response in order to face significant shortcomings in drinking water demand satisfaction from the available freshwater resources.

Table 12: Water exploitation index, Lefkosia district (in hm^3)

Water body	Indicator	1989-2017	2031-2060		2071-2100	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Kouris reservoir	Total inflow	698	579	577	492	282
	Total abstractions	668	1115		1144	
	Average storage	35	0	0	0	0
	WEI	**91%**	**193%**	**193%**	**233%**	**406%**
Arminou reservoir (1999-2017)	Total inflow	333	394	353	292	155
	Total abstractions	315	605		620	
	Average storage	1.4	0.0	0.1	0.0	0.0
	WEI	**94%**	**153%**	**171%**	**212%**	**400%**
Lefkara reservoir	Total inflow	79	60	60	48	26
	Total abstractions	75	102		105	
	Average storage	4.2	0.0	0.3	0.0	0.0
	WEI	**91%**	**170%**	**168%**	**220%**	**402%**
Dipotamos reservoir	Total inflow	149	116	96	94	54
	Total abstractions	143	197		202	
	Average storage	4.9	0.0	0.1	0.0	0.0

Water body	Indicator	1989-2017	2031-2060		2071-2100	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
	WEI	**92%**	**169%**	**205%**	**215%**	**377%**
Total	Total inflow	1259	1150	1087	926	517
	Total abstractions	1200	2019		2071	
	Average storage	45.6	0.0	0.5	0.0	0.0
	WEI	**92%**	**176%**	**186%**	**224%**	**401%**

For the case of Attica region (Table 13) the WEI for the baseline period is also high (94-96%) for both reservoirs, while according to RCP4.5 the WEI for both future periods will decrease to 36-72%. According to RCP8.5, the WEI for the case of Evinos reservoir will increase up to 118% while for the case of Mornos reservoir it will slightly decrease. It is also noted that the water reserves of Evinos reservoir are expected to be depleted for a number of years in both periods according to RCP8.5.

Table 13: Water exploitation index, Attica region (in hm^3)

Water body	Indicator	Baseline period	2031-2060		2071-2100	
			RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Mornos reservoir (1985-2016)	Total inflow	7,462	7,588	5,756	7,015	3,888
	Total abstractions	7,475	5,528		4,283	
	Average storage	449	1,566	397	4,903	860
	WEI	**94%**	**60%**	**90%**	**36%**	**90%**
Evinos reservoir (2002-2016)	Total inflow	3,795	7,721	5,825	6,803	3,923
	Total abstractions	3,720	6,093		4,722	
	Average storage	62	750	41	3,357	82

Water body	**Indicator**	**Baseline period**	**2031-2060**		**2071-2100**	
			RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
	WEI	**96%**	**72%**	**104%**	**46%**	**118%**
Total	Total inflow	11,256	15,309	11,582	13,818	7,811
	Total abstractions	11,194	11,621		9,005	
	Average storage	598	2,316	438	8,260	942
	WEI	**94%**	**66%**	**97%**	**41%**	**103%**

For the case of the Reggio Emilia province and the Enza aquifer (Table 14), the WEI for the baseline period is 60%, while for the period 2031-2060 it will increase up to 109% and for the 2071-2100 period it will further increase up to 164%. As it is also mentioned above, a WEI between 100-200% means that a part of the water demand will not be able to be satisfied from the available water resources. Considering that both the Attica region and the Reggio Emilia province depend on these water bodies for the majority of their drinking water supply, there will be need to increase their preparedness in order to face reduced freshwater availability through the reduction in water demand and/or the exploration of additional water resources.

Table 14 : Water exploitation index, Reggio Emilia province (in hm^3)

Water body	**Indicator**	**1982-2014**	**2031-2060**		**2071-2100**	
			RCP 4.5	**RCP 8.5**	**RCP 4.5**	**RCP 8.5**
Enza aquifer	Total inflow	1,316	1,255	1,270	1,167	1,222
	Total abstractions	2,053	2,140		1,927	
	Average storage	2,091	758	686	4.6	0.3
	WEI	**60%**	**106%**	**109%**	**164%**	**158%**

The WEI values are normalized according to the classification scale presented in Table 15, in order to be used in the water impact assessment. The normalized WEI values are presented in summary in Table 16.

Table 15: Classification of WEI results

Range	Class
[0% - 30%)	1
[30% - 50%)	2
[50% - 70%)	3
[70% - 90%)	4
≥90%	5

Table 16: Normalized WEI values

Area	Baseline period	2031-2060		2071-2100	
		RCP4.5	RCP8.5	RCP4.5	RCP8.5
Lefkosia district	4.3	4.5	4.5	4.6	5.0
Attica region	4.3	3.0	4.3	1.9	4.3
Reggio Emilia province	2.9	4.3	4.3	4.4	4.4

4.3. Droughts

Droughts occur due to lack of precipitation and may be categorized to meteorological, agricultural, hydrological and socio-economic droughts according to Dracup et al. (1980). Meteorological droughts are commonly used, inter alia, as indicators to reflect the impacts of water scarcity on urban systems although they do not have a direct impact on them, because they precede the other types of droughts having a direct impact on urban systems (Swart et al., 2012). The Standardized Precipitation Index (SPI) is one of the most widely used indicators to characterize meteorological droughts. The SPI compares total precipitation received at a location during a specific period of months with the long-term precipitation distribution for the same location (McKee et al. 1993). The data needed for its calculation is monthly precipitation timeseries of at least 30 years. The SPI may be calculated for different timescales, i.e. 3-, 6-,12-, 24- and 48-month timescales, with the shorter timescales reflecting drought impacts on soil moisture, the 12-month timescale depicting impacts on streamflow and reservoir storage while the longer timescales (24-48 month timescales) are considered to reflect impacts on groundwater recharge (Svoboda et al. 2012). According to the classification system on SPI proposed by McKee et al. (1993), the SPI takes values between +2 and -2, with the negative values indicating different levels of drought intensity.

However, as also noted by Svoboda et al. (2012), SPI is not the most appropriate indicator for assessing climate change related drought impacts, since it does not take into account temperature and potential evapotranspiration which also have significant effect on droughts. Therefore, a slightly modified SPI was used, the Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serano et al. 2010), which takes into account potential evapotranspiration in addition to precipitation. Thus the SPEI enables identification of drought in the context of climate change. SPEI may be calculated for different timescales like SPI and is classified based on the same scale suggested for SPI (McKee et al. 1993).

For the aims of the current study, the SPEI was calculated with the use of monthly precipitation and evapotranspiration data timeseries from representative locations of each area for the period 1970-2100. The timeseries are actually a compilation of observation timeseries from the reference period (1970-2015) and data produced from climate change projections until the year 2100. Considering that SPEI (like SPI) is useful for assessing drought conditions for a given period and location compared to the long-term precipitation of this location, it is not recommended for comparing the results for different climate change scenarios but for different periods. Therefore, only one climate scenario was selected for examination, that of RCP4.5. All necessary data for SPEI calculation were provided by the National Observatory of Athens.

Calculation of SPEI was made with the use of the SPEI R package software which is available for free in the web repository of the Spanish National Research Council (website address http://digital.csic.es/handle/10261/10002).

SPEI was calculated with the use of climatic data from represenative locations of the water reservoirs supplying with domestic water Lefkosia district in Cyprus (Kouri, Arminou, Dipotamou, Lefkara) and the Greater Metropolitan Athens area in Greece (Mornos, Evinos) as well as for the aquifer of Enza which supplies domestic water the municipality of Reggio Emilia in Italy. The 12-timescale was selected as most suitable for the calculation of SPEI for the water reservoirs of Cyprus and Greece while for the aquifer in Italy, the 24-timescale was selected which is considered to best reflect drought impacts on groundwater recharge. In the figures that follow, the SPEI results for each water body are presented.

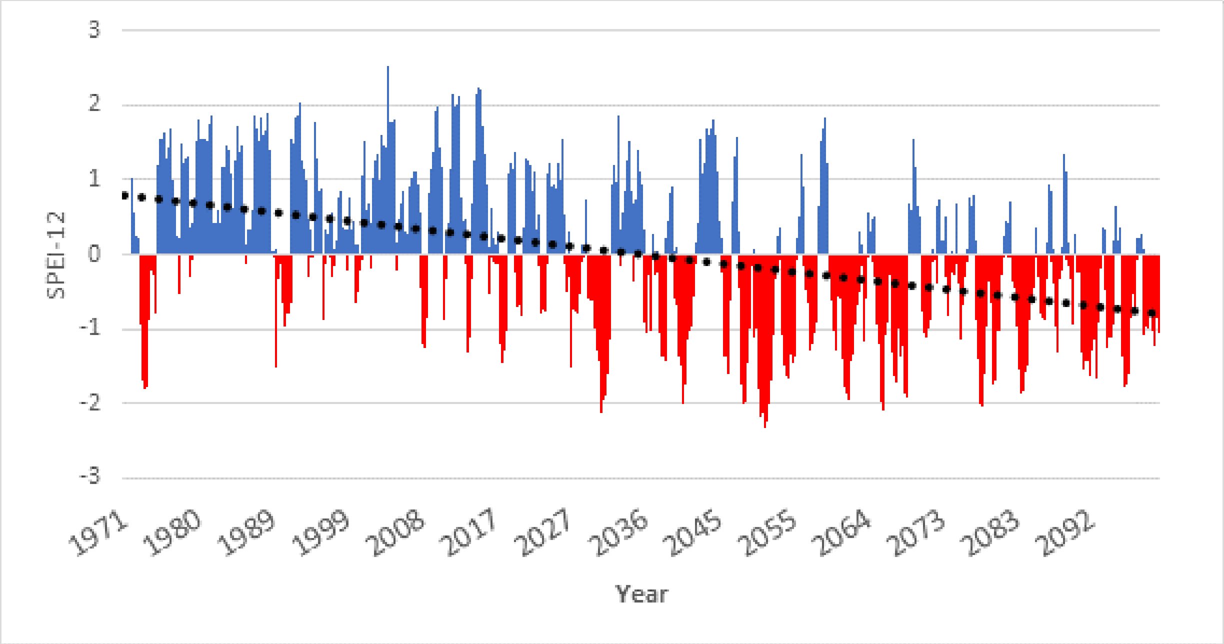

Figure 2: SPEI-12 for the Cyprus' reservoirs Kouri, Arminou, Lefkaron and Dipotamou (1970-2100)

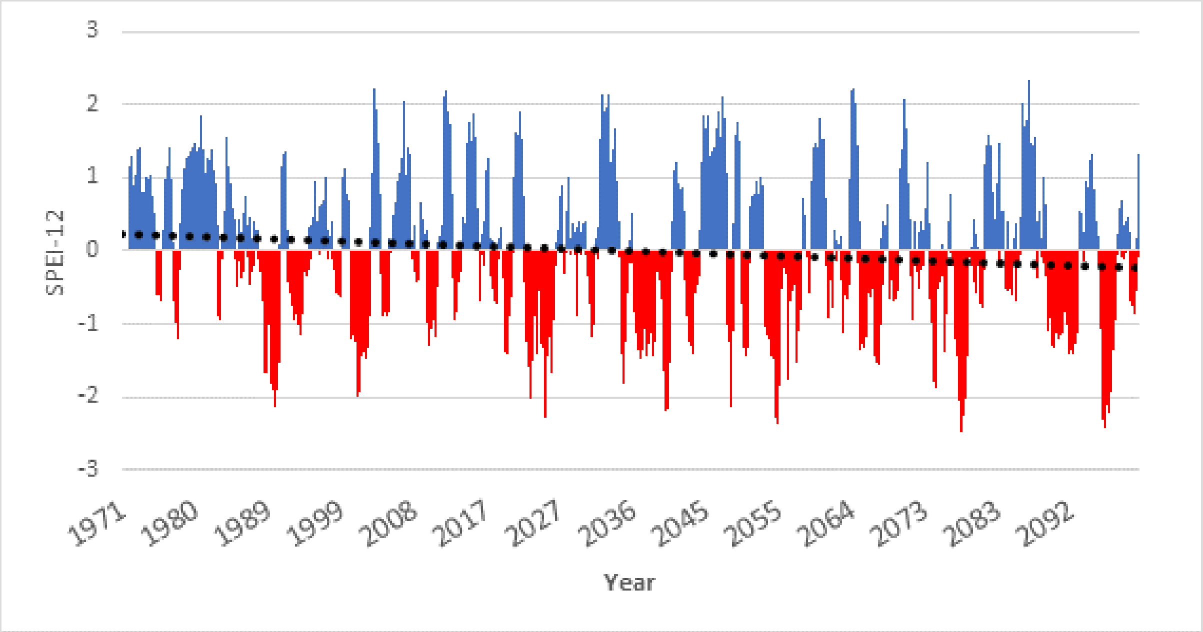

Figure 3: SPEI-12 for the Central Greece basin reservoirs of Mornos and Evinos (1970-2100)

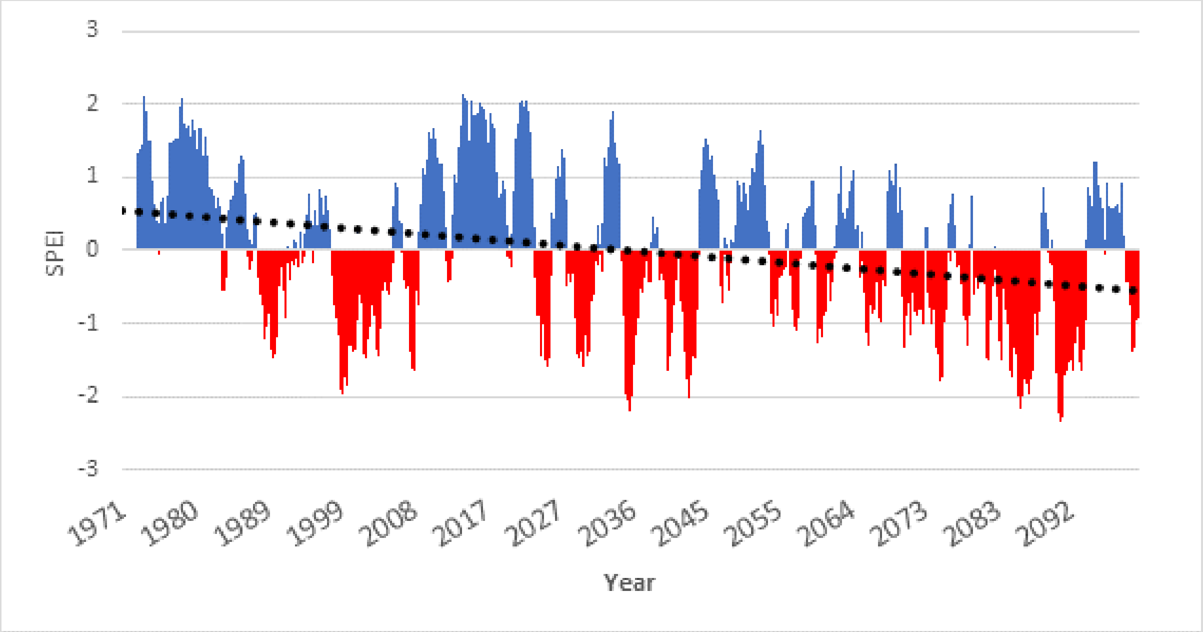

Figure 4: SPEI-24 for the aquifer of Enza in the Emilia-Romagna region, Italy (1970-2100)

To better reflect drought risk two terms were used, that of drought intensity and frequency. Drought intensity is classified based on McKee et al. (1997), while the first class of mild drought was further broken down into two individual classes in order for all classes to be of equal size and at the same time to turn into a five class system without any further need for normalization (see Table 17). To calculate overall drought intensity (DI_t) for a given period and location, the following formula was used:

$$\boldsymbol{Overall\ drought\ intensity, DI_t = \frac{\sum DF_i \times W_i}{\sum W_i}} \qquad \textbf{\textit{(Eq. 14)}}$$

Where *DF* refers to the drought frequency for a specific drought level *i* expressed as the number of months characterized with the specific drought level to the total number of months with drought (negative SPEI values) for the given period, *i* corresponds to the different drought classes A-E presented in Table 17 and *W* is the weight applied to each drought class. As can be seen in Table 17, increasing weights are applied to each drought class according to the level of drought in order to place emphasis on high drought levels. Drought frequency values for the different drought classes, DF_i, are expressed as percentages and then normalised to the 5-degree scale presented in Table 18. Finally, drought risk is estimated with the following formula:

$$\boldsymbol{Drought\ risk, DR = \sqrt{DI_t \times DF_t}} \qquad \textbf{\textit{(Eq. 15)}}$$

where DF_t refers to overall drought frequency and is calculated as the total number of months with drought (negative SPEI values) to the total number of months for the given period. It is firstly expressed as a percentage and then normalized with the use of the general scale for the normalization of percentage values provided in Table 19.

Table 17: Drought intensity classification and weighting

Drought intensity	Class	From	To	Weight
Mild drought	A	0	-0.49	1
	B	-0.5	-0.99	2
Moderate drought	C	-1	-1.49	3
Severe drought	D	-1.5	-1.99	4
Extreme drought	E	-2	<-2	5

Table 18: Drought frequency (DFi) normalization, classes A-E

Drought frequency		Normalized classes	
From	To	From	To
0.0%	5.0%	0	1
5.0%	10.0%	1	2
10.0%	15.0%	2	3
15.0%	20.0%	3	4
20.0%	100.0%	4	5

Table 19: Overall drought frequency (DFt) normalization

Drought frequency		Normalized classes	
From	To	From	To
0.0%	20.0%	0	1

20.0%	40.0%	1	2
40.0%	60.0%	2	3
60.0%	80.0%	3	4
80.0%	100.0%	4	5

The drought assessment results for the water bodies of the three countries supplying with domestic water the project municipalities are presented in Table 20, Table 21 and Table 22. In general, one may observe that overall drought intensity has an increasing trend with the exception of Cyprus and Greece during the period 2071-2100 where drought intensity slightly decreases compared to the period 2031-2060. Overall drought frequency has an increasing trend in all examined water bodies throughout the time periods. The overall results for the case of Cyprus show “low to moderate” drought risk (1.4) for the baseline scenario, “moderate” risk (2.9) for the period 2031-2060 and “moderate to high” risk (3.5) for the period 2071-2100. The results for the case of Greece show “moderate” drought risk for the baseline period and for the two future periods (2.0-2.5). Finally, the results for the case of Italy show “low to moderate” drought risk (1.9) for the baseline scenario and “moderate” risk (2.3-2.9) for the two future periods. It should be noted here that the results are useful for comparing drought risk levels between different periods of the same location and not between different locations. The change of drought risk in the future periods compared to the baseline period (Table 23), is very high for the case of the South Conveyor system where drought risk is almost double for both future periods (92-95% increase). Furthermore, a significant increase is also observed during the period 2071-2100 for the case of Enza aquifer (57%) while lower increases of about 28% are also observed for all other cases.

Table 20: Drought assessment results, South Conveyor system (Cyprus)

Drought class, i	Drought frequency, Df_i	1970-2000	2031-2060	2071-2100
[A] **0 to -0.49**	**Months**	58	58	98
	Share	64.4%	27.6%	39.4%
	Normalized	4.6	4.1	4.2
[B] **-0.5 to -0.99**	**Months**	22	40	69
	Share	24.4%	19.0%	27.7%
	Normalized	4.1	3.8	4.1
[C] **-1 to -1.49**	**Months**	2	69	48
	Share	2.2%	32.9%	19.3%
	Normalized	0.4	4.2	3.9
	Months	8	29	33

[D] **-1.5 to -1.99**	**Share**	8.9%	13.8%	13.3%
	Normalized	1.8	2.8	2.7
[E] **≤ 2**	**Months**	0	14	1
	Share	0.0%	6.7%	0.4%
	Normalized	0.0	1.3	0.1
Overall drought intensity, DIt (norm.)		**1.6**	**2.5**	**2.1**
Overall drought frequency, DFt (%)		25%	58%	69%
Overall drought frequency, DFt (norm.)		**1.3**	**2.9**	**3.5**
Drought risk, DR		**1.4**	**2.7**	**2.7**

Table 21: Drought assessment results, Central Greece basin (Greece)

Drought class, i	**Drought frequency, Df_i**	**1970-2000**	**2031-2060**	**2071-2100**
[A] **0 to -0.49**	**Months**	81	49	72
	Share	53.3%	25.7%	35.5%
	Normalized	4.4	4.1	4.2
[B] **-0.5 to -0.99**	**Months**	37	57	58
	Share	24%	30%	29%
	Normalized	4.1	4.1	4.1
[C] **-1 to -1.49**	**Months**	18	61	44
	Share	11.8%	31.9%	21.7%
	Normalized	2.4	4.1	4.0
[D] **-1.5 to -1.99**	**Months**	14	14	11
	Share	9.2%	7.3%	5.4%
	Normalized	1.8	1.5	1.1
[E] **≤ 2**	**Months**	2	10	18
	Share	1.3%	5.2%	8.9%
	Normalized	0.3	1.0	1.8
Overall drought intensity, DIt (norm.)		**1.8**	**2.4**	**2.2**
Overall drought frequency, DFt (%)		42%	53%	57%
Overall drought frequency, DFt (norm.)		**2.1**	**2.7**	**2.8**
Drought risk, DR		**2.0**	**2.5**	**2.5**

Table 22: Drought assessment results, Enza aquifer (Italy)

Drought class, i	Drought frequency, Df_i	1970-2000	2031-2060	2071-2100
[A] **0 to -0.49**	**Months**	75	90	68
	Share	52.1%	46.2%	27.5%
	Normalized	4.4	4.3	4.1
[B] **-0.5 to -0.99**	**Months**	24	49	76
	Share	17%	25%	31%
	Normalized	3.3	4.1	4.1
[C] **-1 to -1.49**	**Months**	33	32	48
	Share	22.9%	16.4%	19.4%
	Normalized	4.0	3.3	3.9
[D] **-1.5 to -1.99**	**Months**	12	18	46
	Share	8.3%	9.2%	18.6%
	Normalized	1.7	1.8	3.7
[E] **≤ 2**	**Months**	0	6	9
	Share	0.0%	3.1%	3.6%
	Normalized	0.0	0.6	0.7
Overall drought intensity, DIt (norm.)		**1.8**	**2.0**	**2.4**
Overall drought frequency, DFt (%)		39%	55%	70%
Overall drought frequency, DFt (norm.)		**1.9**	**2.8**	**3.5**
Drought risk, DR		**1.9**	**2.3**	**2.9**

Table 23: Change in drought risk compared to the reference period 1970-2000, % (normalized value)

Area	2031-2060	2071-2100
South Conveyor system	95% (5.0)	92% (4.9)
Central Greece basin	28% (1.9)	28% (1.9)
Enza aquifer	27% (1.9)	57% (3.0)

4.4. Water availability and drought impact assessment results

In the current section, the results of the previous sections are synthesized so as to calculate overall water impact based on Equation 3. As it may be seen in Table 24, the highest impact on water resources is expected for the case of Cypriot municipalities as they gather the highest score (5.0) in all future periods and scenarios. The climate change impact on water resources for Peristeri municipality is expected to be "moderate to high" (3.9) in all examined cases apart from the period 2031-2060 and RCP8.5 where the impact is expected to be "moderate" (2.4). The impact for Reggio Emilia municipality is expected to be "moderate to high" (3.7-3.9) in all cases apart from the period 2071-2100 and RCP4.5 where the impact is estimated to be "high" (4.6).

Table 24: Summarized results for the water availability and droughts impact

Municipality	**RCP**	**Period**							
		2031-2060				**2071-2100**			
		WEI	**DR**	**V**	**I_W**	**WEI**	**DR**	**V**	**I_W**
Strovolos & Lakatamia	**4.5**	4.5	5	1.17	**5.0**	5	4.9	1.17	**5.0**
	8.5	4.6	5	1.17	**5.0**	4.2	4.9	1.17	**5.0**
Peristeri	**4.5**	4.3	1.9	1.25	**3.9**	4.3	1.9	1.25	**3.9**
	8.5	1.9	1.9	1.25	**2.4**	4.3	1.9	1.25	**3.9**
Reggio Emilia	**4.5**	4.3	1.9	1.25	**3.9**	4.4	3	1.25	**4.6**
	8.5	4.4	1.9	1.25	**3.9**	2.9	3	1.25	**3.7**

Following, the impact assessment results for water resources are presented in the form of maps.

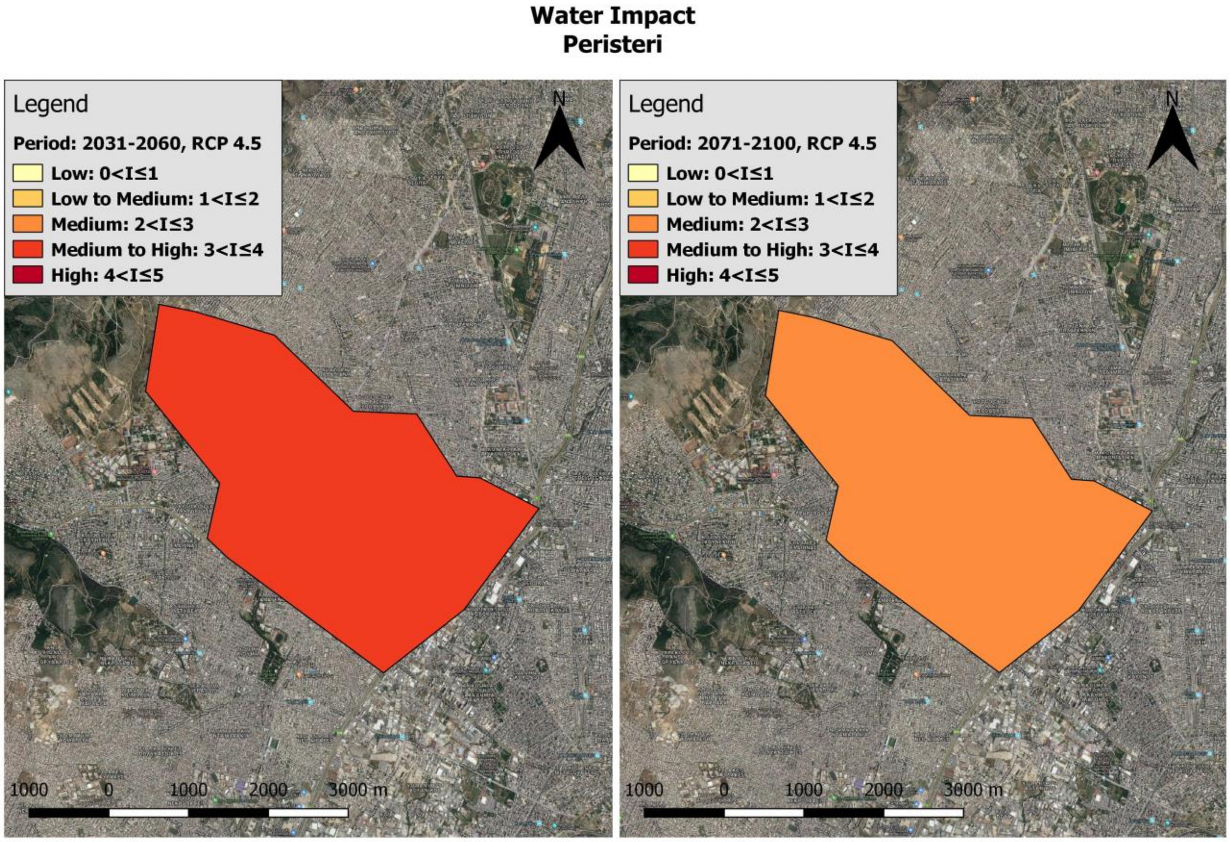

Figure 5: Water impact maps of Peristeri for scenario 4.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

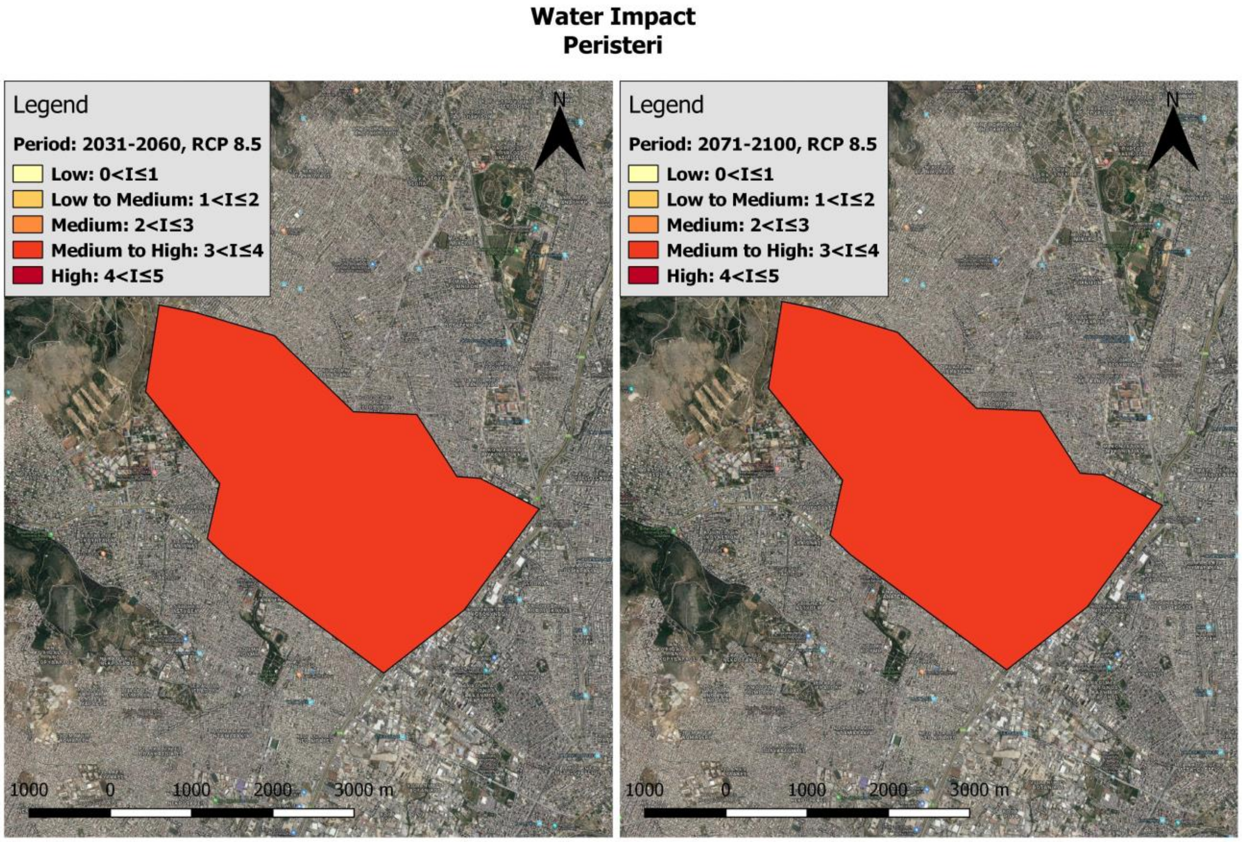

Figure 6: Water impact maps of Peristeri for scenario 8.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

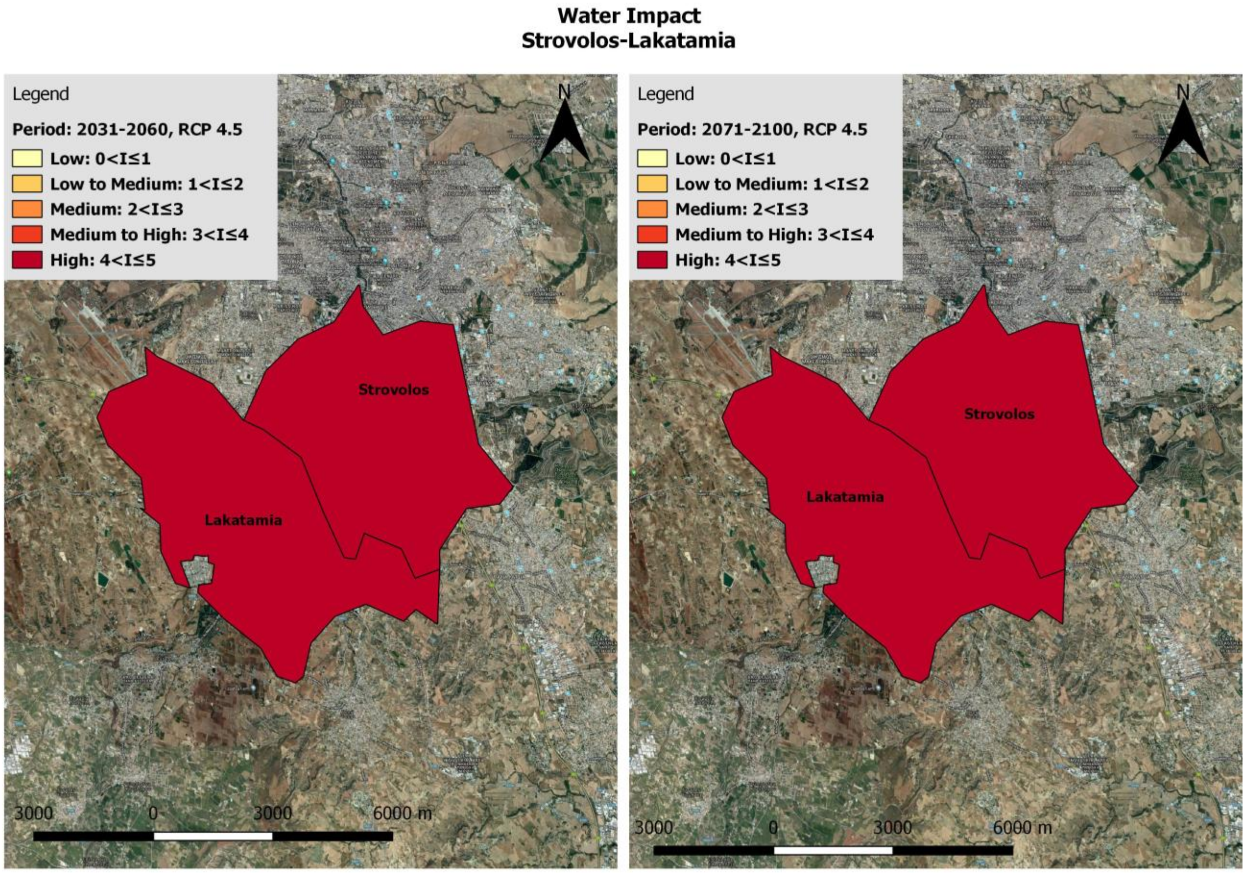

Figure 7: Water impact maps of Strovolos and Lakatamia municipalities for scenario 4.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

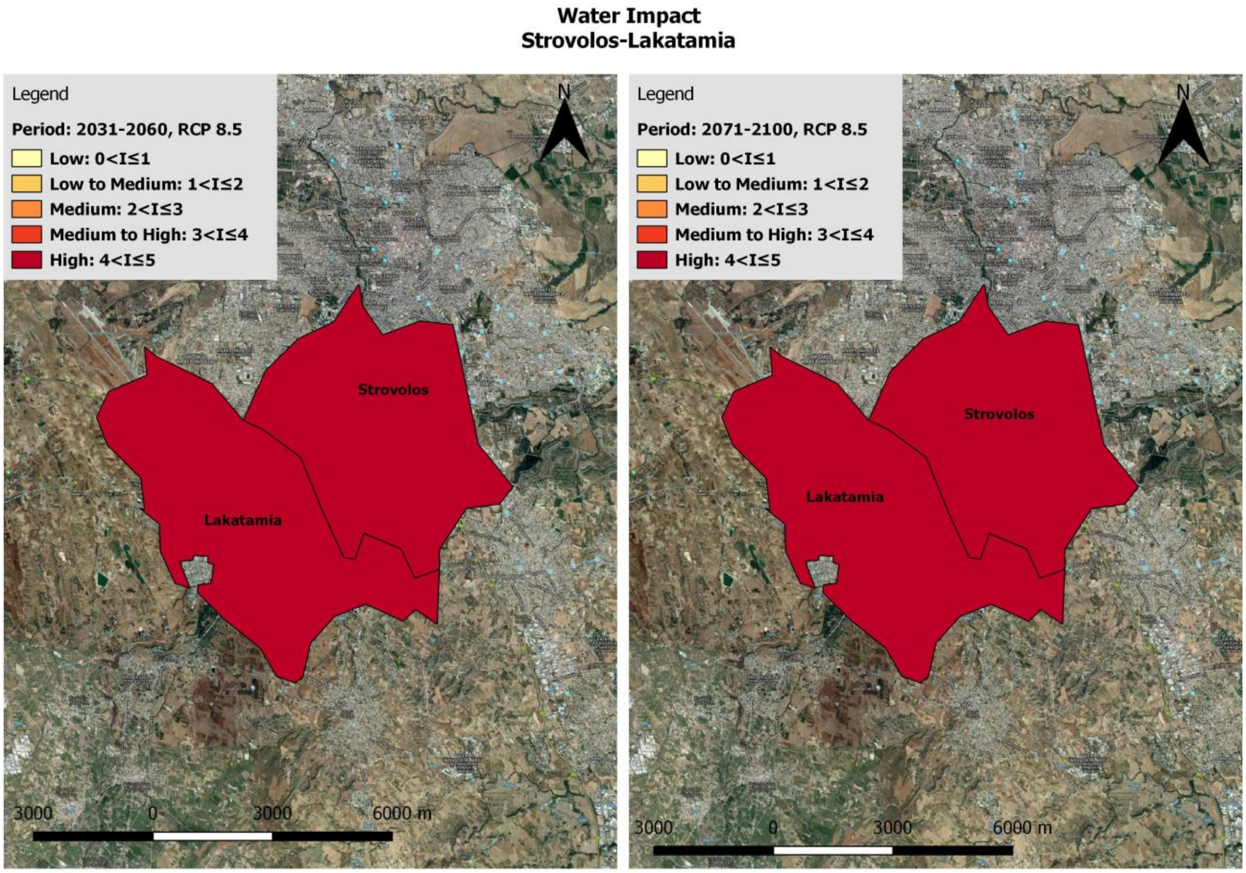

Figure 8: Water impact maps of Strovolos and Lakatamia municipalities for scenario 8.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

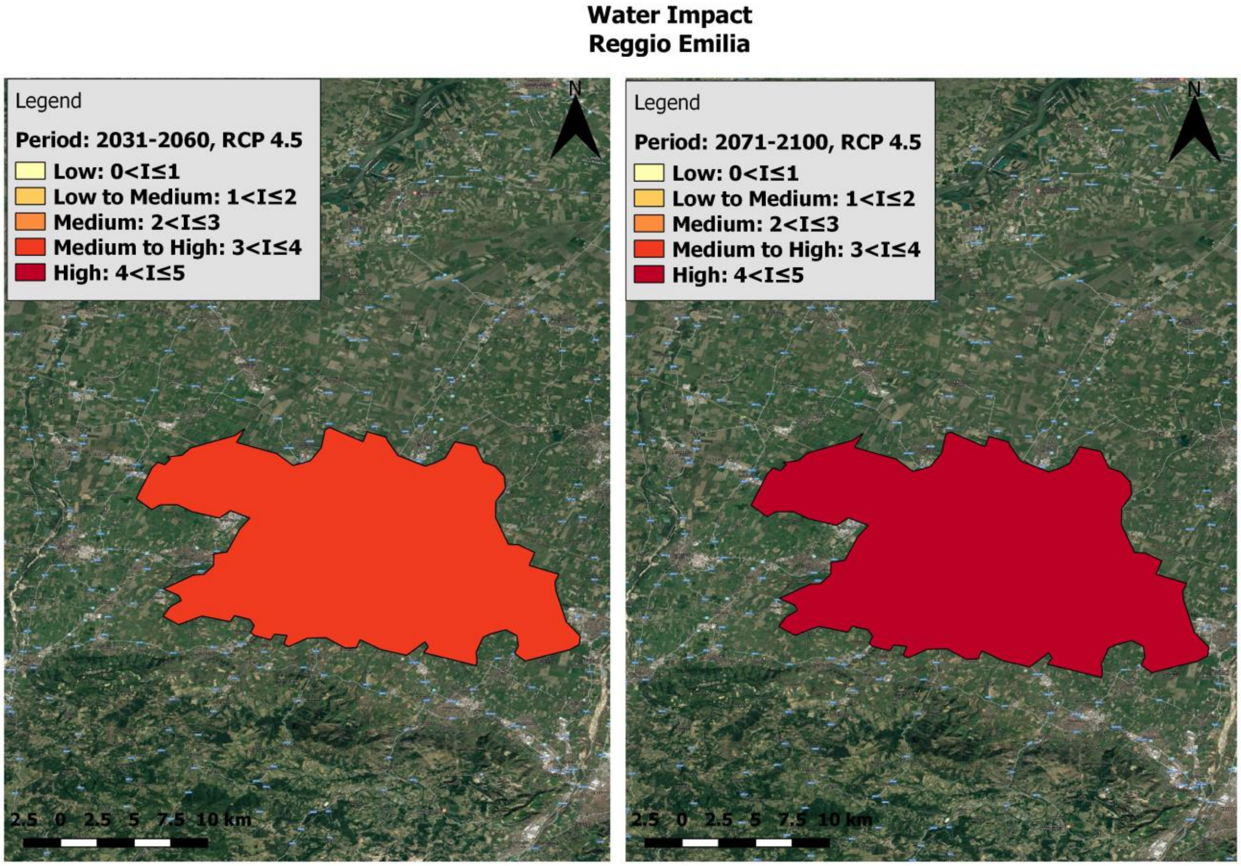

Figure 9: Water impact maps of Reggio Emilia municipality for scenario 4.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

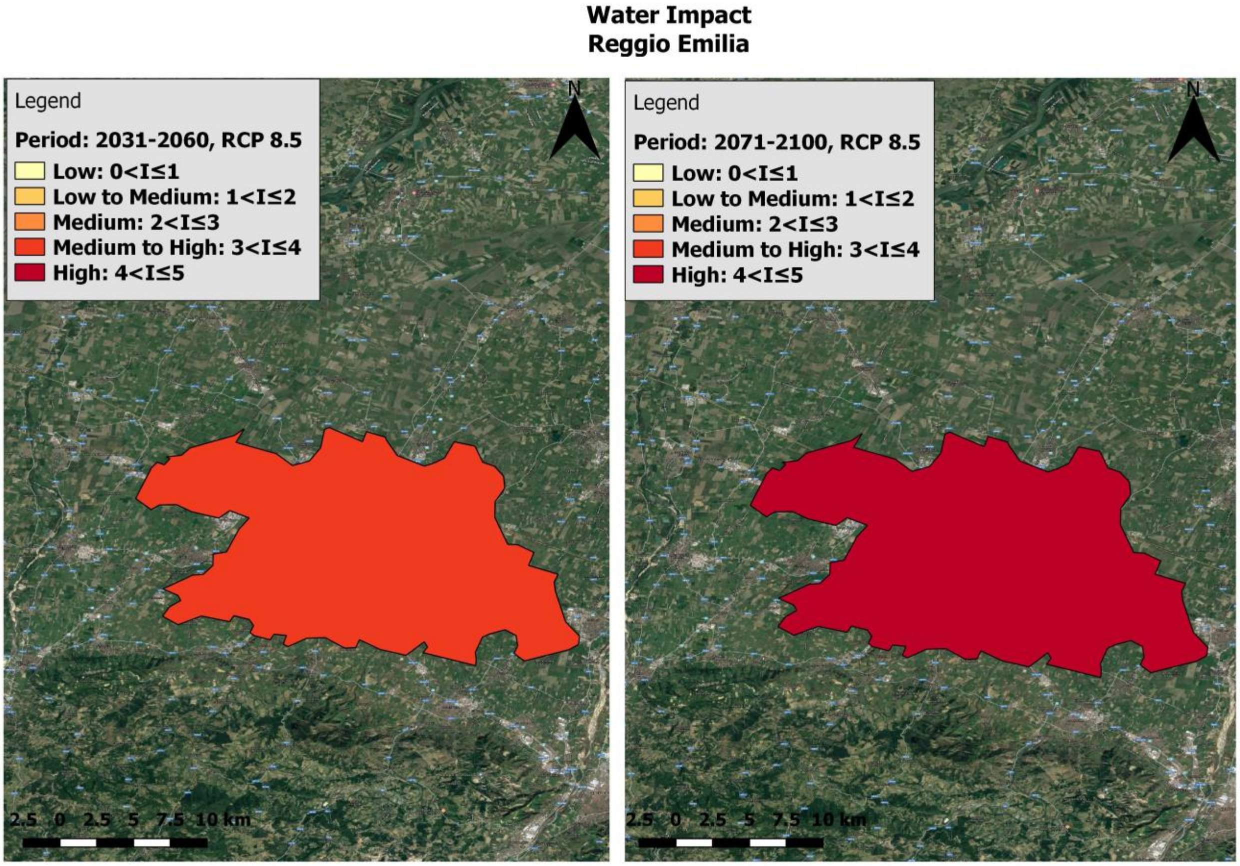

Figure 10: Water impact maps of Reggio Emilia municipality for scenario 8.5. Time period 2031-2060 (left) and time period 2071-2100 (right)

5. Flood impact assessment

For the assessment of flood impact in the project municipalities, a number of hazard, exposure and social vulnerability indicators were used according to Equations 1 and 2.

With respect to the hazard indicators which are related to the climatic information, an investigation of the trends in relevant climatic indicators took place, such as the projected maximum precipitation within one day and five days, as well as, the projected number of heavy and very heavy precipitation days. However, the investigation revealed no statistical significant trends during the examined future periods in all municipalities under both future emission scenarios, RCP4.5 and RCP8.5. Therefore, it was decided to alternatively assess flood hazard.

In particular, flood hazard maps produced by the competent national authorities in compliance with the Floods Directive 2007/60/EC were used for identifying the location and extent of the area potentially affected by flooding (flood hazard zone) in each municipality. The precipitation levels taken into account for the construction of the flood hazard maps for the different flood return periods were correlated to the projected precipitation levels provided by the National Observatory of Athens in the frame of this project, in order to select those flood hazard maps referring to the flood return period which is closer to the projected precipitation levels. The correlation showed that precipitation levels of the 100-year flood return periods are closer to the projected ones in all areas under examination, and therefore the respective maps were used. All areas within the flood hazard zone were assigned a value of “3”, which correspond to a medium level hazard according to the rating scale used in the current study (see Table 1).

The hazard indicator is enhanced with an extra weight where low-lying areas (inclination: $<1^o$) are located next to rivers. In particular, hazard is multiplied with the normalized value of the percentage coverage of low-lying areas in each land use polygon. The normalization is made based on the classification scale presented in Table 25. The information on low-lying areas is provided for each project municipality through Action C1.2 of the project (for more information see Deliverable C1.2).

Table 25: Normalization of low-lying area coverage values

Initial classes		Normalized classes	
From	**To**	**From**	**To**
0.0%	20.0%	1.0	1.15
20.0%	40.0%	1.15	1.30
40.0%	60.0%	1.30	1.45

60.0%	80.0%	1.45	1.60
80.0%	100.0%	1.60	1.75

Exposure to floods takes into account both population and critical infrastructure within the flood hazard zone. In particular for the former, the quantity and spatial distribution of population expressed as population density was used. This indicator serves thus as proxy for expected number of residents exposed to the risk of flooding. The information on population is available at the level of building blocks and land use polygons in general through the Urban Atlas database of the Copernicus Land Monitoring Service. Next, the population data were processed with the use of GIS software in order to calculate population density for each polygon (inhabitants per Km2). Due to the high fluctuation of population density among the project municipalities and for simplicity purposes, the decimal logarithm of all population densities of each land use polygon of each municipality, was used. For the classification, the range was divided into 5 equal classes with scores ranging from 0 to 5, from very low population density to very high, as shown in Table 26.

Table 26: Normalization of population density values (Log10 inh/km2)

Initial classes		Normalized classes	
From	**To**	**From**	**To**
0.0	0.1	0	1
0.1	2.2	1	2
2.2	3.4	2	3
3.4	4.5	3	4
4.5	5.6	4	5

The exposure is also estimated with respect to the critical infrastructure exposed to floods, such as hospitals, schools, commercial and industrial areas, public facilities, cultural units and transport infrastructure. The flood zone areas where critical infrastructure is located may indicate at the same time the exposure of population and of the critical infrastructure to floods. A failure of critical infrastructure means a substantial disturbance of public life and undermine the security of service supply. The scores assigned to the land use polygons where critical infrastructure is located are based on the scores proposed by the Special Secretariat for Water (2017) for the flood vulnerability and risk assessment methodology. In particular, the proposed classification was in a slightly different 5-degree rating scale and it was adjusted so as to fit the scale used in the current study (Table 1). The final scores used are presented in Table 27.

Table 27: Critical infrastructure category values

Category	Values
Education units	2.5
Health units	3.5
Cultural units	0.5
Industrial, commercial areas and public facilities	2.5
Other roads and associated land	2.0
Railways and associated land	2.5
Fast transit roads and associated land	2.5

The social vulnerability indicators that were taken into account in the flood impact assessment are the age, the illiteracy, the low-income, the chronic diseases and the number of hospital beds (for more information see section 3). The impact assessment formula, as this is formed for the case of floods is presented next:

$$\boldsymbol{I_{floods} = bH * (P + I) * aVs} \qquad \textit{(Eq. 16)}$$

Where, I_{Floods} the flood impact, ***H*** the flood hazard zone (value set to 3), ***b*** the weight of the hazard indicator for the low-lying areas, ***P*** the population exposure, ***I*** the exposure of critical infrastructure, ***Vs*** the composite social vulnerability index for floods and ***a*** the weight applied to the social vulnerability to denote its contribution to the overall impact assessment (value set to 0.4).

As one may observe, the equation above does not take into account the retainment of run-off and the increase of infiltration capacity where areas with green space (vegetation, trees etc.) are maintained. The effect of green space in reducing the flood impact is estimated with the use of Equation 3, where adaptation is quantified by means of runoff coefficients. In particular, while a built residential or commercial/industrial area is characterized by a runoff coefficient of 0.7 on average, a green area within a municipality (e.g. a sparsely vegetated area or a forest area with <50% of the land covered) has a runoff coefficient of 0.33-0.44 (Zimmermann et al., 2016). Therefore, it may be suggested that the green areas reduce the impact of floods in approximately half of the initially estimated impact. Geospatial information on the green areas provided for all the project municipalities in the frame of Action C1.2 is exploited in the current study to assess the green area coverage in each land use polygon and the adaptation effect. In the table that follows the respective rating scale for adaptation is presented.

Table 28: Normalization of the adaptation indicator on green area coverage

Initial classes		Normalized classes	
From	**To**	**From**	**To**
0%	20%	0	0.5
20%	40%	0.5	1.0
40%	60%	1.0	1.5
60%	80%	1.5	2.0
80%	100%	2.0	2.5

The proposed rating scale will be tested, calibrated and further defined with field measurements, during the monitoring of the performance of the green infrastructure measures that will be implemented in the project municipalities during Action C.7 of the project.

The flood impact assessment results are presented in the table that follows as well as in the following maps. As it may be seen, the municipality of Peristeri is expected to face the most significant flood impacts with the flood zone covering 29% of its total area, and an overall impact score of the flood zone area classified as “high” (4.6), which is translated to a “medium to high” overall impact score for the municipality (3.7). Next is the municipality of Strovolos and Lakatamia with a “medium” overall flood impact score for the municipality (2.4 and 2 respectively) and the municipality of Reggio Emilia with a “low to medium” overall flood impact score for the municipality (1.5).

Impact class	Peristeri	Strovolos	Lakatamia	Reggio Emilia
Low (0-1)	1.2%	4.3%	4.5%	36.9%
Low to medium (1-2)	1.5%	0.2%	5.4%	8.1%
Medium (2-3)	7.9%	36.7%	53.9%	46.3%
Medium to high (3-4)	18.6%	12.6%	8.5%	6.5%
High (4-5)	70.8%	46.1%	27.8%	2.2%

Impact class	Peristeri	Strovolos	Lakatamia	Reggio Emilia
Overall impact score of the flood zone area [A]	**4.6**	**4.0**	**3.5**	**2.3**
Share of the flood zone area to the municipality area (%)	28.9%	8.1%	5.9%	7.8%
Share of the flood zone area to the municipality area (norm) [B]	**2.9**	**0.8**	**0.6**	**0.8**
Overall flood impact score of the municipality [C]=[A*B] $^{1/2}$	**3.7**	**2.4**	**2.0**	**1.5**

The percentage values depicting the share of the flood zone area to the municipality area have been normalized based on Table 29.

Table 29: Normalization of the % share of the flood zone area to the municipality area

Initial classes		Normalized classes	
From	**To**	**From**	**To**
0%	10%	0	1
10%	20%	1	2
20%	30%	2	3
30%	40%	3	4
40%	100%	4	5

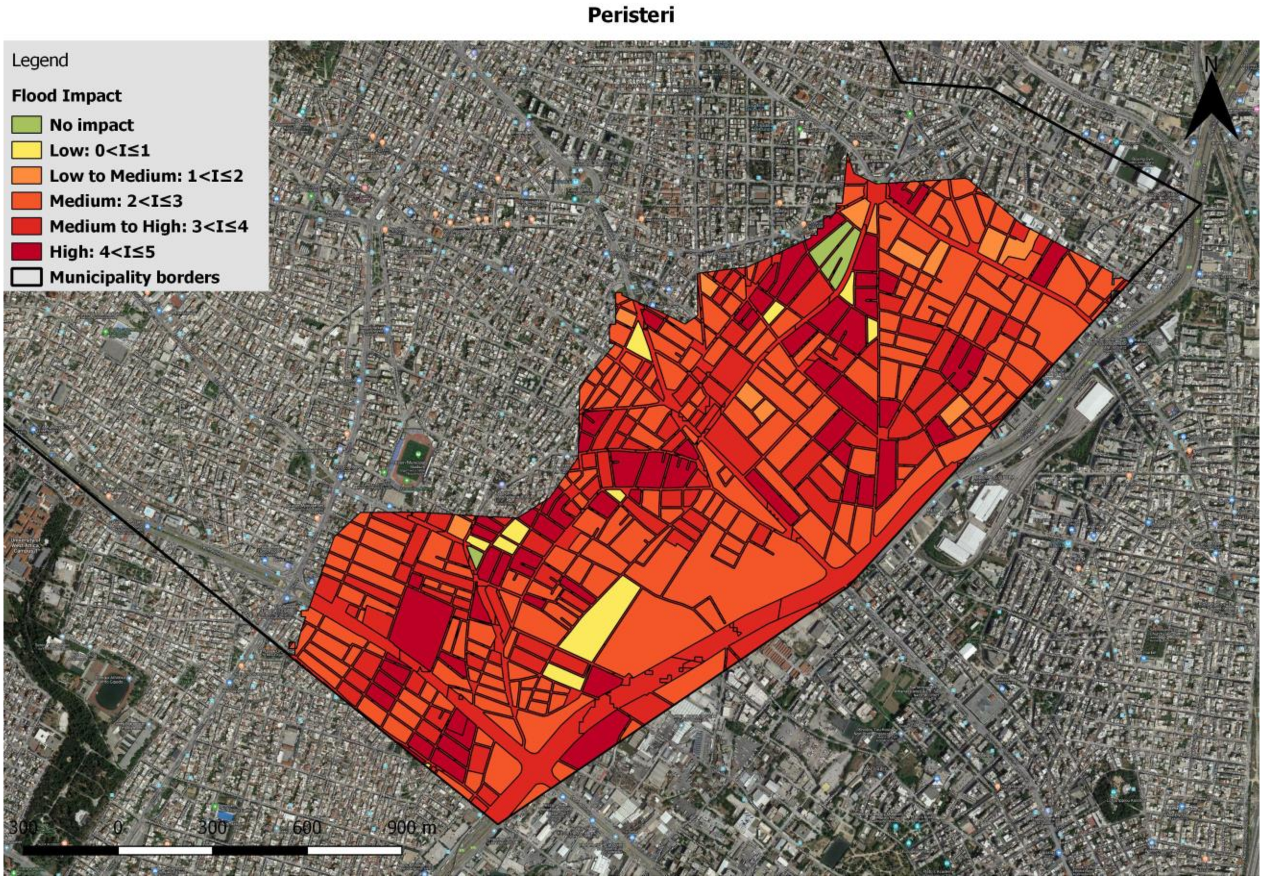

Figure 11: Flood impact map – Peristeri municipality

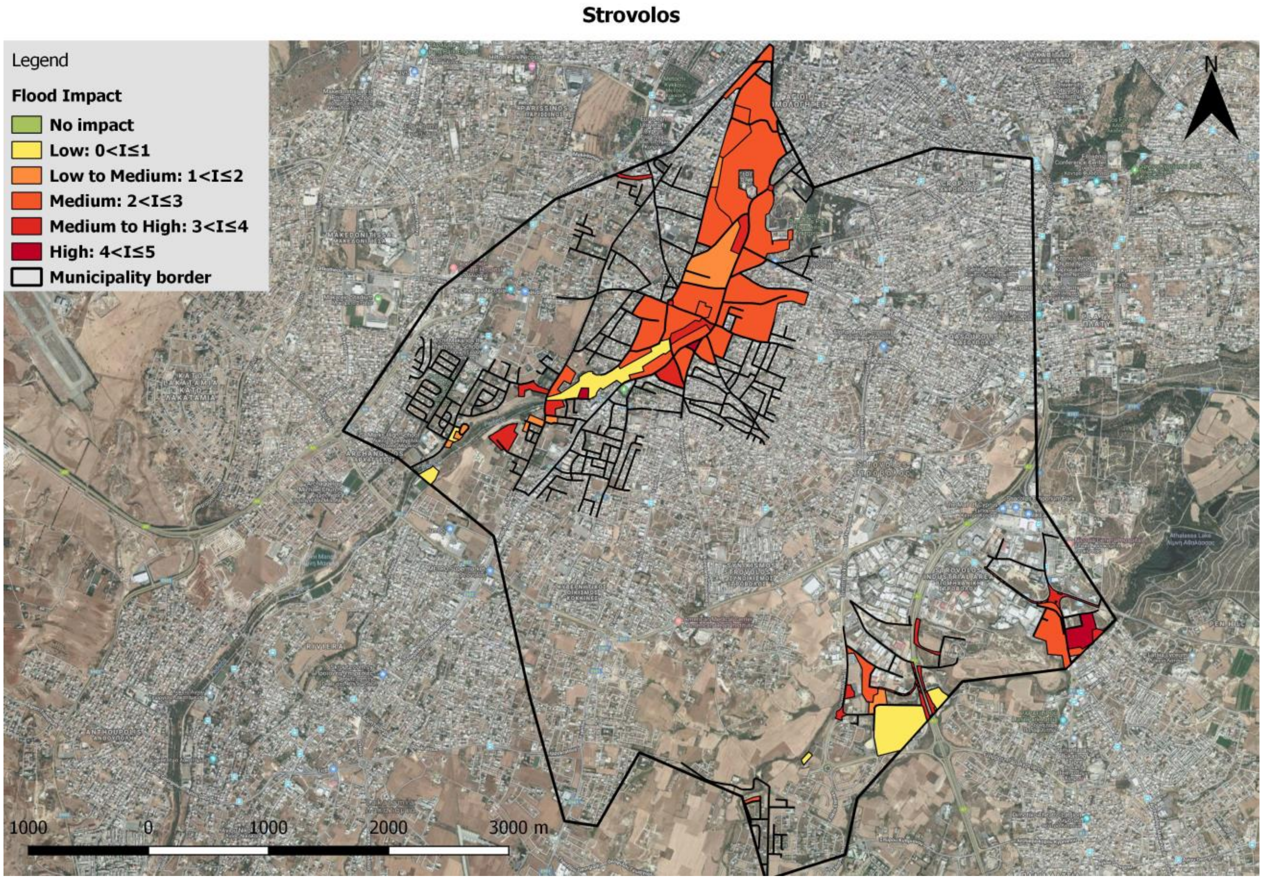

Figure 12: Flood impact map – Strovolos municipalities

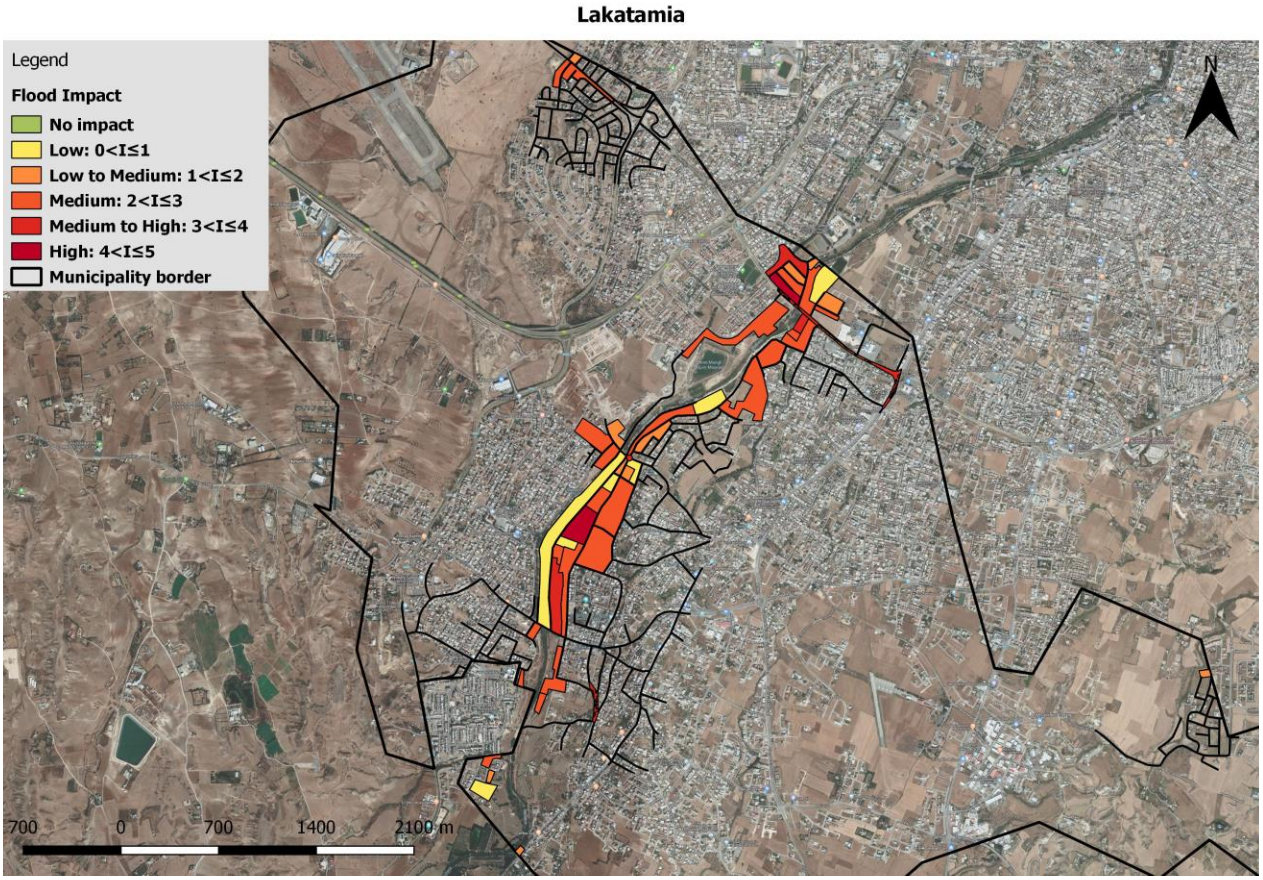

Figure 13: Flood impact map – Lakatamia municipality

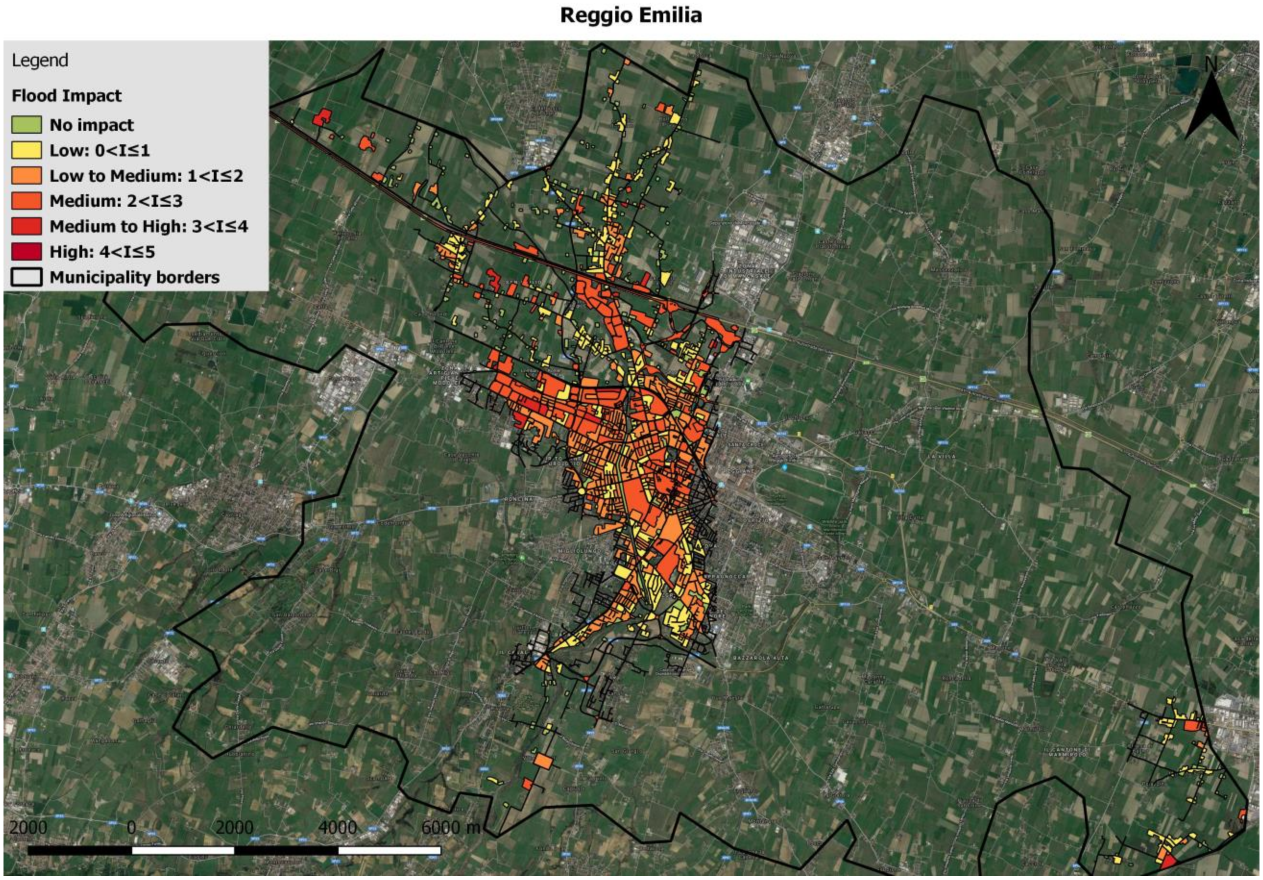

Figure 14: Flood impact map – Reggio Emilia municipality

6. Adaptation assessment

For the adaptation assessment, a review of the available adaptation measures for addressing water availability and flood climate change impacts took place. Following, a questionnaire was developed for the evaluation of the adaptation measures based on a set of criteria (Multi-Criteria Analysis, MCA). Potential adaptation measures evaluation was based on four criteria related to efficiency, environmental friendliness, economic viability and job growth. The measures were evaluated against these criteria by a number of experts & stakeholders (national, regional, local authorities; neighbouring municipalities and Unions; NGOs & CSOs; companies; academic bodies & research institutes) from Italy, Greece and Cyprus. The evaluation scores are presented in the tables that follow, with the total score corresponding to the average value of the scores attained to the four criteria. The total score was used for the prioritization of the adaptation measures in their inclusion to the adaptation strategies of the project municipalities.

Furthermore, the effect of the adaptation measures in moderating the impacts of water availability and floods (impact after adaptation) is presented in the last column of the tables, where the score attained under the criteria "Efficiency in addressing the impact" was subtracted from the maximum impact score of "5", according to Equation 3.

Table 30: Evaluation results of water availability adaptation measures

Adaptation measures	**Criteria**					**Impact after implementation of the measure**
	Efficiency in addressing the impact	Environmental Friendliness	Economic Viability	Job growth	**Total score**	
Water saving appliances for buildings	4.1	4.3	2.4	2.7	**3.4**	**0.9**
Rain gardens	3.1	4.1	2.7	2.3	**3.1**	**1.9**
Greywater re-use (domestic)	3.4	3.9	3.1	1.6	**3.0**	**1.6**
Lake restoration	3.4	4.2	1.3	3.1	**3.0**	**1.6**
Water metering systems	3.3	4.0	2.6	1.9	**2.9**	**1.7**
Infiltration / Detention basins	3.3	3.7	2.5	2.1	**2.9**	**1.7**
Rehabilitation of water distribution network	3.3	3.5	2.5	2.5	**2.9**	**1.7**
Rainwater harvesting at buildings	3.0	3.9	2.8	1.7	**2.8**	**2.0**
Wastewater treatment plants	3.5	3.4	1.7	2.7	**2.8**	**1.5**
Riverbed material restoration and re-naturalization	2.9	4.0	1.9	2.4	**2.8**	**2.1**

Adaptation measures	Criteria					Impact after implementation of the measure
	Efficiency in addressing the impact	Environmental Friendliness	Economic Viability	Job growth	**Total score**	
Permeable paving	2.8	3.6	2.6	2.1	**2.8**	**2.2**
Infiltration trenches and Swales	3.1	3.6	2.2	2.2	**2.8**	**1.9**
Artificial groundwater recharge through wells	2.8	3.3	2.9	1.7	**2.7**	**2.2**
Soakaways	3.1	3.3	2.2	2.1	**2.7**	**1.9**
Desalination	3.6	2.4	1.9	2.7	**2.7**	**1.4**
Water restrictions	2.7	3.6	3.8	0.5	**2.6**	**2.3**
Re-meandering	2.8	3.4	1.1	2.8	**2.5**	**2.2**
Dikes and dams re-enforcing	2.6	2.1	1.5	2.5	**2.2**	**2.4**

Table 31: Evaluation results of flood adaptation measures

Adaptation measures	Criteria					
	Efficiency in addressing the impact	Environmental Friendliness	Economic Viability	Job growth	**Total score**	**Impact after implementation of the measure**
Trees in urban areas	3.3	4.6	3.3	2.0	**3.3**	**1.7**
Retention ponds	4.1	3.6	1.8	2.8	**3.1**	**0.9**
Forest riparian buffers	3.3	4.5	2.3	2.0	**3.1**	**1.7**
Riverbed material restoration and re-naturalization	3.8	3.9	1.5	2.9	**3.0**	**1.2**
Lake restoration	3.8	4.2	1.1	2.8	**2.9**	**1.2**
Channels and rills	3.4	3.6	1.8	3.0	**2.9**	**1.6**
Filter strips	3.2	3.8	2.3	2.4	**2.9**	**1.8**
Green Roofs	3.1	4.0	1.6	2.9	**2.9**	**1.9**
Permeable paving	3.4	3.3	2.2	2.6	**2.9**	**1.6**
Infiltration trenches and Swales	3.7	3.3	2.3	2.2	**2.9**	**1.3**
Rain gardens	3.3	3.6	2.5	2.1	**2.8**	**1.7**
Infiltration / Detention basins	3.8	3.2	1.8	2.3	**2.8**	**1.2**

Adaptation measures	Criteria					
	Efficiency in addressing the impact	Environmental Friendliness	Economic Viability	Job growth	**Total score**	**Impact after implementation of the measure**
Sediment capture ponds	3.5	3.2	2.3	2.0	**2.7**	**1.5**
Re-meandering	3.5	3.3	1.4	2.6	**2.7**	**1.5**
Soakaways	3.1	2.6	1.6	2.5	**2.5**	**1.9**
Dikes and dams re-enforcing	2.6	1.8	0.7	2.7	**2.0**	**2.4**

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