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Challenges of the water supply of Croatian islands in conditions of climate change and tourism growth

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Based on the analysis of water supply, tourist traffic and climatic parameters, the paper assesses the sustainability and possibilities of adapting the water supply system in the future, considering the simultaneity of the peak loads on the water supply system with dry periods in the warm part of the year. The research covers islands from the northern and middle part of the Adriatic Sea (Croatia), which represent examples of islands with Cfa and Csa climates with significant differences in resource reliance on the island and coastal water resources. Given that previous climatological research indicates an increase in spring and summer temperatures on the Croatian coast, as well as spatial and seasonal changes in the amount of precipitation with a decrease during the summer months, the paper describes the possibilities of adapting current and alternative sources of water supply systems on the islands.

Keywords: sustainability, islands, water supply, climate change, tourism, Adriatic Sea

1. INTRODUCTION

From the beginning of civilization to the present day, sustainable water supply has been and remains one of the fundamental limiting development preconditions on which the daily life and economy of local communities rely. This fact is particularly evident in geographically isolated areas such as islands, which are showing different ways of adaptation of local communities, often in conditions of limited natural resources such as available drinking water. In the context of increasingly pronounced recent climate changes and the increase in tourism on the island, the question of the resilience of the island's water supply systems arises in likely scenarios of increasing water supply requirements with decreasing resource support.

This research continues a series of studies already carried out that recognized the issue of the sustainability of water supply on the Croatian islands. The main characteristics of the islands' water supply system are seasonal pressure on the system under a significant peak of the summer tourist season, the simultaneous increase in the number of weekenders on the islands and the trend of increasing high temperatures and increasingly frequent dry periods. Scientists from several fields have dealt with the issue of sustainable water supply on the Adriatic islands until today, and this topic has attracted the interest not only of the Croatian but also of the international scientific community. Among the works that consider the sustainability of water supply on Croatian islands, in the context of tourism and climate change, the following works should be highlighted: Bagarić et al. (1997), Bonacci and Roje-Bonacci (2004), Grofelnik (2017), Lukač Reberski et al. (2020), Luttenberger (2013), Margeta (2022), Muselli et al. (2009), Patekar et al. (2022), Slavuj et al. (2009), Terzić (2004), Terzić (2022b), Terzić and Marković (2010), Tomas and Blaž (2022), Turk (1989) and Vlašić (2022). From the mentioned papers, it is evident that the tourist-attractive areas of the Adriatic islands are not homogeneous in terms of the sustainability of the water supply. This research observes and analyses the differences in the water supply on islands and makes proposals for improving the sustainability of water supply in the context of modern increased pressures on water supply systems.

The aim of this paper is to show the possibilities of adaptation and increasing the resilience of the island's water supply systems in the conditions of growing demands with regard to available water resources, existing infrastructure and tourism growth, the energy crisis and the impact of climate change.

In order to achieve the given goal of the research, a basic research question was posed, which was further elaborated by determining lower-order tasks. The basic research question to which this paper answers is: What are the differences in the sustainability of island water supply systems on which the local community and tourism of Croatian islands rely, and what are the possibilities of sustainability and adaptation to future water supply challenges? In order to answer the given question, the research set out to determine: specific differences between the islands of the Adriatic Sea, with regard to climatic characteristics and climate changes, differences in the tourist load of the water supply system, the possibilities of sustainability and adaptation of the existing water supply system, and the possibilities of alternative water supply that affect future sustainability and island development.

The purpose of determining the specifics, differences and possibilities of action regarding the sustainability of water supply systems on the Croatian islands is to contribute to the design of interventions through planning documents and project ideas that could in the future contribute to the resistance of island communities to the challenges brought by climate change with a simultaneous likely increase in water consumption for tourism.

Four islands in the Adriatic Sea (Republic of Croatia) were selected for the case study that deals with the relationship between climate change, tourism pressure, and alternative water supply options to increase the water supply self-sufficiency of island communities. The differences in the current situation, as well as future impacts on the water supply system on the islands, were analysed, and two pairs of islands in two different climatic areas in the Adriatic area were selected. The pairs of islands were chosen in such a way that one of the islands pair has a water supply system linked to the mainland hinterland, while on the other islands pair water supply system relies on the water resources of the island itself. The different climatic features that have a significant impact on water supply were also analysed. The islands of Rab, Cres and Lošinj were selected within the area of Cfa climate (Cres and Lošinj have a common water supply system), while for comparison the islands of Brač and Vis were selected within the area of Csa climate.

Table 1 *Areas and number of inhabitants of the island for the period 2015-2020*

Jedinice lokalne samouprave / Local Administrative Units	Površina / Area (km²)	Procjena broja stanovnika sredinom godine / Estimated Number of Inhabitants in the Middle of the Year 2015.	2016.	2017.	2018.	2019.	2020.
Otoci / the Islands of Cres and Lošinj	480,1	11084	11018	10889	10812	10783	10858
Otok / the Island of Rab	86,1	9420	9315	9234	9207	9125	9145
Otok / the Island of Brač	395,4	14608	14548	14519	14648	14790	14818
Otok / the Island of Vis	89,7	3559	3528	3546	3536	3552	3575

Izvor / Source: Državni zavod za statistiku (2023), Ministarstvo regionalnog razvoja i fondova Europske unije (2021)

The islands of Cres, Lošinj, Rab, Brač and Vis are part of the wider Adriatic carbonate platform. They they share with it similar features of the basic geological structure, which decisively affects the karst characteristics of the islands, and results in relatively scarce local potential for water supply. In the area of the studied islands, there are no permanent surface water flows due to the pronounced porous and permeable characteristics of the limestone karst substratum. Very soon after contact with the karst substrate, the precipitation completely infiltrates into the subsoil (Terzić et al. 2022b). Surface torrential shorter surface flows are formed exclusively for heavy rainfall. The appearance of puddles on the islands is also significant, which were once crucial for the maintenance of traditional animal husbandry, while today they represent oases of biodiversity and support the islands biocapacity. Freshwater puddles on the islands are naturally predisposed depressions in the karst relief that were often subject to by anthropogenic modifications so that water was available in them throughout the year.

The islands have a layered to partially scaly geological structure, which predominantly consists of limestone deposits of Cretaceous and Quaternary age, on which the karst relief is developed. On the islands, we can follow the slight curvature of the structures that roughly follow the coast, that is, the Dinaric direction of extension northwest-southeast. The rocks are almost exclusively from the sedimentary group with the exception of minor occurrences of volcanic rocks on the island of Vis around Komiža (Terzić et al. 2022a). In the context of water supply, minor occurrences of Paleogene flysch deposits (especially in the area of Lopar on the island of Rab) are also important, which enable local water retention and the appearance of smaller sources of fresh water that are used for water supply purposes.

The only permanent larger surface water in the researched area is Lake Vrana, whose water is used in the water supply of Cres and Lošinj. Lake Vrana on the island of Cres has a volume of 220 million m^3 of high-quality water. The lake is a crypto-depression with an area of 5.75 km^2 and a volume of about 220 million m^3. By monitoring the water level in the lake during the 1980s, it was established that increased pumping of water, especially during the summer tourist season, causes its level to lower, and the causes and consequences of this phenomenon began to be investigated. The researches (Biondić et al. 1995; Bonacci, 1995; Ožanić & Rubinić, 1998) stand out, and they established that the average annual amount of precipitation in the basin of Lake Vrana is 1068 mm, the average annual amount of evaporation from the surface of the lake is 1153 mm, and the annual amount of water pumped from the lake is slightly more than 2 million m^3. The balance of these figures speaks of the obvious vulnerability of the lake during the seasonal summer caused by increased amounts of pumped water and the lake's feeding with water from the underground, which may be exposed to salinity. The sustainability of the water supply to the islands of Cres and Lošinj from Lake Vrana needs to be systematically and continuously monitored to prevent salinization of the aquifer and the lake itself (Grofelnik, 2017; Ožanić & Rubinić, 1998).

The climatic features of the selected islands indicate the complexity of the climate's impact on the water supply, and one of its basic features is the pronounced summer dryness, which is more pronounced towards the southern part of the Adriatic Sea. This is especially evident on the offshore islands of the central and southern part of Dalmatia, where in certain years one or two summer months could be without any precipitation. In such conditions, even relatively small observed climate changes can have a large impact on the water balance, which impacts the availability of water during the summer. The trends of temperature increase, especially in summer months, were determined, while the change in the amount of precipitation is not spatially uniform, although most studies indicate a decrease in the amount of precipitation in the warm part of the year on the largest part of the coast (MZOE, 2023). These studies coincide with similar studies for the Mediterranean area, where the dryness of the region is highlighted as one of the challenging environmental problems of that part of the world (Guemas et al. 2015; Iglesias et al. 2007; Norrant & Douguédroit, 2006; Seager et al. 2014). The IPCC climate change scenarios indicate the continuation of similar trends until the end of the 21st century (Lee et al. 2021). A further increase in temperature is expected, especially in the southern Adriatic area, while the signal of a precipitation change is not so clear, although most climate change scenarios predict a decrease in the amount of precipitation in the summer months (Güttler et al. 2020; MZOE, 2023).

It should be emphasized that the annual fluctuation of demand in the water supply system of the Adriatic islands is not uniform, and for the sustainability of the water supply system a special challenge is the seasonality of tourism (summer peaks of tourist arrivals) which coincides with the dry summer period (Mediterranean summer droughts). The significant trend of a quantitative increase in tourist arrivals could also lead to an increase in the demand for water during the summer and dry season in the near future, which, considering the modern climate change trends, should represent an even greater challenge for the islands' water supply (Bonacci et al. 2012). In addition, the demand for potable water on the islands is increasingly expressed by the development of tourist services of higher added value, which include swimming pool infrastructure, wellness facilities and similar infrastructure (Grofelnik, 2017). Therefore, in the context of sustainable development and the sensitivity of island areas to environmental and social pressures, in addition to current ones, it is necessary to anticipate future processes and circumstances that may impact island water supply systems. It is necessary not to ignore the trend of increasing energy prices, affecting the price of pumping, processing, storing and transporting water, especially over longer distances, which increases the costs of water supply system building and maintenance, so in this aspect, it is necessary to consider possible alternative solutions of water supply on islands, that are more sustainable, economically profitable and resilient.

2. DATA, METHODS AND RESEARCH AREA

In the context of this research, which deals with water as a basic resource that is necessary for the daily needs of people and the functioning of the economy, the indicators of potable water consumption from surface or underground sources (blue water) will be taken into account.

The secondary data sources of the Croatian Hydrological and Meteorological Service, Croatian Bureau of Statistics, as well as local tourist boards, and water supply and water supply infrastructure data, were used. The latter was obtained in direct contact with the municipal water supply companies of selected Croatian islands (islands: Cres, Lošinj, Rab, Brač and Vis) and used in analyses. The aforementioned data were used for correlation analyses to get relevant conclusions on the topic of this research. The average annual course of the water consumed on the islands and the data that present the change in the number of tourists and overnight stays on the islands were correlated for the 2015 - 2020 period.

In order to analyse the impact of the climate on the water supply system of the selected islands, temperature and precipitation data for the 1981 - 2020 period collected at meteorological and climatological stations on the islands (Cres, Mali Lošinj, Rab), as well as data of stations within water protection areas on the mainland used for water supply systems of the island (Senj, Gospić, Split-Marjan) were used. The data were obtained from the Croatian Hydrological and Meteorological Service. The priority was given to those meteorological or climatological stations that had complete sets of precipitation data.

Besides the basic climate indicators, linear trends of changes in annual and seasonal values of temperature and precipitation were determined, and their significance was analysed with the Mann-Kendall trend test (Kendall, 1975) using the computer program XLSTAT (Lumivero, 2023). A decrease in the amount of precipitation and an increase in temperature can have a negative impact on the water supply because these changes lead to an increase in evaporation and can reduce the amount of water available to nature and the people. As relevant papers indicate the increase in drought occurrence in the Mediterranean area (Gao & Giorgi, 2008; Iglesias et al. 2007; Solaraju-Murali et al. 2019), the Standardized Precipitation Index (SPI) was used as an indicator of dryness in the paper (Mckee et al. 1993). The SPI represents the number of standard deviations from the mean of the data series and it is based on the normalized gamma distribution of precipitation. If the precipitation amounts are higher than the mean precipitation the SPI values are positive and if they are lower than the mean value, the SPI values are negative, while index values between -1 and 1 are considered to be normal. This method is relatively often used because it only requires the data series of precipitation over a longer period and it can be applied to different time scales, and most common time scales that are used are 1, 3, 6, 12 and 24 months. Therefore, SPI can be used to assess the precipitation deficit for different water resources (groundwater, open watercourses, soil moisture) (Tadić et al. 2015). SPI3 was used in the paper, i.e. a time scale of 3 months was analysed because it provides a seasonal assessment of precipitation deviations. The SPI was calculated using the statistical software DrinC (Drought Indices Calculator) developed by the National Technical University of Athens (Tigkas et al. 2015).

The RAPS (Rescaled Adjusted Partial Sums) method (Garbrecht & Fernandez, 1994) was used to determine the time of occurrence of changes (increases or decreases) in the time series of analysed data. It is often used in the climate analysis for that purpose (Bonacci et al. 2020; Bonacci et al. 2021).

The primary areas of this research are selected Adriatic islands with their water supply systems, i.e. the islands of Cres, Lošinj, Rab, Brač and Vis (Fig. 1). Since the water supply of the mentioned islands in some cases partially relies on the water resources of the neighbouring mainland area, the climatological analyses of that areas were also conducted within the research.

Slika 1. Područje istraživanja

Figure 1 *Study area*

Izvor: izradio autori / Source: made by authors

The islands of Cres and Lošinj form one water supply system that is resource-dependent on the local aquifer. The central part of the island's water supply system is the water pumping station on Lake Vrana, which is currently the only water pumping station for the islands of Cres and Lošinj. The development of public water supply system of the islands of Cres and Lošinj was initiated in the first half of the 20th century, while the modern water supply system of the islands of Cres and Lošinj started to develop in 1952 (URL 3).

The island of Rab has a water supply system with a dual source of water. In smaller part it uses local sources of fresh water on the island, while it mostly relies on water from the mainland hinterland, which is transported using a submarine pipeline. The public water supply began to develop at the beginning of the 20th century and it was based on the island's small springs and wells, which could not meet the increasing need for potable water due to the development of tourism on the island. Therefore, the island of Rab was connected to the water supply system of Hrvatsko Primorje - the southern branch in 1986, and since then it has been receiving water from the Senj HPP hydropower system, i.e. from Lika (URL 4).

Until the 1970s, the island of Brač traditionally relied on local water resources (cisterns, puddles and wells). With the construction of the regional submarine water supply system Omiš - Brač - Hvar, the island started receiving potable water from the Zakučac HPP hydropower system, i.e. the Cetina River. The modern water supply system of Brač relies entirely on water from the mainland area (URL 5).

The island of Vis has its public water supply system based only on its local water sources. It has been planned since the 1970s to connect the island water supply system to Cetina River water source with a submarine pipeline system, but this system has never been built. It should also be noted that the connection to the existing water supply system on the island of Hvar would not be sufficient because the current water supply system Omiš - Brač - Hvar does not have sufficient capacity during the summer tourist season (Fidon, 2018; URL 6).

3. RESULTS

In the analytical part of the research, the following data were used: monthly amounts of pumped and sold water on the islands, monthly trends in tourist overnight stays, and climatological data of temperature and precipitation in the water pumping area.

Based on the analysed climate data, an insight was obtained into the features of the dryness of the researched stations, which is most pronounced in the summer months and in the stations located further south (Csa climate). In order to indicate the impact of climate change the two thirty-year periods were considered, the first from 1981 to 2010 and the second from 1991 to 2020 (although those are not two consecutive periods). In the second thirty-year period, the temperature increase occurred, but also the increase in the amount of precipitation, compared to the first thirty-year period (Tab. 2). The mean annual temperature amplitude increased in most stations, and mostly in the stations with pronounced maritime thermal influences.

Table 2 *Changes in mean annual temperature, mean annual temperature amplitude and mean annual precipitation in the analysed stations for the 1981 – 2010 and 1991 – 2020 periods*

Postaja Station	Razdoblje Period	Sr. god. temp. (°C) Mean ann. temp. (°C)	Ampl. temp. (°C) Temp. amp. (°C)	Sr. god. kol. pad. (mm) Mean ann. prec. (mm)
Cres	1981. – 2010.	14.7	18.4	1099.5
	1991. – 2020.	15.1	18.4	1144.0
Gospić	1981. – 2010.	9.1	20.2	1354.6
	1991. – 2020.	9.7	20.1	1391.7
Mali Lošinj	1981. – 2010.	15.6	16.9	927.3
	1991. – 2020.	16.1	17.1	997.0
Rab	1981. – 2010.	15.6	17.6	1087.1
	1991. – 2020.	16.1	17.7	1125.3
Senj	1981. – 2010.	15.1	18.9	1223.6
	1991. – 2020.	15.6	18.9	1284.5
Split-Marjan	1981. – 2010.	16.4	18.4	776.1
	1991. – 2020.	16.9	18.6	800.7

Izvor / Source: Croatian Meteorological and Hydrological Service

The maximum temperature is in the summer months, July or August, and the minimum is in January or February (Fig. 2). Maximum precipitation occurs in winter, in November and the minimum is in July (Fig. 3). The mean annual temperature increased in the period 1991 – 2020 compared to the period 1981 – 2010, in almost all months, mostly in summer, which is in accordance to the observed climate changes, i.e. the global temperature increase. Changes in the amount of precipitation in the researched periods are more complex. Although the mean annual amount of precipitation increased in all stations (Tab. 2), it is not uniformly distributed within the annual course. The largest increase occurred in the autumn and winter months, in most stations from September to February, then in July and less in May, while in the remaining spring and summer months the decrease in the amount of precipitation occurred in the period 1991 – 2020 compared to the period 1981 – 2010, which coincides with the period when the greatest demands for water resources are in agriculture and tourism and has an unfavourable impact on water supply. The Gospić station stands out for its temperature and precipitation values. The amount of precipitation at that station is the result of relatively large amounts of precipitation received by the mountain hinterland, which is extremely important for replenishing the water of the karst aquifer that supplies the water supply system Hrvatsko primorje.

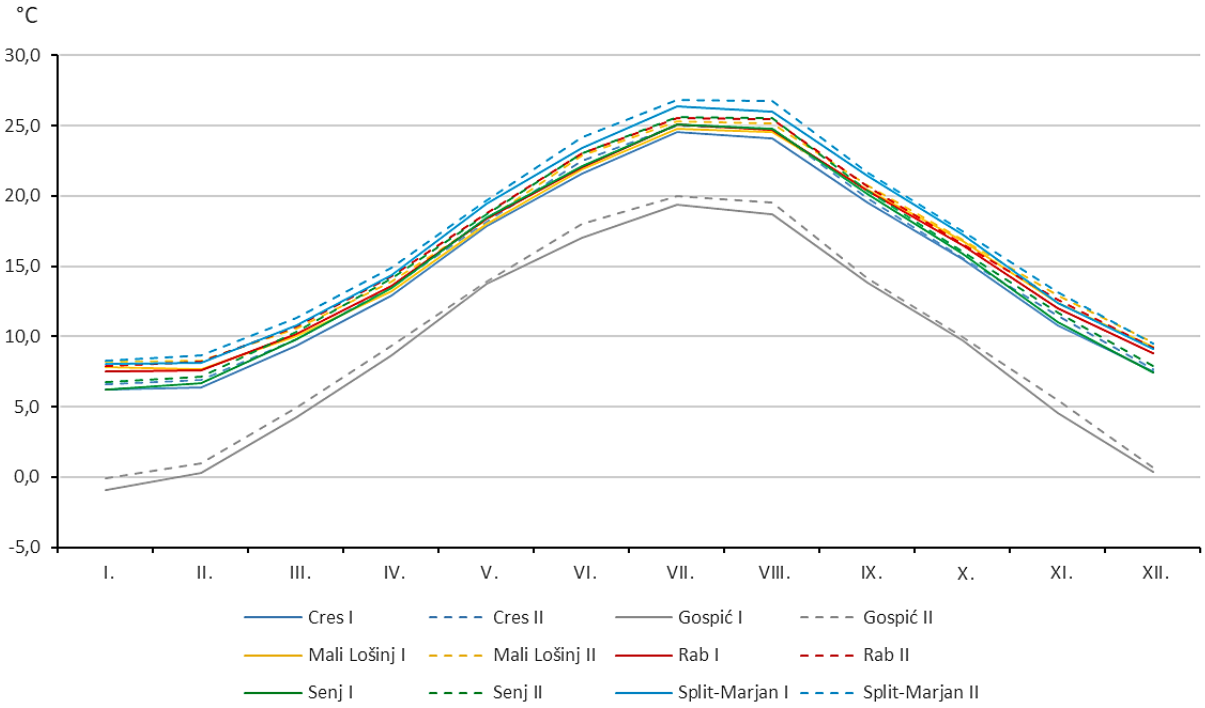

Figure 2 *Annual trend of temperature in the research stations for the periods 1981 - 2010 (I) and 1991 - 2020 (II).*

Izvor: izradio autori / Source: made by authors

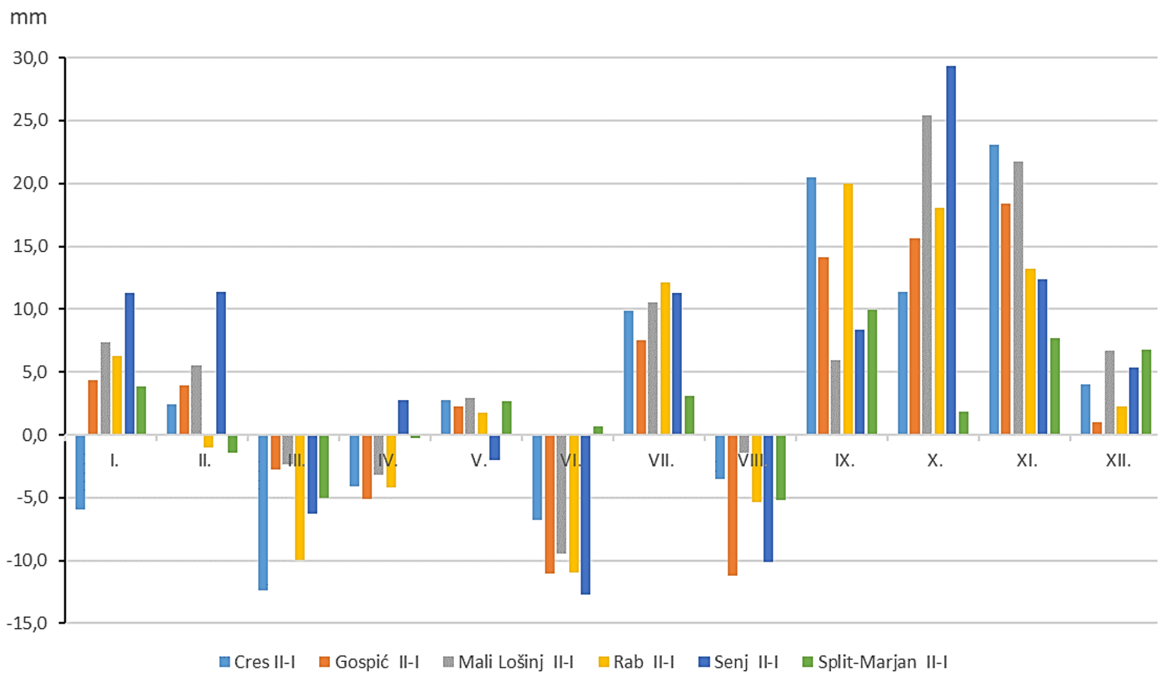

Figure 3 *Differences in monthly values of the precipitation amounts during the researched periods ($\Delta P = P_{1991\text{-}2020} - P_{1981\text{-}2010}$) for the analysed stations*

Izvor: izradili autori / Source: made by authors

Besides the mean values of climatic elements, the trend of their changes in the researched period is also of great importance for the analysis of the impact of climate on the water supply system. The increase in the mean annual temperature measured in all stations is statistically significant (α = 0.05) for most stations (Fig. 4 and Tab. 3) and can cause an increase in evaporation, which can lead to a decrease in the amount of water available for the water supply system. An increase in the precipitation amount was measured in all stations (Fig. 5 and Tab. 3), but unlike the temperature, it is statistically significant only for Mali Lošinj station (α = 0.05). The determination coefficients of linear trend have higher values for the change in the mean annual temperature than for the change in the annual amount of precipitation, which indicates a significant increase in temperature in relation to the change in the value of the precipitation amount in the same period. In order to obtain a better insight into the impact of precipitation on the water supply, seasonal trends should be analysed instead of annual trends due to the significant difference in the precipitation amount between the summer and autumn months.

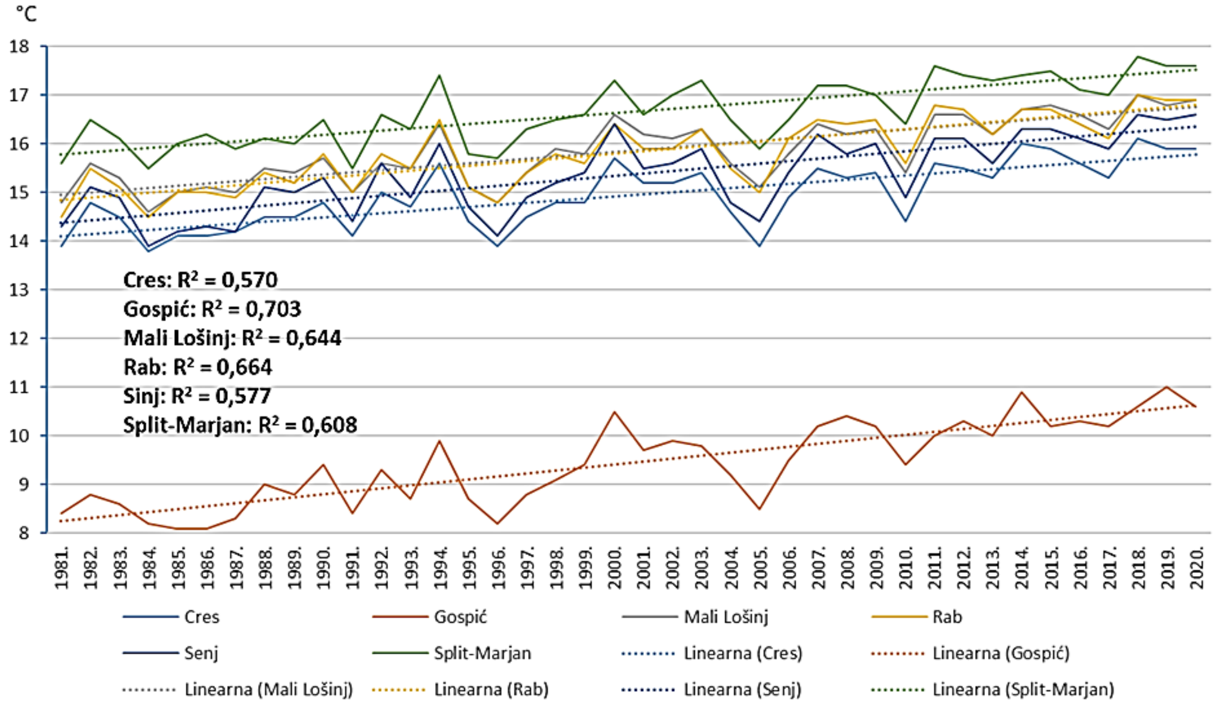

Figure 4 *Mean annual temperature, coefficients of determination and trends of change for the analysed stations in the 1981 – 2020 period*

Izvor: izradili autori / Source: made by authors

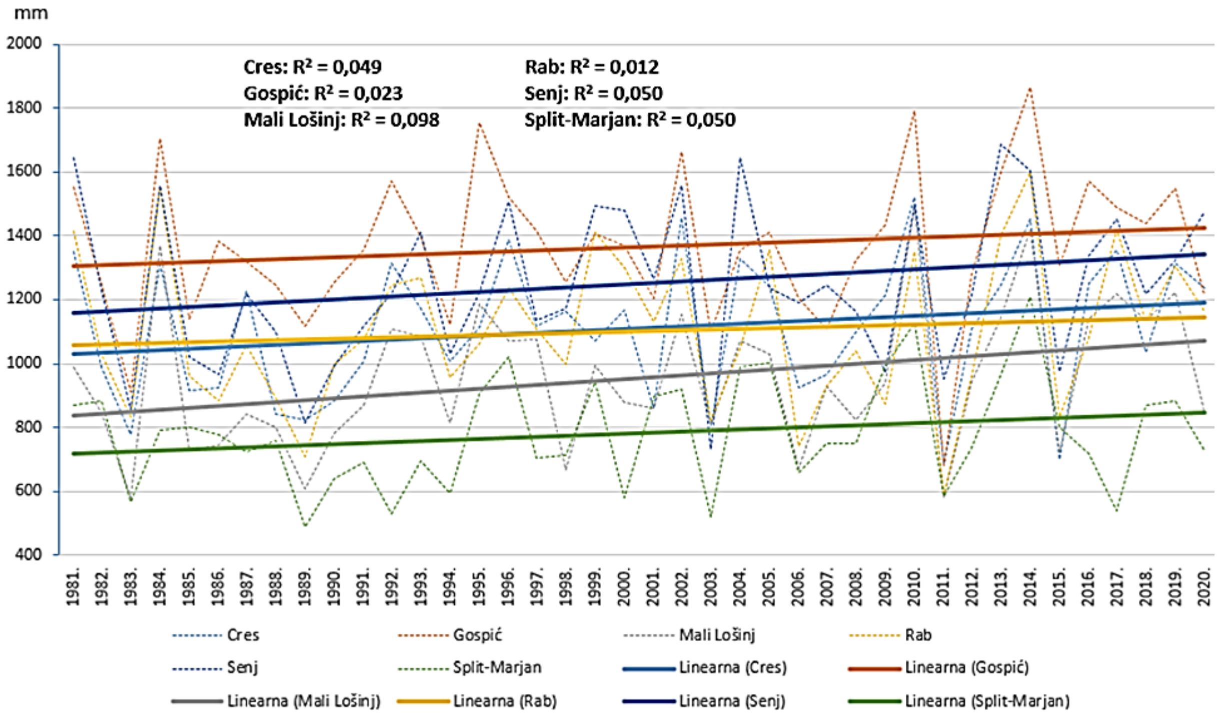

Figure 5 *Mean annual precipitation, coefficients of determination and trends of change for the analysed stations in the 1981 – 2020 period*

Izvor: izradili autori / Source: made by authors

Seasonal trends of temperature change show an increase in temperature during all seasons (Tab. 3), which is statistically significant for all stations in the researched 40-year period. The increase in temperature is most accentuated in summer at most stations, which is in accordance with previous research, that obtained the most significant increase in temperature on the Croatian coast in the summer (MZOE, 2023).

The values of the trend of the precipitation amount changes are in most cases not statistically significant (Tab. 3). The trend of the precipitation amount changes is positive in winter, when they are at the highest (positive) values, while they have negative values in summer (except at the Cres station). Trends in the precipitation amount change are mostly positive in autumn, and mostly negative in spring. Negative trends of the precipitation amount changes in summer indicate an unfavourable trend of precipitation decrease in the season that is already the driest in the annual course.

Table 3 *Seasonal trend changes of mean temperature (°C) and precipitation amounts (mm) for the 1981 – 2020 period*

	Temperatura (°C) Temperature (°C)					Padaline (mm) Precipitation (mm)				
	Prolj. Spring	Ljeto Summer	Jesen Autumn	Zima Winter	God. Year	Prolj. Spring	Ljeto Summer	Jesen Autumn	Zima Winter	God. Year
Cres	**0.047**	**0.062**	**0.030**	**0.034**	**0.043**	-0.913	0.109	3.211	1.714	4.122
Gospić	**0.052**	**0.079**	**0.046**	**0.068**	**0.062**	-0.330	-1.395	2.890	1.894	3.058
Mali Lošinj	**0.051**	**0.068**	**0.026**	**0.038**	**0.046**	0.193	-0.112	**3.053**	2.910	**6.045**
Rab	**0.053**	**0.069**	**0.034**	**0.043**	**0.050**	-0.744	-0.886	2.772	1.091	2.233
Senj	**0.051**	**0.070**	**0.034**	**0.049**	**0.051**	-0.377	-1.325	3.105	3.284	4.686
Split-Marjan	**0.046**	**0.062**	**0.033**	**0.037**	**0.045**	0.263	-0.018	1.257	1.797	3.299

* trend values in bold indicate statistically significant trends at the α = 0.05 confidence level
Izvor: izračunali autori / Source: calculated by authors

Monthly trends of temperature changes in the researched period, similarly to seasonal ones, indicate an increase in temperature for all months, which is mostly accentuated and statistically significant for the summer months and in the largest number of analysed stations for February, April and November (Tab. 4). Unlike the temperature change trends, precipitation change trend is not statistically significant in almost no station (Tab. 5). The trend changes of the precipitation amount in the spring and summer months are mostly negative, while the trend changes of the precipitation amount in the winter months are mostly positive, therefore, although the change signal is not statistically significant, they confirm similar changes that were determined for seasonal values, which can have a negative effect on water supply system on the Croatian coast, especially on the islands.

Table 4 *Monthly trend changes of mean temperature (°C) for researched stations in the 1981 – 2020 period*

	Cres	Gospić	Mali Lošinj	Rab	Senj	Split-Marjan
I.	0.029	0.070	0.028	0.035	0.046	0.019
II.	**0.056**	**0.092**	**0.060**	**0.064**	0.061	**0.058**
III.	0.044	0.055	**0.047**	**0.051**	0.046	0.043
IV.	**0.064**	**0.078**	**0.067**	**0.067**	**0.075**	**0.064**
V.	0.033	0.024	**0.039**	0.041	0.031	0.029
VI.	**0.091**	**0.093**	**0.091**	**0.095**	**0.094**	**0.072**
VII.	**0.047**	**0.066**	**0.059**	**0.054**	**0.057**	**0.048**
VIII.	**0.048**	**0.078**	**0.053**	**0.059**	**0.060**	**0.066**
IX.	0.022	0.019	0.019	0.029	0.018	0.019
X.	0.006	0.019	0.007	0.012	0.015	0.013
XI.	**0.063**	**0.099**	**0.052**	**0.062**	**0.068**	**0.066**
XII.	0.017	0.040	0.025	0.030	**0.040**	**0.033**

* bolded trend values indicate statistically significant trends at the $\alpha = 0.05$ confidence level
Izvor: izračunali autori / Source: calculated by authors

Table 5 *Monthly trend changes of precipitation amounts (mm) for the researched stations in the 1981 – 2020 period*

	Cres	**Gospić**	**Mali Lošinj**	**Rab**	**Senj**	**Split-Marjan**
I.	0.396	0.954	1.156	0.903	1.490	0.782
II.	0.684	0.707	0.861	0.212	1.291	0.235
III.	-0.934	0.004	-0.073	-0.636	-0.516	-0.201
IV.	-0.243	-0.420	-0.211	-0.415	0.351	0.176
V.	0.264	0.086	0.477	0.307	-0.212	0.287
VI.	-0.673	-1.166	-1.004	**-1.189**	-1.516	0.137
VII.	0.816	0.477	0.821	0.853	0.788	0.209
VIII.	-0.034	-0.706	0.071	-0.550	-0.596	-0.364
IX.	1.503	1.027	0.038	1.291	0.365	0.597
X.	-0.079	0.301	1.423	0.644	1.730	-0.031
XI.	1.788	1.563	1.592	0.837	1.009	0.692
XII.	0.634	0.232	0.893	0.300	0.502	0.779

* bolded trend values indicate statistically significant trends at the $\alpha = 0.05$ confidence level
Izvor: izračunali autori / Source: calculated by authors

In order to assess the temperature change in the 1981 – 2020 period in more detail, the series of mean annual temperatures for the analyzed stations were transformed using the RAPS method (Fig. 6). The results indicate that in most stations the change occurred in 1999 (except in the Senj station, where the change occurred in 1998). Although an increase in the mean annual temperature was obtained for both sub-periods, until 1999 it was less intense and mostly not statistically significant. The trend of temperature increase is more pronounced and statistically significant in all stations after 1999 (Tab. 6), which indicates an increasingly intense increase in temperature in the second half of the researched period, which will have pronounced negative impacts on the water supply system on the Croatian islands. No such regularity was observed for the change of precipitation amount time series transformed by the RAPS method.

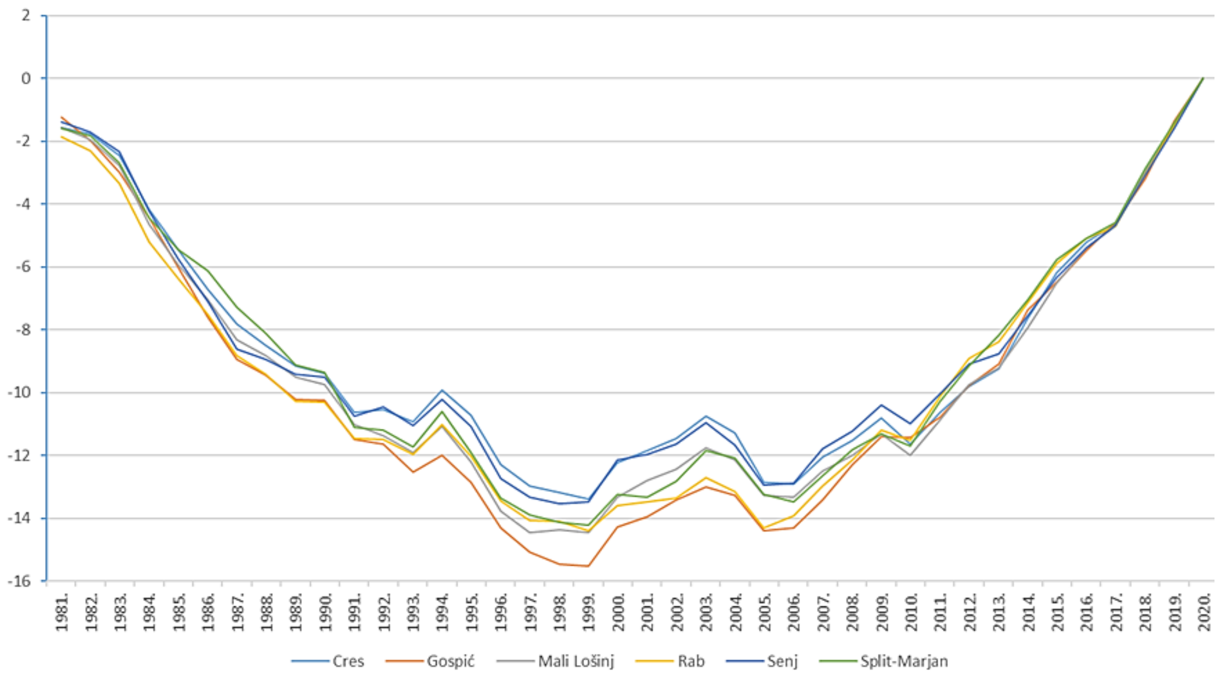

Figure 6 *Time series of mean annual temperatures transformed by the RAPS method for the researched stations in the 1981 – 2020 period*

Izvor: izradili autori / Source: made by authors

Table 6 *Trend changes of the mean annual temperature for the 1981 – 1999 and 1999 – 2020 periods (*for the Senj station, the periods are 1981 – 1998 and 1998 – 2020)*

	Cres	**Gospić**	**Mali Lošinj**	**Rab**	**Senj***	**Split-Marjan**
1981. –1999.	0.032	**0.043**	0.036	**0.044**	0.037	0.030
1999. – 2020.	**0.046**	**0.054**	**0.045**	**0.051**	**0.050**	**0.043**

* trend values in bold indicate statistically significant trends at the α = 0,05 confidence level
Izvor: izračunali autori / Source: calculated by authors

Based on the predictions of the relevant regional climate models (Güttler et al. 2020.; Lee et al. 2021; MZO, 2023) for the 2041 - 2070 period, a further increase in annual and seasonal temperatures is expected for the coastal areas of Croatia, especially in the summer months. The lowest increase in temperature is obtained for the spring months. In the same period, the changes in precipitation amount are predicted to be of different signs, but there is a certain decrease in precipitation in the summer for the whole area of Croatia (between 10 and 15 %). The highest precipitation decrease is predicted for the large part of the coast and in the mountainous area (between 15 and 20 %). A decrease in the precipitation amounts can be expected in the hinterland of the coastal area in the spring months, which may adversely impact the restoration of water reserves before the dry summer period, and therefore impact the water supply on the coast. There are similar trends in other indicators that will influence the occurrence of dryness, such as an increase in the number of warm days and nights, an increase in the number of dry days, and a decrease in the number of moderately and very humid days. The aforementioned trends are predicted for the coastal area, especially for the summer months. According to the results of climate change scenarios of global climate models, the presented trends could continue with varying intensity until the end of the 21st century (Lee et al. 2021).

The variability of precipitation presented by the coefficient of variation also indicates the impact of precipitation on water supply in the summer months (Fig. 4). The values of precipitation variability are highest in the summer months and in the stations that have a relatively low precipitation amount, which was already confirmed by similar research (Maradin, 2013). The stations of Mali Lošinj and Split Marjan, and then Rab and Senj stand out due to the high values of precipitation variability in the summer months. In other seasons, the precipitation variability values in the researched stations are more similar. The relative minimum variability of precipitation in spring, in April, is a favourable circumstance because it means that precipitation in the spring months, before the summer minimum of precipitation, is relatively reliable.

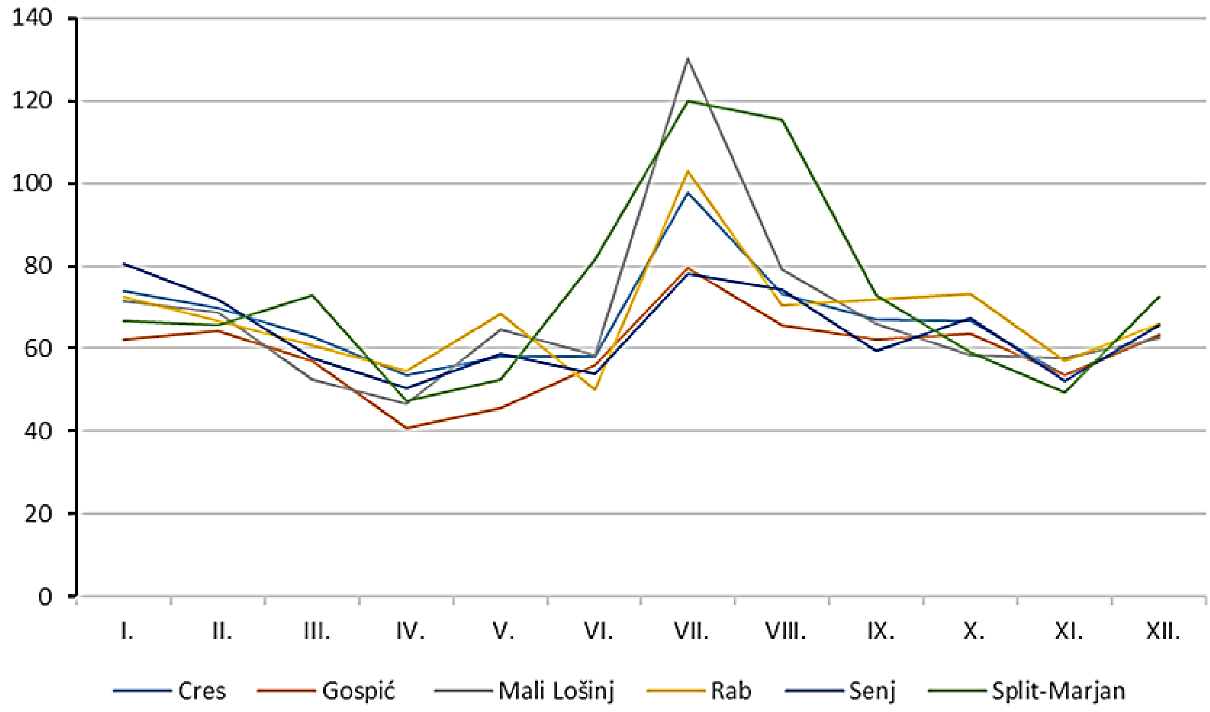

Figure 7 *Annual trend of the coefficient of variation of the precipitation amounts for the 1981 – 2020 period*

Izvor: izradili autori / Source: made by authors

The occurrence of dryness in the researched period was additionally analysed using the SPI3 indicator (Fig. 8). The change in annual SPI3 values shows the changing periods with relatively high and relatively low values of this indicator. The SPI3 values were extremely low in the year 2006 when at most stations the values were within categories of very or extremely dry. It is a favourable circumstance that the periods with low SPI3 values are relatively short, which can be explained by seasonal differences in the amount of precipitation, i.e. the increase in the amount of precipitation in the autumn and winter months can compensate for the water deficit after the dry summer. Moreover, there are no periods with extreme dryness over a longer period in a single station, and no significant trend of change in the SPI3 indicator was observed for any station. Considering the scenarios of predicted climate changes, the intensity and duration of dry periods could change, especially in the summer months, when for the largest part of the coast an increase in temperature and a decrease in the amount of precipitation are predicted. In particular, the increase in the number of consecutive dry days during the summer can contribute to this, as indicated by certain climate change scenarios (MZOE, 2023), which, along with the increase of potable water consumption pressure, can lead to certain problems in the water supply system, especially on the islands that depend on their water resources.

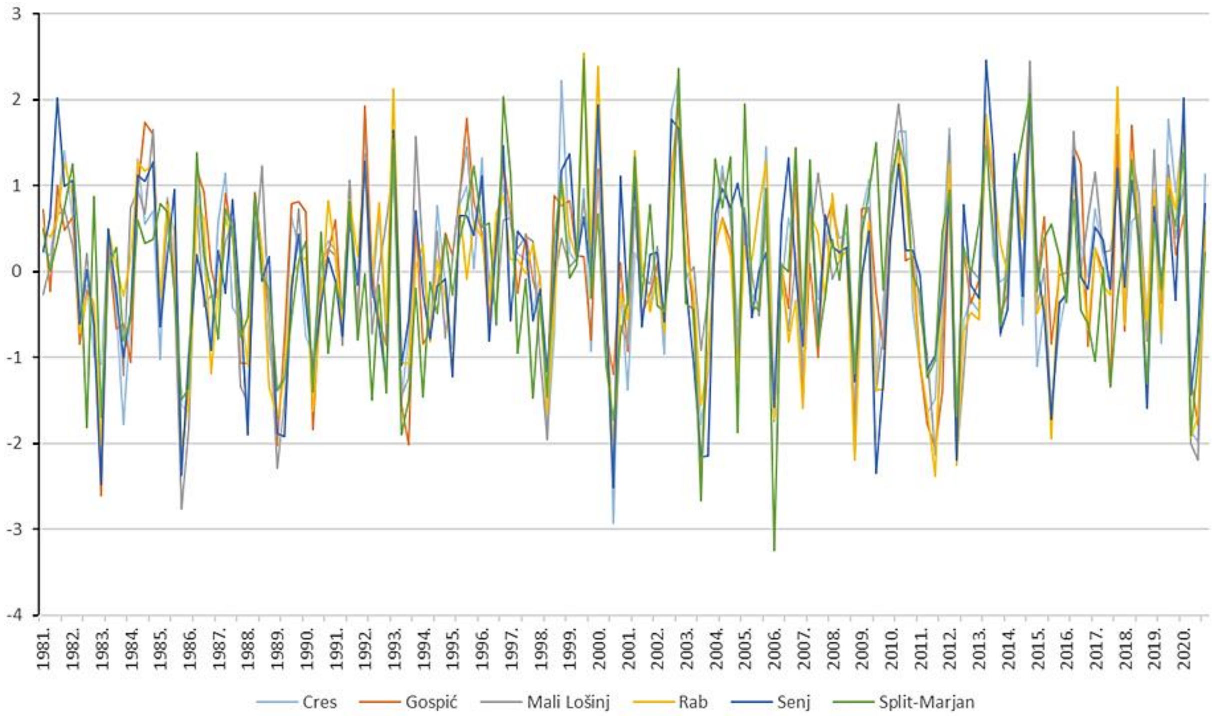

Figure 8 *Changes in SPI3 values for the researched stations for the 1981 – 2020 period*

Izvor: izradili autori / Source: made by authors

The analysis of the collected data of the island's water supply systems and tourist indicators shows the relationship between water consumption and tourist overnights with a clear seasonality. Coincidence of the monthly values is most pronounced in the summer tourist peak (July/August), which results in a significant increase in water consumption and the pressure on the water supply system (Fig. 9, 10 and 11). Further analysis revealed an inversely proportional relationship between the monthly values of water consumption in relation to the seasonal (summer) availability of water resources, average monthly temperatures and the occurrence of the characteristic Mediterranean dry summer period (Fig. 9, 10 and Tab. 3).

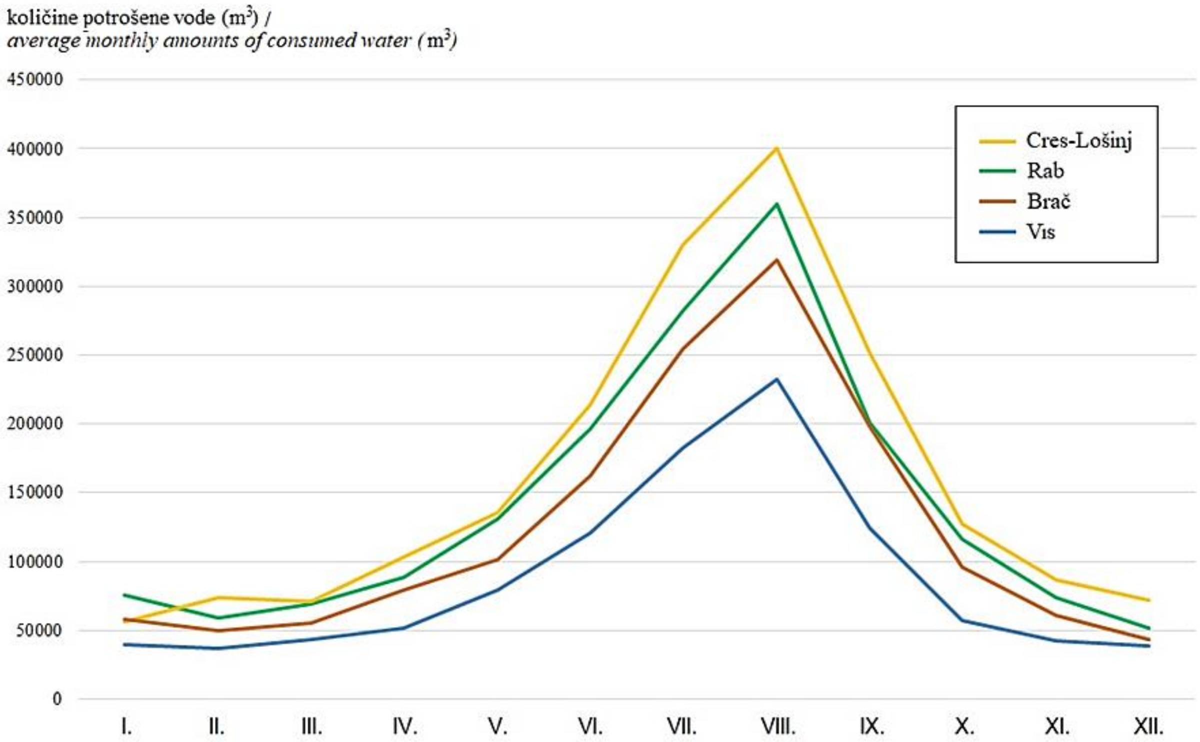

Figure 9 *Average monthly amounts of water consumed on the islands in the period 2015 – 2020*

Izvor: izradili autori / Source: made by authors

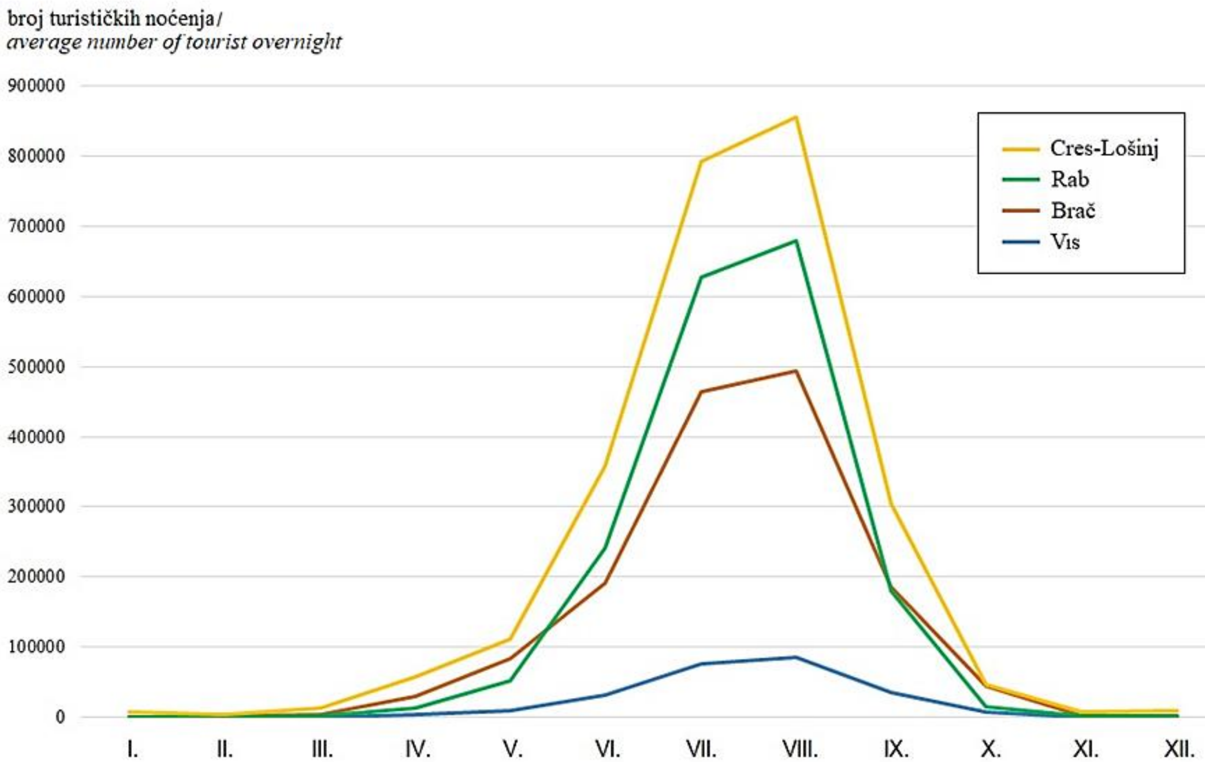

Figure 10 *Average number of tourist overnight stays per month on the islands in the period 2015 – 2020*

Izvor: izradili autori / Source: made by authors

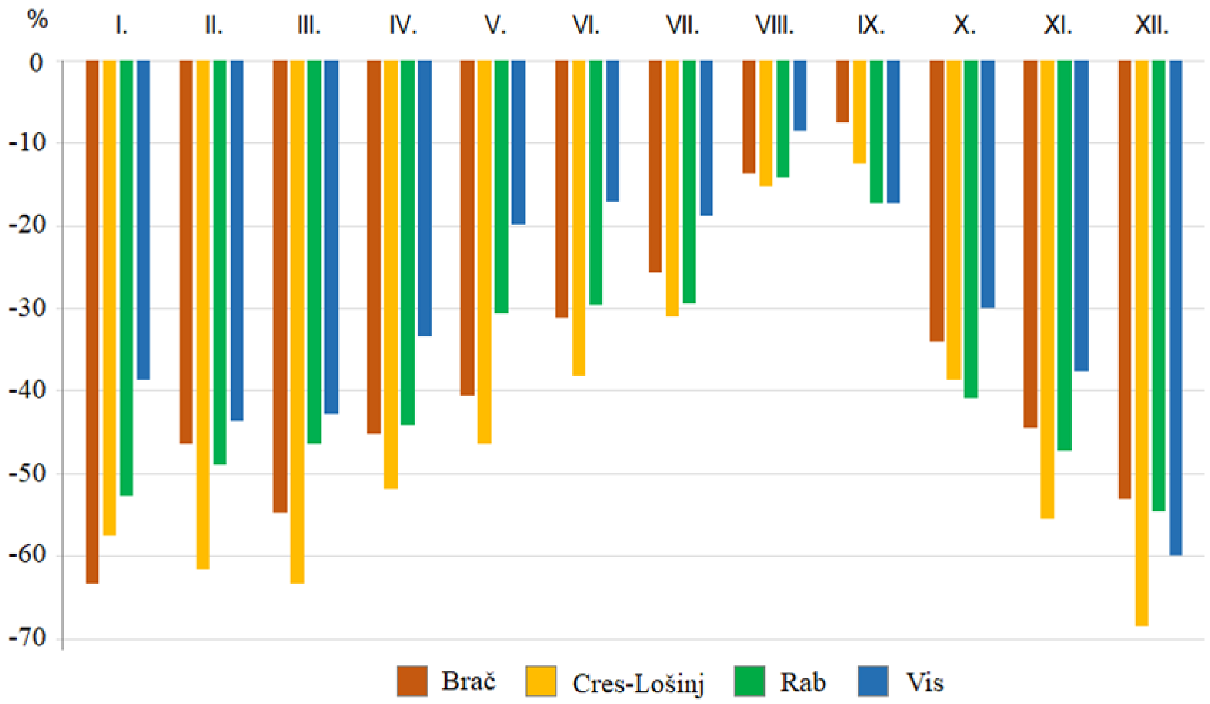

Figure 11 *Share of monthly losses of captured water by the island's water supply systems in the period 2015 – 2020*

Izvor: izradili autori / Source: made by authors

It is evident from Figure 11 that a significant systematic "stock for future consumption" on the islands is similar to the lost amount of water, which varies between 31% and 39% on the annual basis on the islands. In the research so far, this segment is the so-called "potential water supplies in the system" often emphasized, so for example in the analysis of the sustainability of water supply in the conditions of climate change Margeta (2022) states that the biggest threat to the sustainability of water supply is large water losses that threaten the available capacity of the system. However, it is necessary to underline the seasonal differences in losses, i.e. the shares of water losses by month vary significantly and show regularity in such a way that the losses are the smallest (and thus the "potential water supply in the system" is the smallest) during the summer months when the water supply systems are at their maximum utilization and consumption is the highest. Margeta (2022), states that by reducing the losses of the existing water supply system to the level of 20%, many problems of adapting the capacity of water supply systems to climate change could be solved. Analysing the situation on the islands of Lošinj, Cres, Rab, Brač and Vis, it is evident that the months of July and August have losses between 8% and 17%, which indicates insufficient amounts of "water supply in the system" specifically during peak loads that overlap with the dry season. Water losses are significantly reduced in relative proportion during the summer tourist season (Fig. 11) because of the increased consumption or speed of water flow through the water supply system. Thus, losses as a result of leaks in the pressurized water supply system increase in relative proportion as the flow or consumption of water in the system is slower, i.e. they are highest in the winter months.

4. DISCUSSION

The differences of the values of pumped and sold water in the water supply systems of the observed islands has a seasonal character with a visible summer maximum (Figs. 9 and 10). A further probable decrease in the amount of precipitation in summer will further complicate water supply in the future on those islands whose water supply system is not connected to the system on the mainland and directly depends on the amount of precipitation, and in conditions of increased demand due to a large number of tourist consumers. The annual course of water consumption by month is extremely similar to the course of tourist overnight stays on the islands (Fig. 9, 10 and 11). In addition to the current values of water consumption on the islands from the aspect of development sustainability, it is very important to take into account the possibility of increasing the amount of available water, especially during the summer months.

Given that there is a dry period on the islands in the summer months (Tab. 3), it is important to consider a significant reduction of losses in the water supply system for its future. The losses of the island's water supply systems vary significantly by month and show regularity in such a way that during the summer months, when consumption is the highest, the relative losses are the lowest, and thus the "potential water supply in the system" is the lowest (Fig. 11). The above points to the effective possibility of relying on the reduction of losses in the system as a solution to increase sustainability in conditions of increased demand due to the increase in the tourist traffic on the islands. Therefore, in the context of the further development of tourism, it is necessary to make adjustments to the peak seasonal loads of the island's water supply systems during dry summer periods, considering all possible options and combining available solutions.

Terzić et al. (2022a), for example, in their research describe possible scenarios for the adaptation of island water supply systems: 1) increasing the pumping of water from aquifers (which could further lower the level of groundwater at water pumping stations and open the possibility of salinization of island aquifers); 2) drilling new wells outside the existing areas of current pumping stations (which could also lead to lowering of water in the island's aquifer and possible salinization); 3) construction of brackish or seawater desalination devices (which entails higher initial investments but also increased energy costs during system exploitation), and 4) the possibility of reusing already used water with its treatment depending on the degree of pollution (which in the conditions of purchasing energy can call into question the cost-effectiveness compared to other systems). Modern strategies for managing water resources in the European Union, and especially in the Mediterranean, as a response to the challenges of seasonal loads on water supply systems under conditions of climate change, seriously consider the possibilities of water reuse (Regulation 2020/741 of the European Parliament on minimum requirements for water reuse). The aforementioned Regulation aims at the treatment of municipal wastewater as an alternative way of water supply in areas with lower natural water capacity, which are unequivocally islands during the summer months. Tomas i Blaž (2022) state that in the Republic of Croatia, the reuse of water would especially help alleviate the problems with water supply on the islands during dry periods when the number of water consumers is manifold due to the tourist load on the water supply system and, depending on the degree of purification, recycled water could be used street washing, irrigation of green areas or alternatively for the needs of artificial recharge of aquifers. Vlašić (2022) claims that it is reasonable to think about the use of purified wastewater on the islands as support for the development of agricultural activity during the dry period. Taking into account the above, the question arises as to whether it might be profitable in future cycles of investments in the water supply to separate the drinking water system from the water system for irrigation, washing or rinsing (especially when planning the reconstruction or construction of new larger facilities such as hotels and similar).

Research done before the current energy crisis, for example Lutenberger (2013), shows that the sustainability of water supply from the mainland is expensive and exposed to risks considering infrastructure and climate. Lutenberger (2013) supports desalination water treatment systems on islands as sustainable scenarios for the development of water supply. In the context of the analysed impacts of climate change and future scenarios of climate change, the priority action measures of the Climate Change Adaptation Strategy in the Republic of Croatia for the period up to 2040 with a view to 2070 include the strengthening of resistance to climate change through the construction of desalination devices (HM-06-06) and the construction of collection systems to increase the use of rainwater (HM-06-05), and the application of lower quality water for secondary use (HM-06-04) and the reuse of purified waste and storm water (HM-06-03).

In contrast to the previously mentioned approaches to solving the issue of the sustainability of the island's water supply, this paper will highlight the traditional system of sustainable management of water resources by collecting and storing rainwater, which has been used for centuries. Already in 1997, the national island development program, in the breakdown of the irrigation program for the island's agricultural areas, provided for the reconstruction of existing and the construction of new cisterns, the arrangement of neglected ponds, the use of geomembranes and the procurement of irrigation systems, but after that, the aforementioned collection, storage and use systems were not implemented of local water resources. In the continuity of strategic development documents, the National Island Development Plan 2021-2027. under priority 3. Smart and sustainable management of island resources and the environment, envisages projects for the reconstruction of the rainwater collection system for the maintenance of elements of green infrastructure and recognizes and emphasizes the need for the aforementioned during the dry summer months. In addition to national strategic documents, other research, especially from the Mediterranean area, such as Muselli et al (2009), state that rainwater harvesting is economically profitable because it has smaller initial financial investments, does not leave a large environmental footprint and requires low investments during system exploitation. According to the aforementioned research, it is possible to restore and improve the abandoned rainwater collection systems that are widespread on the islands, and which, in addition to the existing water supply system, could increase the sustainability of the water supply during peak periods. Water from the collection system from roofs and dedicated surfaces can be untreated for the needs of rinsing, washing or irrigation, or treated in order to make it potable. The current energy crisis is also in favour of the rainwater collection systems on the islands because these systems were functional on the islands even at a time when the electrical network on the islands was unknown. For example, Margeta (2022) states that the limiting factor for alternative water supply is building a desalinizer and the price of electricity, while the rainwater collection system is incomparably more efficient.

5. CONCLUSION

Sustainable management of water resources on the islands is a challenge for the future, and it needs to be approached analytically with constant adaptation to the local specificities of the islands, with the ultimate goal of achieving long lasting benefits for the local community. Raising the self-sufficiency of local island communities considering all resources, including water supply, is a strategic issue and a necessity for the future development of island communities.

Climatic changes along with the expected development of tourism with an increase in overnight stays and an increase in water consumption will affect the necessity of adapting the water supply systems on the Croatian islands. Climate change scenarios indicate that their impact will be manifested in the reduction of summer recharge of aquifers, the quality of water in them and may also lead to an increase in the risk of salinization of karst islands aquifers. A decrease in the amount of precipitation and unfavourable indicators of dryness in the warm part of the year, which coincide with the maximum tourist load and water demand, will necessarily bring the need for the reconstruction of water supply systems on the islands. With the aim of making the system more sustainable and resilient, it will be necessary: 1) to increase water reservoirs as water reserves from the part of the year in which water resources are under less pressure, 2) to reduce the general consumption of water, 3) to find new natural (springs, wells, connections to coastal water supply systems) or artificial (desalinizers, purifiers) incoming amounts of water on the islands with the necessary monitoring of water quality, 4) to reactivate traditional methods of rainwater collection and build new collection surfaces, 5) to separate drinking water systems from sanitary/technical water. In addition to all of the above on the islands, the usual amount of water that is used every day is not all to have in mind. It is important not to forget the safety aspect of the water supply systems, which should have a certain reserve, depending on the surface and features of the island, in case of fires, which are also common on islands in the summer period.

In conclusion, it can be said that this research has shown that there are significant differences in water supply systems between the islands. The islands' resistance to possible climate and tourism changes in the near future has to be approached individually and each island has its specifics on how to achieve its water supply sustainability. Considering the islands included in this research, it is necessary to distinguish the situations of the water supply systems of the islands of Rab and Brač, which are connected by submarine water supply pipes to terrestrial water resources and therefore are in a more favourable and stable situation. In contrast to them, the islands of Cres, Lošinj and Vis currently depend on their own water capacities and during the summer months so the sustainability of their water supply is impaired. The water supply situation on Cres, Lošinj and Vis with the further expansion of tourism as a basic activity will result in increased needs for water from local aquifers, which increases the potential risk of salinization and loss of functionality of the current water supply system.

The sustainability and prosperity of the local island community of each of the studied islands undoubtedly depends on the stability of the water supply in the future. The search for the most favourable solutions for the resilience of local communities in the context of the further development of tourism in conditions of climate change and the striving for self-sustainability of the island leads to a possible partial return to traditional ways of water supply by harvesting rainwater. By upgrading traditional rainwater harvesting systems and incorporating newer systems for filtration, disinfection, water quality protection and distribution, it will contribute to the progress of local communities in terms of their self-sufficiency, sustainability and resistance to climate change.

Possible solutions on the way to increasing the sustainability and self-sufficiency of the island in terms of water supply have several scenarios with different implementation combinations and need to be adapted to the specifics of each island. No less important element that contributes to the revitalization and upgrading of traditional rainwater harvesting systems on the islands is respect for local heritage because traditional cisterns are not only architectural but also cultural heritage of the islands, which makes recognizable in terms of architecture and landscape, sustainable considering water supply and environmentally friendly.

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Data availability statement: Data are available upon request to the authors

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