Uvod

Rezultati proučavanja klimatskih promjena na globalnoj razini u nekim se slučajevima nastoje prikazati toliko drastičnim da su doveli do klimatske uzbune. Osobito se to odnosi na naglašenu opasnost od globalnog zatopljenja, o čijoj bi se pak opravdanosti mogli naći pro i contra argumenti. Ostalim klimatskim elementima ne pridaje se tolika pažnja, iako bi značajnije promjene tih elemenata mogle bitno utjecati na život na Zemlji. Jedan od tih elemenata su svakako padaline.

Promjena količine padalina u Hrvatskoj od sredine 20. stoljeća do danas. Na temelju podataka za 22 postaje linearni trendovi za razdoblje 1950. – 2010. pokazuju vrlo male promjene. U istočnoj Hrvatskoj evidentan je blagi porast, a u ostalim krajevima utvrđen je blagi pad ili stagnacija. Ipak, kada bi se takvi trendovi nastavili, dugoročno bi mogli imati geografske posljedice. U analiziranom razdoblju moguće je utvrditi i cikličke promjene godišnje količine padalina.

Ključne riječi: padaline, Hrvatska, dugogodišnji trend

Introduction

In some cases, the presentation of results of investigating climatic changes at the global level has been so drastic that it has led to climatic alarm. This particularly pertains to the pronounced threats of global warming, and there are arguments for and against as to whether these threats are justified. Other climatic elements receive less attention, though significant changes of those elements could significantly affect life on Earth. One such element is certainly precipitation.

Many local authors (Penzar et al., 1967; Šegota, 1969; Gajić-Čapka, 1992; Gajić-Čapka, 1994; Gajić-Čapka, Zaninović, 2006) have addressed changes in the precipitation levels in Croatia. Several of these papers are based on selected weather stations and whole-year values, while others analyse seasonal values. The Second,
Third and Fourth National Report of the Republic of Croatia to the UNFCCC (2006) also address the changes in precipitation levels in Croatia, and these reports are based on analyses of four weather stations in Croatia.

Trends in the quantity of precipitation in this part of Europe primarily indicate a decrease in precipitation levels (Romero et al., 1998; Ventura et al., 2002; Dore, 2005; Cannarozzo, 2006), which is consequently leading to aridification of the Mediterranean (Gao, Giorgi, 2008).

The objective of this paper was to investigate the changes in precipitation levels in Croatia from the mid 20th century to the present day, and to determine whether regional differences can be ascertained.

**Data and methods**

Given Croatia’s dynamic relief, the network of meteorological stations, particularly primary weather stations, is insufficient to provide a detailed regional analysis. This should certainly be taken into account while interpreting the results of climatic elements’ spatial distribution. For this reason, certain authors often analyse the data from only one station, treating it as representative for a wider area, which need not always be the case.

In this paper, data on annual precipitation levels from 22 weather stations (Figure 1) were analysed. The source of the data is the Hydrological and Meteorological Service of the Republic of Croatia. A 60-year period, from 1950–2010 was analysed. Stations were selected as representative for continental Croatia (Osijek, Slavonski Brod, Donji Miholjac, Bjelovar, Križevci, Koprivnica, Varaždin, Zagreb-Maksimir, Karlovac, Ogulin, Gospić), and for the coastal region (Rovinj, Pazin, Rijeka, Senj, Mali Lošinj, Split-Marjan, Dubrovnik). The share of interpolated values was minimal, and amounted to only 0.3% for all stations and all annual data. Values were interpolated for the following stations: Osijek (from October 1991 to February 1992), Rovinj (from listopada 1986. do svibnja 1988.) and Dubrovnik (travanj 1978.).

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Rezultati

Velike međugodišnje varijacije količine padalina bile su sasvim očekivane. Za izgrađivanje krivulje korišteni su 5-godišnji i 10-godišnji klizni srednjaci (Slika 2.). Iz njih je vidljivo da se na svim postajama mogu izdvojiti manje ili više izraženi periodi s nešto višom i periodi s nešto nižom godišnjom količinom padalina. Početkom 1990-ih godina većina postaja bilježi znatno smanjene količine padalina, što je posljedica postupnog pada koji je nastupio 10 godina ranije i trajao do kraja stoljeća. Na postajama Koprivnica, Varaždin, Rovinj i Dubrovnik taj je pad počeo još i ranije. U istom je razdoblju na postajama Križevci, Zagreb-Maksimir i Gospić umjesto pada nastupila stagnacija. S tim u skladu na svim postajama bi se mogla izdvojiti dva ili tri sukcesivna trenda kraćeg trajanja.

Results

The large annual fluctuations seen in precipitation levels were expected. To smooth the curve, 5- and 10-year running means were used (Figure 2). With these, certain pronounced periods with higher levels and periods with lower annual precipitation levels became evident. In the early 1990s, the majority of stations recorded substantially lower precipitation levels, which is the consequence of the gradual decrease that started ten years earlier and continued to the end of the century. At the stations Koprivnica, Varaždin, Rovinj and Dubrovnik, this decline began even earlier. In the same period, stagnation instead of a decrease was recorded at the stations Križevci, Zagreb-Maksimir and Gospić. In line with this, two to three successive short-term trends could be isolated at all stations.
Linearni trend kao jedna od osnovnih statističkih analiza vremenskog niza daje nam vjerodostojnu informaciju o ukupnoj promjeni koja je nastupila između početne i završne točke toga niza, što u ovom slučaju znači razliku u količini padalina od 1950. do zaključno 2010. godine, s tim da valja uzeti u obzir činjenicu da su u cijelom tom razdoblju postojele velike međugodišnje razlike.

The linear trend, as one of the fundamental statistical analysis of time series, provides reliable information about the overall change that occurred between the initial and the final point of a series, which in this case is the difference in precipitation levels from 1950 to 2010. It should be noted that there were large annual fluctuations during this period.
Usporedbom linearnih trendova (Slika 2.) može se zaključiti da, osim Dubrovnika, niti na jednoj postaji nije došlo do izrazite promjene količine padalina, iako je na većini postaja evidentirano njihovo smanjenje (Tablica 1.). U istočnoj Hrvatskoj taj trend stagnira ili bilježi tek neznatan porast. U ostalim dijelovima Hrvatske trend pokazuje stagnaciju ili pad. Smanjenje količine padalina u promatranom je razdoblju najizražitije u Dubrovniku (45 mm svakih 10 godina) čime se ta postaja bitno izdvaja od svih ostalih u Hrvatskoj, što bi se moglo tumačiti i time što je geografski najbliža dijelu Mediterana u kojemu je smanjenje količine padalina dosta izraženo (Norrant, Douguédroit, 2006.).

Tablica 1. Trendovi padalina za razdoblje 1950. – 2010. izraženi kao desetogodišnja vrijednost

| Meteorologski postaj | Trend 1950-2010 (mm/10 god.) | Meteorologski postaj | Trend 1950-2010 (mm/10 god.) |
|----------------------|-------------------------------|----------------------|-------------------------------|
| Osijek               | +3,7                          | Rovinj               | -7,6                          |
| Slavonski Brod       | +2,2                          | Pazin                | -17,2                         |
| Donji Miholjac       | +6,5                          | Rijeka               | +8,5                          |
| Bjelovar             | -7,3                          | Senj                 | -17,2                         |
| Križevci             | -8,2                          | Mali Lošin           | -9,9                          |
| Koprinica            | -19,4                         | Zadar                | -18,4                         |
| Varaždin             | -19,0                         | Šibenik               | -13,0                         |
| Zagreb-Maksimir      | -8,5                          | Split-Marjan         | -1,5                          |
| Karlovac             | -11,7                         | Hvar                 | +2,6                          |
| Ogulin               | -9,9                          | Lastovo              | -10,6                         |
| Gospić               | -9,1                          | Dubrovnik            | -45,4                         |

From the analysis of linear trends (Figure 2), it can be concluded that none of the stations, with the exception of Dubrovnik, experienced a pronounced change in the quantity of precipitation, though a decline was recorded at the majority of stations (Table 1). In eastern Croatia, that trend has either stagnated or recorded a slight increase. In the remainder of Croatia, the trends indicate stagnation or decrease. A reduction in precipitation levels during the observed period was mostly pronounced in Dubrovnik (45 mm every 10 years), making this station stand out. This could be explained by its position close to the part of the Mediterranean where precipitation declines have been most pronounced (Norrant, Douguédroit, 2006). This particularly refers to Greece. Although many papers dealing with precipitations decrease in the Mediterranean have been published (e.g. Palutikof, 2003), the reasons for such a decline have not been fully explained, though an inverse relationship has been observed between decreasing precipitation levels and increasing air pressure (Norrant, Douguédroit, 2003). There are opinions that the changes in hydrological cycle are influenced by a higher concentration of greenhouse gases (Piervitali, Colacino, 2003). The correlation between precipitation trends and ENSO and NAO has also been investigated (PRICE ET AL., 1998; RODÒ ET AL., 1997). Investigation of correlation between ENSO and precipitations in the Mediterranean resulted in different conclusions: some scientists think that the correlation can be established, and the other have the opposite opinion (COLOCINO ET AL., 2001; MARIOTTI ET AL., 2002).
Na većini ostalih analiziranih postaja smanjenje nije veće od 20 mm u 10 godina. Iznimku čini Rijeka sa zabilježenim uzlaznim trendom. S obzirom na geografski položaj i cirkulacijske uvjete, Rijeka je specifična. Do nje dopiru vlažne zračne mase iz južnog kvadranta koje relativno niski jadranski otoci ne uspijevaju zaustaviti. Tek je planinsko zaleđe Rijeke dovoljna visinska prepreka za kondenzaciju vlažnog zraka. Osim toga, zbog koncentracije kopna, maritimni utjecaj u Rijeci je slabiji nego duž ostatka obale. Sličnih izuzetaka nalazimo i u ostalom dijelu Mediterana (Ben-Gai i dr., 1994.).

Iz 5-godišnjih i 10-godišnjih kliznih srednjaka naziru se periodi povećanja, odnosno smanjenja količine padalina. Periodičnost ciklusa padalina u Hrvatskoj već je bila predmet nekih istraživanja (Gajić-Čapka, 1992.; Gajić-Čapka, 1994.; Cvitan, 1998.).

Kako bi se naglasila periodičnost količine padalina u Hrvatskoj, konstruirani su polinomni trendovi šestog stupnja. To je učinjeno posebno za postaje u unutrašnjosti Hrvatske (Slika 3.).

At the majority of the remaining stations in Croatia, the decrease in precipitation is not more than 20 mm in 10 years, whereas the Rijeka station recorded an increase. According to its geographical position and circulation circumstances, the Rijeka area is specific in terms of precipitation quantity. The flow of air from the southern quadrant passes relatively easily over the Adriatic islands, as their altitude does not represent a significant barrier to the movement of wet air masses. However, the tall mountainous inland of Rijeka causes the humid air to rise, which results in condensation. Besides that, due to the land concentration, the maritime influence in Rijeka is less than in other coastal areas. Similar exceptional cases exist elsewhere in the Mediterranean (Ben-Gai, T. et al., 1994.).

The 5- and 10-year running means show periods of increasing and decreasing precipitation levels. The periodic precipitation cycle in Croatia has been examined earlier (Gajić-Čapka, 1992; Gajić-Čapka, 1994; Cvitan, 1998).

In order to emphasise the periodicity of precipitation levels in Croatia, a six-degree
a posebno za obalne i otočne postaje (Slika 4.). Na većini analiziranih postaja uočava se ciklus u kojem je maksimum padalina nastupio sredinom ili potkraj 60-ih godina prošlog stoljeća. Na većini je postaja vidljivo da je početak tog ciklusa nastupio neposredno nakon 1950. godine, dok se na nekim (Lastovo, Hvar, Split-Marjan, Slavonski Brod) njegov početak ne može sa sigurnošću utvrditi u analiziranom razdoblju, tj. započeo je prije 1950. godine. Na Lastovu i u Slavonskom Brodu je i maksimum nastupio ranije. Spomenuti ciklus završava 80-ih godina prošlog stoljeća, a u nekim jadranskim postajama (Lastovo, Hvar, Šibenik, Split-Marjan, Pazin, Dubrovnik) nešto kasnije, oko 1990. godine. Tada započinje drugi ciklus padalina koji je za nešto više od 50% postaja završio između 2000. i 2010. godine. Neke se postaje (npr. Lastovo) ne mogu uklopiti u opisanu cikličku shemu. Razlike između minimalnih i maksimalnih količina padalina unutar ciklusa u pravilu su manje u unutrašnjosti nego na obalnim i otočnim stanicama, što bi moglo biti povezano i s izrazitom sezonalnošću padalina tijekom godine.

a polynomial trend line was constructed. This was performed separately for the stations in continental Croatia (Figure 3), and separately for the coastal and island stations (Figure 4). In the majority of analysed stations, a cycle in which the maximum precipitation occurred in the mid to late 1960s was observed. At certain stations, it is evident that the cycle began just after 1950, while at other stations (Lastovo, Hvar, Split-Marjan, Slavonski Brod), its beginning within the analysed period cannot be determined with certainty, i.e. it began prior to 1950. At Lastovo and Slavonski Brod the maximum occurred earlier. This cycle ended in the 1980s, and somewhat later at certain Adriatic stations (Lastovo, Hvar, Šibenik, Split-Marjan, Pazin, Dubrovnik), i.e. around 1990. This marked the beginning of a second cycle, the end of which occurred between 2000 and 2010 at most of the stations. There are stations (e.g. Lastovo) that stand apart from such a cyclic scheme. The differences between the minimum and the maximum precipitation level within the cycle are generally greater at the coastal and island stations than at inland stations. That could be related to the strong precipitation seasonality during the year.
Zaklučak

Prema analizi podataka 22 postaje u Hrvatskoj, u razdoblju 1950. – 2010. godine količine padalina pokazuju vrlo malu promjenjivost. Linearni trendovi upućuju na stagnaciju ili neznatan porast količine padalina u istočnoj Hrvatskoj, dok se istodobno u ostalim dijelovima Hrvatske bilježi stagnacija ili vrlo blagi pad. Drugim riječima, niti jedan dio Hrvatske ne pokazuje veliku i naglu promjenu količine padalina. Iznimka je Dubrovnik. Ipak, ako bi se ovakvi trendovi nastavili, dugoročno bi mogli dovesti do geografskih posljedica. One se prije svega odnose na opskrbu stanovništva vodom te nedostatak vode za uzgoj kultura. Na većini postaja mogu se uočiti cikličke promjene u količini padalina. Ciklusi padalina razlikuju se trajanjem i amplitudom padalina unutar ciklusa.

Conclusions

An analysis of the data of 22 weather stations in Croatia in the period from 1950 to 2010 showed very little overall change in the annual precipitation levels. The linear trends indicate a stagnation or slight increase in the precipitation levels in eastern Croatia, while the remaining regions of Croatia recorded stagnation or very slight decreases. In other words, no large or sudden changes in precipitation levels were recorded in any part of Croatia. The exception is Dubrovnik. However, if these trends continue, they could lead to long-term geographic consequences regarding water management and agriculture. At the majority of stations, cyclic precipitation changes can be observed. The precipitation cycles differ in duration and precipitation amplitude.

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