SUVREMENE PROMJENE KLIME I SMANJENJE PROTOKA SAVE U ZAGREBU

CONTEMPORARY CLIMATE CHANGES AND DECREASE OF SAVA RIVER FLOW THROUGH ZAGREB

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Koeficijent korelacije 0,81 između protoka Save u Zagrebu i padalina u Ljubljani ukazuje na dominantno značenje padalina. U najtoplijim mjesecima protok Save mnogo ovisi o evapotranspiraciji. Protok Save ima silazni trend, a oštro se luče dva razdoblja: 1926.-1959. i 1960.-1995. To je posljedica isto takvog hoda padalina u gornjem toku Save. U cijelom promatranom razdoblju postoji trend porasta atmosferskog tlaka. Za "padalinsku kontinentalnost" značajna je promjena trenda. Od 1960. god. opada udio "ljetnih" padalina.

Ključne riječi: promjena klime, godišnje padaline u Ljubljani i Zagrebu, srednji godišnji protok Save u Zagrebu, atmosferski tlak u Zagrebu

Correlation coefficient of 0.81 between Sava River flow through Zagreb and precipitation in Ljubljana points at dominant significance of precipitation. In the warmest months Sava flow is very much dependent on evapotranspiration. Sava River flow has downward trend, and two intervals can be sharply distinguished: 1926-1959 and 1960-1995. That is the result of the identical precipitation trend at the Upper Sava. There is the trend of atmospheric pressure rise in the entire observed period. "Precipitation continentality" is characterized by change of trend. Share of "summer" precipitation has been declining since 1960.

Key words: climate change, annual precipitation in Ljubljana and Zagreb, mean annual Sava flow through Zagreb, atmospheric pressure in Zagreb

Uvod

Poznata je činjenica da se sve više piše i govori o klimatskim promjenama. Naime, hidrološke suše i poplave kao i vodoopskrba sve su teži (skuplji) problemi suvremenog svijeta. Stoljeće (pa i više) pokazalo je da je erozija Save postala faktor o kojem treba voditi računa (Biondić, 2000). Zbog silne kompleksnosti odnosa klimatskih elemenata, u ovom su radu izdvojene padaline u Ljubljani i njihov utjecaj na protok Save u Zagrebu. Pokazalo se da su padaline u Ljubljani reprezentativne za porječje Save uzvodno od Zagreba.

Podatci

Budući da je težište rada na protoku Save u Zagrebu, taj hidrološki parametar odredio je duljinu analiziranog razdoblja. Protok Save u

Introduction

It is a known fact that we can read and hear more and more about climate changes. Specifically, hydrological droughts and floods as well as water supply are an increasing (more expensive) problems of the modern world. Century (and more) has shown that Sava erosion has become a factor that should be taken into account (Biondić, 2000). Due to complexity of correlation between climatic elements, this paper deals with precipitation in Ljubljana and their influence on Sava River flow through Zagreb. It was found that precipitation in Ljubljana are representative for Sava River basin upstream of Zagreb.

Data

Since the emphasis of this paper is on Sava River flow through Zagreb, that hydrological parameter

Zagrebu prati se od 1926. god., ali se niz podataka prekida 1996.-1998. god., pa zato nisu korišteni inače postojeći podatci nekoliko sljedećih godina poslije tog prekida. Naime, poznato je pravilo da se uspoređivati mogu (ili smiju) samo podatci iz jednako dugih razdoblja bez prekida.

Iz prirode odnosa protoka i padalina za analizu uzeti su podatci o padalinama u Ljubljani. Podatci su uzeti onakvi kakve je izdala službena ustanova, iako, strogo uzevši, nisu homogeni (Manohin, 1952; Furlan, 1972).

Metode istraživanja

Zbog izrazite varijabilnosti procesa težište je na utvrđivanju linearnih trendova. Pokazalo se da je linearni trend bolje prilagođen nekim dijelovima niza nego cjelini. Zato su izdvojena dva razdoblja različitog trajanja. Nizanje 10-godišnjih kalendarskih "okruglih" razdoblja ne daje pravu sliku prikazivanih procesa. S dinamičkog stajališta kalendarska "okrugla" razdoblja nemaju nikakvu prednost ili privilegiju kao "miljokazi" u nizovima analiziranih veličina (B. Penzar i dr., 1992). To vrijedi i za 30-godišnja razdoblja.

Metoda pokretnih srednjaka mnogo se koristi u klimatološkim, ali ne i u hidrološkim analizama. Zornosti radi, ali i da se na minimum svedu negativne osobine pokretnih srednjaka (preveliko isticanje ekstremnih veličina i u susjednim godinama), prikazali smo samo 3-godišnje pokretne srednjake.

U radovima ove vrste često se godina dijeli u dva dijela, hladnu polovicu godine (listopad – ožujak) i na topliju polovicu (travanj – rujan). Težište je na analizi padalina u toploj polovici godine, budući da u porječju Save uzvodno od Zagreba pretežu "ljetne" kiše.

Analizom se pokazalo da meteorološka periodizacija po tridesetljećima ne odgovara posve periodizaciji protoka Save u Zagrebu, to više što se "suvremeno otopljavanje" odnosi na temperaturu zraka, a protok prije svega ovisi o padalinama, o njihovoj godišnjoj količini, pa i godišnjem hodu. To komplicira međusobne odnose relevantnih parametara, prije svega utjecaj temperature (zraka i podloge) na evapotranspiraciju, a tek preko nje na protok.

Zbog poznatih razloga protok je suptilnija veličina od vodostaja. Međutim, mjerenje vodostaja mnogo je jednostavnije i "trenutno", za razliku od

determined the length of the analysed period. Sava flow through Zagreb has been recorded since 1926, but there was a break between 1996 and 1998, therefore the existing data from the following few years after the break were not used. It is a known rule that only data from equally long periods without a break can (or may) be compared.

From the correlation between the flow and precipitation, the analysis used the data on precipitation in Ljubljana. Data are taken the way the official institution published them, even though, strictly speaking, they are not homogeneous (Manohin, 1952; Furlan 1972).

Research methods

Due to prominent variability of the process the emphasis is on establishing linear trends. It was found that linear trend is better adapted to some parts than to the whole. Therefore two intervals of different duration have been singled out. Listing ten-year "round" calendar periods does not give the true picture of those processes. From dynamic point of view, "round" calendar periods have no advantage or privilege as "landmarks" in series of analysed data (Penzar et al., 1992). That also applies to thirty-year periods.

Method of shifting arithmetic means is frequently used in climatological, but not as much in hydrological analyses. In order to be realistic, but also to reduce to a minimum the negative characteristics of shifting arithmetic means (emphasizing the extreme data in adjoining years), we showed only three-year shifting arithmetic means.

In this kind of papers, the year is often divided into two parts, the cold part of the year (from October to March) and the warm part (from April to September). The emphasis is on the analysis of precipitation in warm part of the year, since "summer" rains predominate in Sava basin upstream of Zagreb.

Analysis showed that meteorological periodisation by thirty-year periods does not correspond completely to the periodisation of Sava flow through Zagreb. Additionally, "present-day warming" refers to air temperature, and the flow depends above all on precipitation, their annual quantity and annual trend. That complicates the correlation between relevant parameters, primarily the effect of temperature (air and ground temperature) on evapotranspiration, and consequently the flow itself.

mjerenja i izračunavanja protoka. Zato se u mnogo više radova analiziraju vodostaji nego protok Save kod Zagreba. Naime, najveću praktičnu hidrološku važnost imaju minimalni i maksimalni vodostaji (Bonacci, Trninić, 1989; Trninić, 1984; Trninić, 1990; Trninić, 1992; Trninić, 1993; Trninić, Slamar, 1993). Moguća je usporedba Ljubljane sa Zagrebom, jer obje postaje pripadaju "istom" godišnjem režimu padalina i protoku Save. Međutim, režim padalina u obrađenom prostoru osnova je za neke pokušaje klasifikacije vodostaja Save, ali ne postoji regionalizacija na temelju protoka vode.

Rezultati istraživanja

Uzročno-posljedični odnos između padalina i protoka teoretski je jasan i jednostavan. Ali, potrebno je imati na umu nekoliko činjenica koje silno kompliciraju prostorno-vremenski tok i veličinu tih odnosa. Za protok (m^3) odlučna je količina padalina (mm) sa što veće površine (porječja), ili sa što većeg dijela porječja uzvodno od postaje gdje se mjeri protok. Sljedeći važan parametar je isparavanje padalinskih voda. Zatim dolazi "nestanak" vode ispod površine, koja se prije ili kasnije pojavljuje u vodotoku. Protok i padaline mogu se dosta točno izmjeriti u jednoj "točki", ali koliki je udio pojedinih parametara podložnih stalnim prostorno-vremenskim varijacijama, neusporedivo je teže odrediti.

Uobičajeno je najprije odrediti odnos padalina u porječju Save uzvodno od Zagreba barem u jednoj postaji. Taj se odnos kvantificira određivanjem koeficijenta korelacije.

U našem slučaju uzete su (Sl. 1.) godišnje padaline u Ljubljani i protok Save u Zagrebu. Već se na prvi pogled vidi opće pravilo da se povećanjem godišnjih količina padalina u Ljubljani može očekivati povećanje protoka Save u Zagrebu. Udio snijega zasad je teško odrediti to više što se za snijeg uzima vodeni ekvivalent u milimetrima i dodaje se količini pale kiše. Odnos padalina i protoka je linearan, pa se radi o linearnoj korelaciji. Izračunati koeficijent korelacije iznosi 0,81. Odnos čvrstoće veze među varijablama i koeficijenta korelacije nije definiran i unificiran, ali uzima se da koeficijent korelacije 0,91 ukazuje kako je veza vrlo čvrsta (Srebrenović, 1986). "U hidrologiji općenito se smatra da se korelacijski odnos može koristiti ako je apsolutna vrijednost veća od 0,6." (Žugaj, 2000).

Because of the well-known reasons, the flow is more subtle indicator than water level. However, measuring water level is more simple and "momentary" as opposed to measuring and calculating the flow. Therefore, more papers analyse water level than Sava flow near Zagreb. Minimum and maximum water levels have the most practical hydrological importance (Bonacci, Trninić, 1989; Trninić, 1984; Trninić, 1990; Trninić, 1992; Trninić, 1993; Trninić, Slamar, 1993). It is possible to compare Ljubljana with Zagreb because both stations have "the same" annual precipitation regime and Sava flow. However, precipitation regime in the analysed area is the foundation for some attempts of classifying Sava level, but regionalization based on water flow does not exist.

Research results

Cause-and-effect correlation between precipitation and flow is theoretically clear and simple. But it is necessary to remember a few facts that complicate spatio-temporal course and magnitude of those relations. Flow (measured in cubic metre) depends on precipitation amount (measured in millimetres) in wider area (basin), or in the wider part of the basin upstream of the station where the flow is measured. The next important parameter is evaporation of precipitation. Besides that, there is also "disappearance" under the surface. That water appears in the water flow sooner or later. Flow and precipitation can be quite accurately measured in one "spot", but it is more difficult to determine share of individual parameters that are subjected to constant spatio-temporal variations.

It is customary to determine the correlation of precipitation in Sava basin upstream of Zagreb in at least one station. That correlation is quantified by determining correlation coefficient.

In this case (Fig. 1) the annual precipitation in Ljubljana and Sava flow through Zagreb are analysed. The general trend can be observed immediately – the increase of annual precipitation amount in Ljubljana leads to increased Sava flow through Zagreb. (It is difficult to determine the share of snow at the moment, particularly because the snow is measured as the water equivalent in millimetres, and it is added to the amount of rain.) Correlation between precipitation and flow is linear therefore, we have linear correlation. Calculated correlation coefficient is 0.81. The

Vidjet ćemo da prijelomno značenje ima 1960. godina. Zato smo posebno analizirali odnos mjesečnih padalina u Ljubljani i protoka Save u Zagrebu u godišnjem prosjeku 1960.-1995. (Sl. 2.).

Lako se opaža složenost usporednih varijabli. Najviše je pri tome važno ukazati na važnost evapotranspiracije u toplom dijelu godine. U ovom času nije moguće istražiti promjene utjecaja podzemnih voda. Određeno značenje ima kalendarska podjela godine na mjesece, pa se, na primjer, podaline krajem nekog mjeseca odražavaju u porastu protoka sljedećeg mjeseca; dakako, postoje i druge kombinacije.

Usporedbom s 12 drugih meteoroloških postaja u promatranom porječju Save utvrđeno je da su u svim postajama jesenske kiše veće u listopadu, a protok Save u Zagrebu najveći je u sljedećem mjesecu, u studenom. U svim meteorološkim postajama, osim u Ljubljani, postoji znatna razlika u razdoblju rujan – studeni. Dakako, maksimalni protok Save u Zagrebu u studenom nije posljedica isključivo kiše u studenom u širem zagrebačkom području.

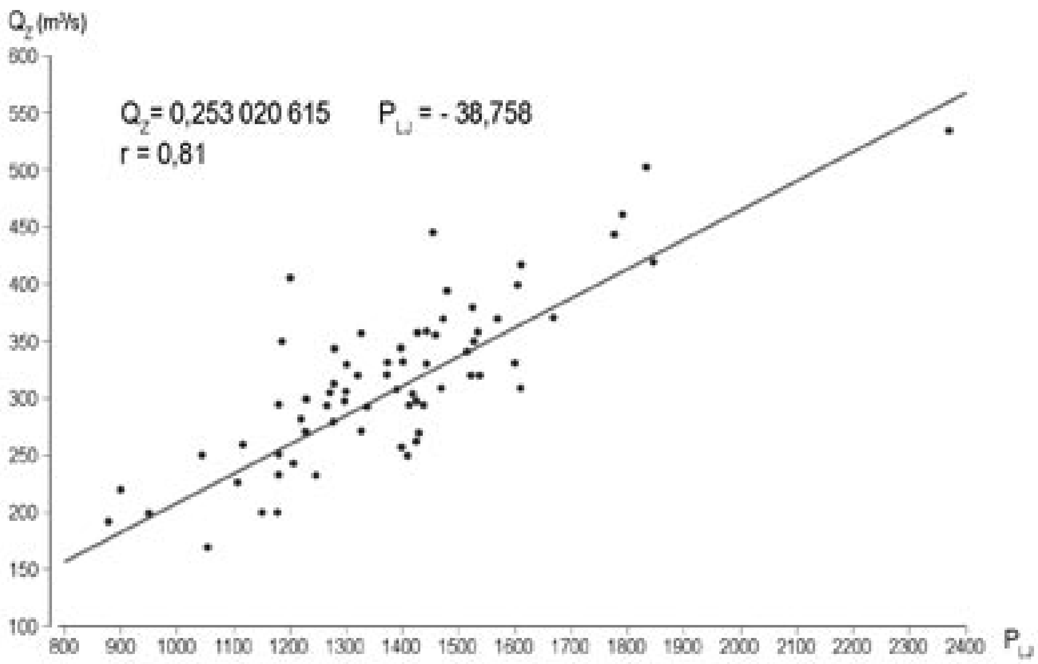
Na kompleksnost procesa ukazuje odnos padalina u Ljubljani i protoka Save u Zagrebu u

correlation between the connection strength among the variables and correlation coefficient is not defined or standardized. However, it is considered that correlation coefficient of 0.91 shows that the connection is very strong (Srebrenović, 1986). "In hydrology, that correlation can be used if the absolute value is above 0.6" (Žugaj, 2000).

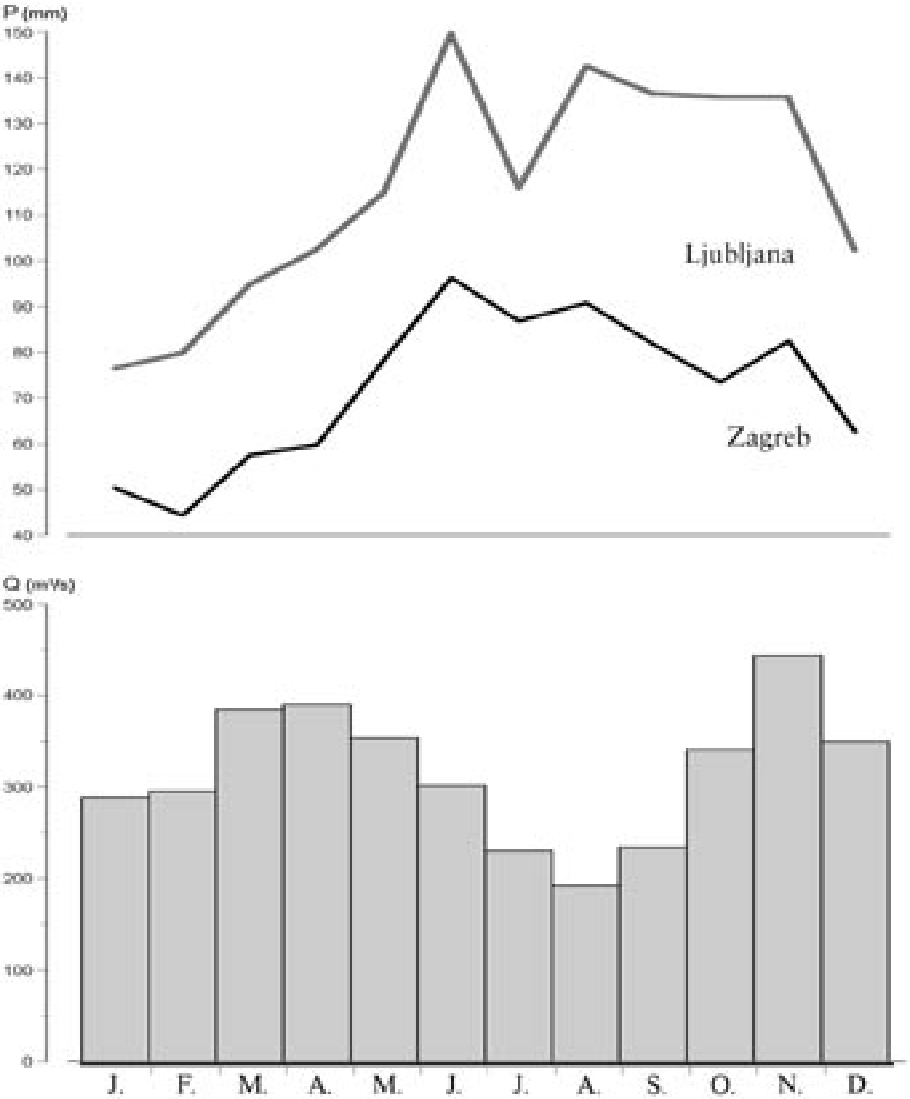
The year 1960 can be considered as a turning point. Therefore, we analysed separately the correlation between monthly precipitation in Ljubljana and Sava flow through Zagreb by using the annual average values between 1960 and 1995 (Fig. 2).

Complexity of parallel variables can be seen easily. It is most important to point at the importance of evapotranspiration in the warm part of the year. At this moment, it is not possible to examine the changes of groundwater effect. Division of a calendar year into months has a certain importance, for example precipitation at the end of one month is reflected in the flow increase in the next month; of course, other combinations exist, too.

In comparison with twelve other weather stations in the investigated Sava basin, it was determined that all stations have large amount



Slika 1. Linearna korelacija između srednjeg godišnjeg protoka Save u Zagrebu (Q_Z) (izvor: DHMZ RH, arhivski podatci) i godišnjih količina padalina u Ljubljani (P_{LJ}) (izvor: Agencija Republike Slovenije za okolje, arhivski podatci). Podatci za razdoblje 1926.-1995.
Figure 1. The linear correlation between the Sava river mean annual discharge at Zagreb (Q_Z) and the annual precipitation at Ljubljana (P_{LJ}).



Slika 2. Gore, godišnji hod srednjih mjesečnih padalina u Ljubljani za razdoblje 1960.-1995. (izvor: Agencija Republike Slovenije za okolje, arhivski podatci) i godišnji hod srednjih mjesečnih padalina u Zagrebu-Griču za razdoblje 1960.-1995. (I. Penzar i dr., 1992, plus dopuna.). Dolje, srednji mjesečni protoci Save u Zagrebu za razdoblje 1960.-1995. (izvor: DHMZ RH, arhivski podatci).

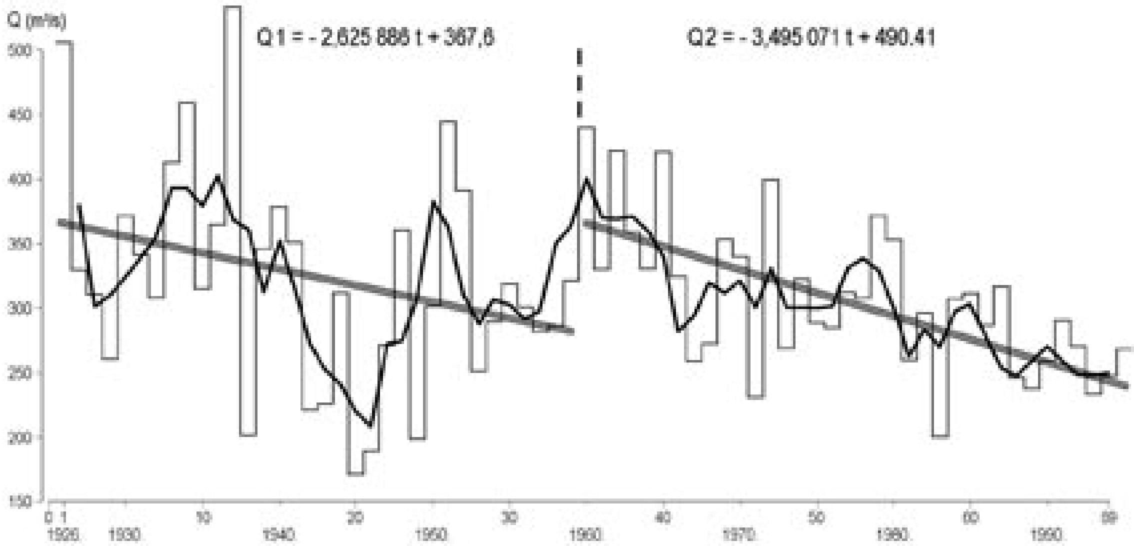
Figure 2. Monthly mean amounts of precipitation at Ljubljana, Slovenia, for the period 1960-1995. Montly mean amounts of precipitation at Zagreb, Croatia, for the period 1960-1995. Mean monthly discharge of the Sava river at Zagreb in the period 1960-1995.

proljetnim mjesecima. Očito je da je velika važnost proljetnog kopnjenja snijega.

Tek sada možemo poći s konačnom posljedicom, s protokom Save u Zagrebu (Sl. 3.). Već se na prvi pogled vidi, a to potvrđuje izračunati trend, da od 1926. god. postoji trend smanjenja protoka Save u Zagrebu. Međutim, postoji izrazita razlika između starijeg razdoblja, 1926.-1959. god., te mlađeg razdoblja, 1960.-1995. god. U starijem razdoblju (Q1) karakteristična je velika međugodišnja varijabilnost protoka Save. To pokazuju i trogodišnji pokretni srednjaci. Kao da se smjenjuju razdoblja

of autumn rainfall in October, and Sava flow through Zagreb is the biggest in the following month, November. At all weather stations, except in Ljubljana, there is a significant difference in the period between September and November. Of course, maximum Sava flow through Zagreb in November is not only the result of November rainfall in wider Zagreb area.

Correlation between precipitation in Ljubljana and Sava flow through Zagreb in spring months points at the complexity of the process. It is obvious that thawing of the spring snow is very important.



Slika 3. Godišnji srednjaci protoka Save u Zagrebu za period 1926.-1995. te 3-godišnji pokretni srednjaci i linearni trendovi (izvor: DHMZ RH, arhivski podatci). Trendovi za razdoblje 1926.-1959 (N=34 god.) i 1960.-1995. (N = 36 god.).
Figure 3. Mean annual discharge of the Sava river at Zagreb in the period 1926-1995.

s pretežno većim protocima, ali takve osobine nisu osnova za prognozu godišnjih protoka.

Protok 1960. godine kraj je prvog razdoblja, Q1, a početak je mlađeg razdoblja, Q2, koje traje sve do 1995. godine, do kraja niza (a zasigurno se produžuje i nekoliko godina kasnije, nakon prekida motrenja). Karakteristično je za ovo mlađe razdoblje, Q2, smanjenje međugodišnjih razlika srednjih godišnjih protoka Save. Ne manju važnost ima izraziti trend pada protoka. Nema sumnje da on utječe na povremene hidrološke suše i probleme koje one donose. Konkretno, linearni trend pokazuje da je "linearizirani" godišnji protok između 1960. god. (368,1 m^3/s) i 1995. god. (249,25 m^3/s) pao za 118,85 m^3/s. Nema sumnje da je to alarmantan podatak!

Ljubljana je vrlo vjerojatno najpovoljnije geografski smještena za klimatološka i hidrološka istraživanja na Savi u Sloveniji (Sl. 4.).

U prvom je razdoblju karakteristična velika amplituda godišnjih količina padalina, dok je u drugom razdoblju primjetno manja. Očito je da 3-godišnji pokretni srednjaci mnogo pridonose zornosti tog procesa. Hod godišnjih padalina nije pravilan, pa ne može poslužiti za pouzdaniju prognozu ni u neposrednoj budućnosti.

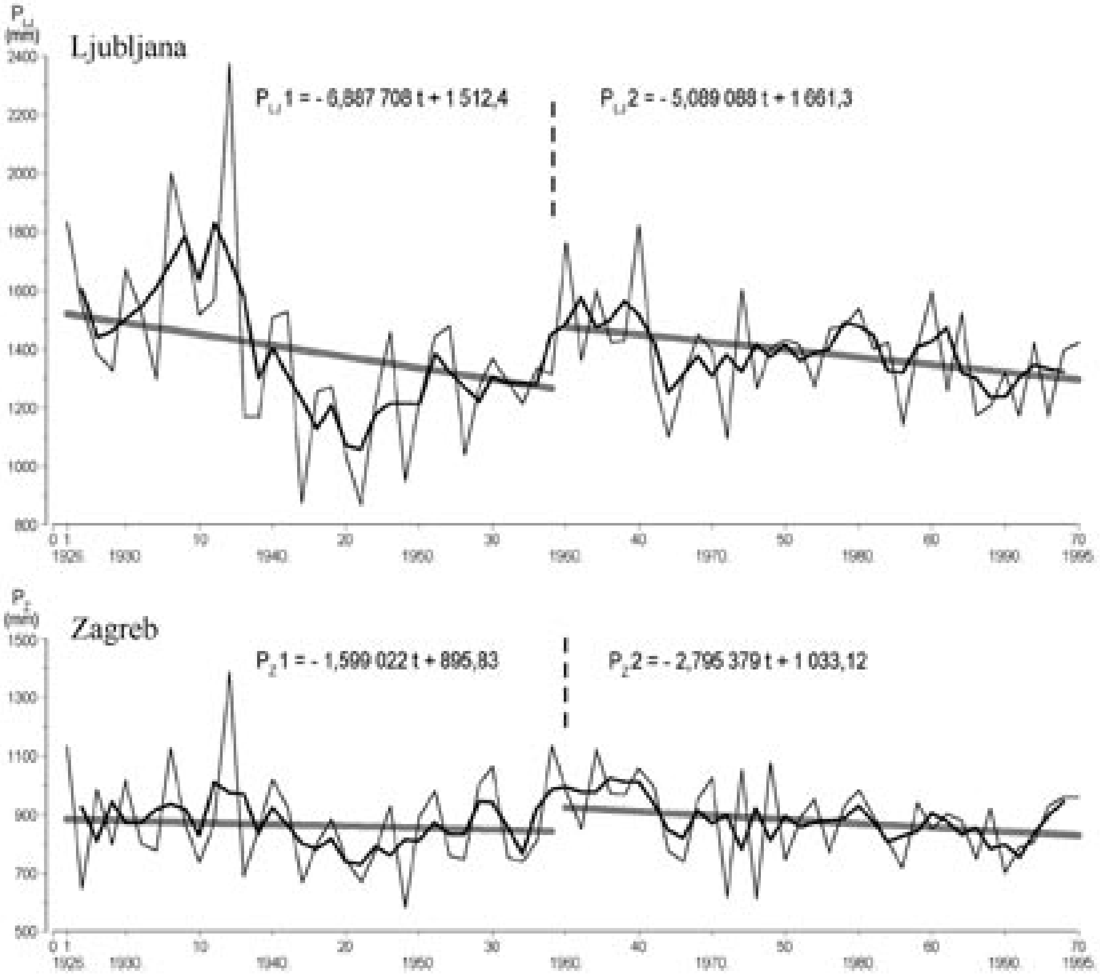
U drugom razdoblju, od 1960. god. nastavlja se silazni trend godišnjih količina padalina. Primjetno je smanjenje međugodišnjih varijacija; graf je "smireniji". U tom 36-godišnjem nizu

Only now we can we refer to the final result, Sava flow through Zagreb (Fig. 3). As one can observe at first glance, and calculated trend confirms it, there has been a downward trend of Sava flow through Zagreb since 1926. However, there is a distinct difference between the older period, between 1926 and 1959, and the recent period between 1960 and 1995. Characteristic feature of the older period (Q 1) is big variability of Sava flow through years. Three-year shifting arithmetic means also prove it. It looks as if intervals with bigger flow are alternating, but such characteristics are not basis for annual flow prediction.

Flow in 1960 is the end of the first period, Q1, and the beginning of recent period, Q2, that lasts up to 1995, to the end of the sequence (and is certainly extended a few years later, after the observation ended). The recent period, Q2, is characterized by a decrease of difference in mean annual Sava flows through years. Distinct trend in flow decrease is also very important. There is no doubt that it affects periodical hydrological droughts and problems they bring along. Specifically, linear trend shows that "linear" annual flow between 1960 (368.1 m^3/s) and 1995 (249.25 m^3/s) decreased by 118.85 m^3/s. That is undoubtedly alarming information!

Ljubljana has probably the most favourable geographic position for climatological and hydrological research on Sava in Slovenia (Fig. 4).

The first period has big amplitude in annual amount of precipitation, while in the second



Slika 4. Gore: Godišnje padaline u Ljubljani 1926.-1995. god. (izvor: Agencija Republike Slovenije za okolje, arhivski podatci). Dolje: Godišnje padaline u Zagrebu-Griču 1926.-1995. god. (I. Penzar i dr., 1992 + arhivska dopuna), 3-godišnji pokretni srednjaci.
Figure 4. Upper: Annual amounts of precipitation at Ljubljana, Slovenia, for the period 1926-1995. Lower: Annual precipitation at Zagreb-Grič, Croatia, for the period 1926-1995.

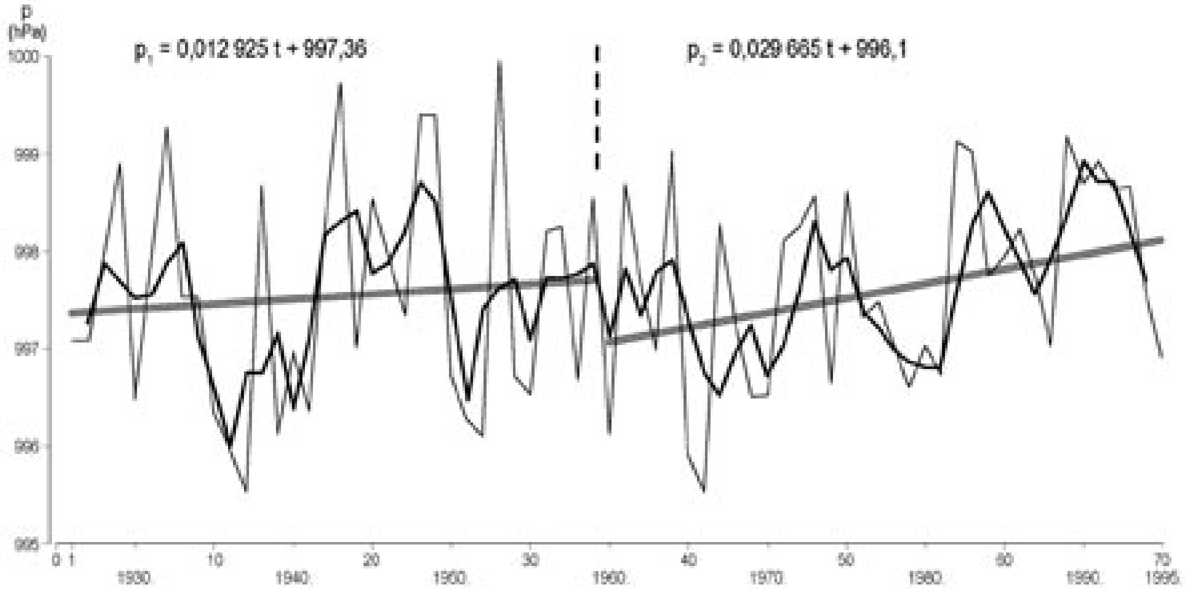
srednja godišnja količina padalina u Ljubljani reprezentirana linijom trenda pala je s 1483 mm 1960. god. na 1305 mm 1995. god., tj. pala je za 178 mm, tj. za okruglo 5 mm godišnje.

Budući da se radi o istoj klimatskoj regiji i istom porječju, korisno je za usporedbu prikazati višegodišnji hod padalina u Zagrebu-Griču (Sl. 4.). Kolebanje je godišnjih padalina u Zagrebu mnogo manje nego u Ljubljani. (U Zagrebu se jasno izdvajaju dva razdoblja s trendom pada godišnjih padalina. Posebno je značajno razdoblje P_Z 2, 1960.-1995. god. U tih je 36 godina po trendu količina padalina s 935,3 mm 1960. god. pala na 837,4 mm 1995. god. Dakle, trendom "izglađene" količine padalina pale su za okruglo 98 mm, odnosno 2,8 mm prosječno godišnje.

period it is significantly smaller. It is obvious that three-year shifting arithmetic means contribute a lot to vividness of that process. Annual trend of precipitation is not regular therefore it can not be used for reliable prediction, even in the near future.

In the second period, from 1960, downward trend of the annual amount of precipitation continued. Variations between years are noticeably smaller; the graph is "calmer". In that 36-year sequence, mean annual amount of precipitation in Ljubljana represented by trend line declined from 1,483 mm in 1960 to 1,305 mm in 1995, i.e. it declined by 178 mm (5 mm per year).

Since this is the same climate region and river basin, it is useful for a comparison to show long-



Slika 5. Srednji godišnji atmosferski tlak (hPa) u Zagrebu-Griču 1926.-1995. god. (izvor: I. Penzar i dr., 1992, plus arhivski dodatak), 3-godišnji pokretni srednjaci i linearni trendovi.
Figure 5. Mean annual atmospheric pressure at Zagreb-Grič, 1926-1995.

Atmosferski tlak prostorno mnogo manje varira nego padaline. Zato je za potpunije shvaćanje promjene protoka Save u Zagrebu korisno prikazati trend atmosferskog tlaka u Zagrebu (Sl. 5.). U cijelom promatranom razdoblju, 1926.-1995. očituje se trend porasta atmosferskog tlaka. Međutim, i u ovom slučaju jasno se luče dva razdoblja: p_1, 1926.-1959. god. i p_2, 1969.-1995. god.

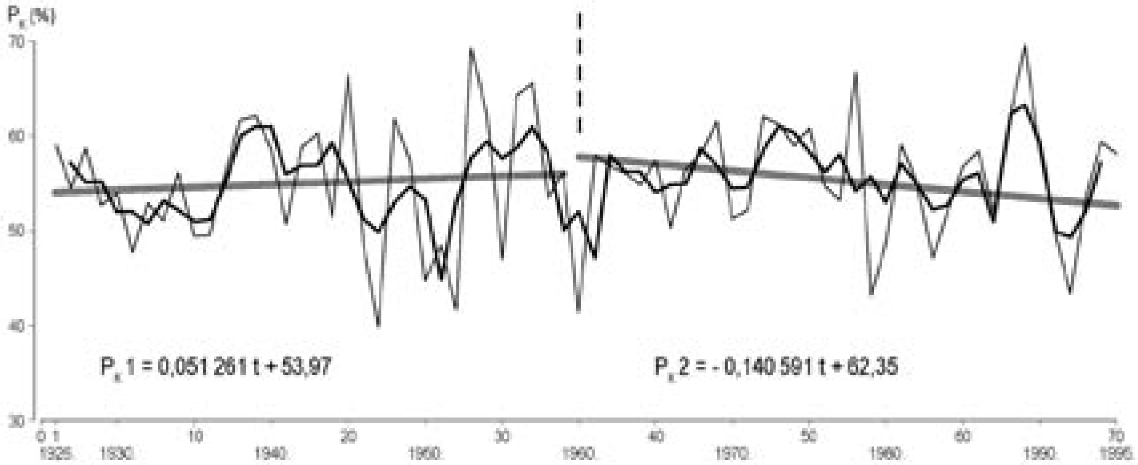
U prvom razdoblju porast atmosferskog tlaka bio je manji nego u drugom razdoblju, 1960.-1995. god. Zanimljiva je činjenica da su međugodišnje varijacije atmosferskog tlaka bile veće nego u drugom razdoblju. S obzirom na protok Save, i vezu s njim, jasno se vidi nagli porast atmosferskog tlaka sa 997,1 hPa 1960. god. na 998,1 hPa 1995. god. Dakle, u ovom drugom 36-godišnjem razdoblju atmosferski je tlak u Zagrebu porastao za 1 hPa. Ni u drugom razdoblju porast atmosferskog tlaka nije bio linearan, nego su se smjenjivala kraća razdoblja s relativno višim ili nižim atmosferskim tlakom. Takva smjena godišnjeg atmosferskog tlaka nekim istraživačima služi za eventualnu prognozu srednjega godišnjeg atmosferskog tlaka.

Da se omogući usporedba apsolutnih količina padalina u toploj polovici godine, upotrebljavaju se relativne vrijednosti količine padalina u toploj polovici godine. P_{tp} se podijele s godišnjom sumom

term precipitation trend in Zagreb-Grič (Fig. 4). Fluctuation of annual precipitation in Zagreb is much smaller than in Ljubljana. (There are two intervals with downward trend of annual precipitation in Zagreb. Interval P_Z 2, between 1960 and 1995, is especially important. In those 36 years precipitation amount decreased from 935.3 mm in 1960 to 837.4 mm in 1995. Therefore, the amount of precipitation "smoothed down" by trend decreased by 98 mm, i.e. 2.8 mm per year.

Atmospheric pressure exhibits much less spatial fluctuations than precipitation. Therefore in order to understand fluctuations of Sava flow through Zagreb, it is useful to show atmospheric pressure trend in Zagreb (Fig. 5). In the entire observed period between 1926 and 1995 there was an upward trend in atmospheric pressure. However, two periods can also be distinguished in this case: p_1, between 1926 and 1959, and p_2, between 1969 and 1995.

Increase of atmospheric pressure was smaller in the first than in the second period, between 1960 and 1995. It is an interesting fact that variations in atmospheric pressure through years were bigger than in the second period. Considering Sava flow and its connection to the pressure, it can be clearly seen that atmospheric pressure increased from 997.1 hPa in 1960 to 998.1 hPa in 1995. Therefore, in this second 36-year period atmospheric pressure



Slika 6. Udio padalina u toploj polovici godine. Postotak godišnjih količina u Ljubljani u razdobljima 1926.-1959. i 1960.-1995. god. (izvor: Agencija Republike Slovenije za okolje, arhivski podatci).
Figure 6. The march and the trend of the precipitation in the warmer half-year at Ljubljana

padalina i pomnože sa sto. Najprije treba izračunati prosjek za cijelo promatrano razdoblje. Izolinija (ili samo numerička vrijednost) od 50% naziva se crta kontinentalnosti (ili granica kontinentalnosti ako se radi o jednoj postaji). Očito je da bi bilo ispravnije reći padalinska kontinentalnost, pa otuda i crta padalinske kontinentalnosti; jer je kontinentalnost kompleksan pojam (odnosno klima nije definirana samo jednim klimatskim elementom).

U višegodišnjem prosjeku i u najvećem broju godina (odnosno toplih polovica godina) padalinska kontinentalnost u Ljubljani (Sl. 6.) iznosi više od 50%.

U razdoblju 1926.-1959. ona je u prosjeku iznosila 54,87%, a u drugom razdoblju, 1960.-1995. iznosila je 54,95% (ovo je primjer uporabe isključivo srednjaka). Međutim, za protok Save u Zagrebu bitno značenje ima trend, jer ukazuje na velike razlike, odnosno na "tendenciju razvoja". Dakle, u prvom razdoblju, 1926.-1959. god., vidi se trend *porasta* padalinske kontinentalnosti u Ljubljani. U drugom razdoblju, 1960.-1995. trend je silazan, izrazit je *pad* padalinske kontinentalnosti, tj. smanjuje se udio "ljetnih" padalina u godišnjim padalinama. (Treba biti oprezan, pa se ne smije izjednačavati količine ljetnih padalina s količinom padalina u toploj polovici godine. Za to je potrebna posebna analiza.)

"Crta kontinentalnosti" srednja je višegodišnja vrijednost. Unutar nje se nalazi cijelo porječje Save uzvodno od Zagreba (Vujević, 1954). To je potvrđeno i za razdoblje 1931.-1960. god. (Šegota, 1986). Budući da je "crta kontinentalnosti"

in Zagreb increased by 1 hPa. Even in the second period the increase of atmospheric pressure was not linear, but shorter periods with relatively higher or lower atmospheric pressure were alternating. This kind of annual atmospheric pressure shift serves as a possible prediction of mean annual atmospheric pressure to some researchers.

In order to enable comparison of total precipitation amount in the warm part of the year, relative values of precipitation amount in warm half of the year are used. P_{tp} is divided by total annual amount of precipitation and multiplied by hundred. First of all, the average for the entire observed period should be calculated. Isoline (or only its numerical value) of 50% is called continentality line (or continentality border if there is only one station). It is obvious that it would be more correct to say precipitation continentality, which explains the term precipitation continentality line, particularly because continentality is a very complex term (i.e. climate is not defined by only one climatic element).

In the long-term average and in the maximum number of years (i.e. warm parts of the year) precipitation continentality in Ljubljana (Fig. 6) is more than 50%.

In the period between 1926 and 1959 it was on average 54.87%, and in the second period between 1960 and 1995 it was 54.95% (this is an example where only arithmetic means were used). However, the trend is very important for Sava flow through Zagreb, because it indicates big differences, i.e. "development trend". Consequently, in the first period, between 1926 and 1959, precipitation dinamička veličina onda je i u nešto udaljenijoj Ljubljani u nekim godinama izmjereno više padalina u hladnoj nego u toploj polovici godine. (U 6 od 36 godina u razdoblju 1960.-1995. više je padalina palo u hladnoj polovici godine.)

Za važnije, drugo razdoblje, P_k2, 1960.-1995. god. iz jednadžbe pravca lako se dolazi do egzaktne veličine trenda. God. 1960. udio padalina u toploj polovici godine iznosio je 57,4%, a u 1995. god. smanjio se na 52,5%.

Informacije radi možemo podsjetiti da se u literaturi za oceanski režim (više padalina u hladnoj polovici godine) upotrebljavaju još termini maritimni ili mediteranski, sredozemni ili primorski te maritimno-mediteranski režim. Za unutrašnjost se, osim kontinentskog režima, koriste i termini panonsko-kontinentski, kontinentalno-srednjoeuropski režim, te konačno umjereno kontinentski režim.

Zaključak

Svjedoci smo silnog porasta važnosti recentne promjene klime. Međutim, globalna promjena klime, čini se, vrijedi samo za temperaturu zraka. Nema dokaza da se tlak zraka i padaline povećavaju ili smanjuju na cijelom svijetu. Promjene atmosferskog tlaka i padalina imaju samo (makro)regionalno značenje. Ograničili smo se na uže područje (u globalnom smislu) koje je povezano s hidrološkim kompleksom, s protokom Save u Zagrebu. Regionalna ograničenost određenog trenda padalina utvrđena je već u samom početku istraživanja klime na Zemlji.

Pod utjecajem Alpa u gornjem toku Save (i pritoka) pada mnogo kiše i snijega. Živi reljef utjecao je na malen volumen kvartarnog akvifera, što znači da se on brzo napuni i isprazni. To se očituje u činjenici (Sl. 1.) da postoji vrlo čvrsta korelacija između padalina u Ljubljani i protoka Save u Zagrebu.

Utjecaj malenog volumena kvartarnog sedimentnog akvifera jasno se očituje u godišnjem hodu protoka Save (Sl. 2.). Relativno niži reljef južno od gornjeg porječja Save i živahna ciklonska aktivnost nad Sredozemljem uzrok su povećanja proljetnog i jesenskog maksimuma padalina i maksimalnog protoka Save. U najtoplijem dijelu godine veliko značenje ima evapotranspiracija. Velik porast temperature zraka (i vode), a time i evapotranspiracije te zagrijavanja podloge, i jaka konvekcija uzrok su obilnih padalina u najtoplijem

continentality in Ljubljana had an *upward* trend. In the second period, between 1960 and 1995, precipitation continentality had a prominent *downward* trend, i.e. the share of "summer" precipitation in total annual precipitation decreased. (However, summer precipitation amount should not be levelled with precipitation amount in warm part of the year. That requires special analysis.)

"Continentality line" is a long-term mean value. The entire Sava basin upstream of Zagreb is located within it (Vujević, 1954). That has also been confirmed for the period between 1931 and 1960 (Šegota, 1986). Since "continentality line" is a dynamic indicator, in Ljubljana, which is somewhat remoter, some years had more precipitation in cold than in warm part of the year. (In the period between 1960 and 1995 in 6 out of 36 years there were more precipitation in cold part of the year.)

The more important, second period (P_k2, between 1960 and 1995) linear equation easily provides the exact trend value. In 1960, precipitation share in warm part of the year was 57.4%, and in 1995 it was reduced to 52.5%.

To set the record straight, it is worth noting that some other terms for oceanic regime (more precipitation in cold half of the year) can be found in literature, such as maritime or Mediterranean, or maritime Mediterranean regime. For the inland, apart from continental regime, terms Pannonian, Central European, and moderate continental regime are also used.

Conclusion

We are witnessing an increasing importance of contemporary climate changes. However, global climate changes seem to refer only to air temperature. There is no proof of air pressure and precipitation change in the whole world. Changes in atmospheric pressure and precipitation only have macro(regional) importance. We have restricted our research to a narrow area (in global terms), which is connected to hydrological complex – Sava River flow through Zagreb. Regional restriction of a certain precipitation trend was established in the beginnings of climate research on Earth.

Under the influence of the Alps, the upper Sava (and its affluents) has a lot of snow and rainfall. Dynamic relief has influenced the small volume of the Quaternary aquifer, which means that it is quickly filled up and drained. That is observable in the fact (Figure 1) that there is a very strong dijelu godine. Međutim, te su padaline često intenzivne, ali kratkotrajne, pa malo utječu na protok Save, koji je u tim mjesecima smanjen.

Protok Save u Zagrebu (Sl. 3.) odraz je vrlo kompleksnog odnosa analiziranih veličina. Jasno se vidi da se izdvajaju dva razdoblja, oba karakterizirana trendom smanjenja protoka Save. Međutim, u prvom se razdoblju, 1926.-1959., opaža veliko međugodišnje variranje protoka Save. Ono se bitno smanjuje u drugom razdoblju, 1960.-1995. god. Ovo je životno važno razdoblje u razvoju Zagreba. Silno je porastao broj stanovnika, gospodarstvo i potrošnja vode. Prirodno (klimatsko) smanjenje protoka Save tako je veliko da se time povećala zagađenost vode u površinskom toku. Poznavajući mehanizam postanka i "nestanka" vode u ovom zamršenom hidrosustavu, zaključili smo da je osnovni uzrok smanjenja protoka Save u Zagrebu promjena (mezo)cirkulacijskih atmosferskih uvjeta u ovom dijelu sjeverne hemisfere. Iznimka je temperatura zraka koja je globalno porasla.

Smatramo da analizirani podatci potvrđuju našu pretpostavku o ključnom značenju padalina u Ljubljani (Sl. 4.), odnosno u porječju Save uzvodno od Zagreba. U cijelom analiziranom razdoblju, 1926.-1995., i u Ljubljani i u Zagrebu (usporedbe radi) postoji trend smanjenja godišnjih količina padalina. Međugodišnje varijacije padalina u Ljubljani su apsolutno mnogo veće nego u Zagrebu. Posebno je važno mlađe razdoblje, 1960.-1995. god, a daje pečat protoku Save u Zagrebu. Trend pada godišnjih količina padalina u analiziranom porječju Save odgovara istom trendu u pojasu od Pirenejskog poluotoka preko Alpa do naših krajeva (Schönwiese, 1997).

Za višegodišnji trend količine padalina bitno je važan višegodišnji trend tlaka zraka (Sl. 5.). Tlak zraka horizontalno se manje mijenja nego padaline, pa je opravdana uporaba podataka Zagreba-Griča. U ovom slučaju postoji trend porasta tlaka zraka u cijelom analiziranom razdoblju, 1926.-1995. Trend porasta tlaka zraka osobito je izrazit u drugom razdoblju, 1960.-1995., a prati ga smanjenje količina padalina u porječju Save uzvodno od Zagreba.

Opisani uzročno-posljedični odnosi odražavaju se na "padalinskom kompleksu", tj. na relativnom udjelu padalina u toploj polovici godine (Sl. 6.). U drugom razdoblju, 1960.-1995. god. smanjio se udio količine padalina (u Ljubljani) u toploj polovici godine. To odgovara trendu smanjenja godišnjih količina padalina, ali

correlation between precipitation in Ljubljana and Sava flow through Zagreb.

Influence of the small volume of the Quaternary sedimentary aquifer can be clearly seen in the annual Sava flow trend (Fig. 2). Relatively lower relief south of the Upper Sava basin and dynamic cyclonic activity above the Mediterranean are the reasons for increased spring and autumn precipitation maximum and maximum Sava flow. In the warmest part of the year evapotranspiration is very important. Great increase of air temperature (and water temperature), the increase of evapotranspiration and ground heating, as well as strong convection cause heavy precipitation in the warmest part of the year. However, these precipitation are very often intensive, but transitory, so they have a weak influence on Sava flow, which is reduced in those months.

Sava flow through Zagreb (Fig. 3) is the reflection of a very complex correlation between the analysed indicators. Two periods can be distinguished clearly, and both of them are characterised by downward trend of Sava flow. However, in the first period, between 1926 and 1959, there were big fluctuations of Sava flow through years. They were significantly reduced in the second period, between 1960 and 1995. This is vitally important period in Zagreb development. Population, economy, and water consumption increased significantly. Natural (climatic) decrease of Sava flow was so big that it increased water pollution in the surface flow. Knowing the mechanism of the origin and "disappearance" of water in this complex hydrosystem, we came to conclusion that the basic cause of decreased Sava flow through Zagreb was change of (meso)circulatory atmospheric conditions in this part of the Northern hemisphere. An exception is the air temperature, which rose globally.

We consider that the analysed data confirm our hypothesis about vital importance of precipitation in Ljubljana (Fig. 4), i.e. in Sava basin upstream of Zagreb. In the entire analysed period between 1926 and 1995 both Ljubljana and Zagreb had downward trend of annual precipitation. Precipitation fluctuations through years in Ljubljana are in total much bigger than in Zagreb. Recent period, between 1960 and 1995, was especially important, and it marked Sava flow through Zagreb. Downward trend of annual precipitation in analysed Sava basin matches the same trend in the belt stretching from Pyrenean Peninsula across the Alps to our Croatia (Schönwiese, 1997).

Long-term trend of atmospheric pressure is very important for the long-term trend of i trendu godišnjeg porasta temperature zraka, tj. "globalnom otopljavanju" klime. Naime, i "crta kontinentalnosti" nije fiksna granica nego se povremeno "zalijeće" u porječje Save uzvodno od Zagreba, a u nekim se godinama pomiče bliže obali Jadranskog mora.

precipitation amount, (Fig. 5). Horizontal change of atmospheric pressure is smaller than the change of precipitation, therefore the use of data from Zagreb-Grič is valid. In this case, there is an upward trend of atmospheric pressure in the entire analysed period between 1926 and 1995. Upward trend of atmospheric pressure is very pronounced in the second period, between 1960 and 1995, and it is followed by decreased precipitation amount in Sava basin upstream of Zagreb.

Cause-and-effect correlations described are reflected in "precipitation complex", i.e. in relative share of precipitation in warm part of the year (Fig. 6). In the second period, between 1960 and 1995, the share of precipitation amount (in Ljubljana) in warm part of the year decreased. That matches downward trend of annual precipitation amount, but also upward trend of annual air temperature, i.e. "global warming". Namely, "continentality line" is not a fixed border, but it "trespasses" periodically in Sava basin upstream of Zagreb, and in some years it is moving closer to the Adriatic Sea coast.

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