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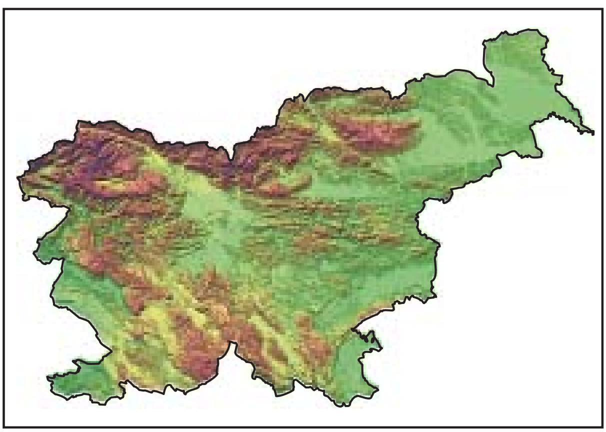
GEOGRAPHICAL OVERVIEW OF WATER BALANCE OF SLOVENIA 1971–2000 BY MAIN RIVER BASINS

GEOGRAFSKI PREGLED VODNE BILANCE SLOVENIJE 1971–2000 PO GLAVNIH POREČJIH

Peter Frantar

PETER FRANTAR

Surface runoff is only a part of water balance.
Površinski odtok je le del vodne bilance.



Geographical overview of water balance of Slovenia 1971–2000 by main river basins

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ABSTRACT: This overview of the hydrogeographical characteristics of the Slovenian water balance 1971–2000 reviews three main water cycle elements: precipitation, evapotranspiration and runoff. Results show their spatial distribution and strong interdependency in by main river basins of Slovenia. Greatest amounts of water are in the Soča river basin and the smallest in the Slovenian part of the Mura river basin. Average yearly quantities of water in Slovenia for the period 1971–2000 are: precipitation 1579 mm, evapotranspiration 717 mm and runoff 862 mm. Compared with the water quantities data of 1961–1990 period, the precipitation is in same rank, the evapotranspiration increased and the runoff decreased. Despite being a »wet« country by world standards, available water resources in Slovenia are declining.

KEYWORDS: hydrogeography, water balance, precipitation, evapotranspiration, runoff, river basins, Slovenia

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Contents

1 Introduction

Water on Earth is available in all three physical states: liquid, gaseous and solid. It may be found in all environments that are important for humans: air, sea and land. Water passes between all the physical states and the environments both in space and in time. It has the character of dynamic medium (WMO 1994; Jones 1997).

This article shows the characteristics of water cycle elements in the river basins of Slovenia. Water balance is the separation of the hydrological processes of the water cycle based on system analysis, both in space and time. The hydrological system is the sum of all elements, its interdependencies and characteristics, that are all part of the overall water cycle in the bounded area (Fürst 2006; Schöniger et al. 2003; Neff et al. 2004). It is a simple system that is very complicated to analyse (Davie 2004).

2 Methodology of analysis of water balance elements

The water balance equation evolved from the water cycle theory of water circulating between atmosphere and the earth's surface (Van Abs et al. 2000; Kolbezen et al. 1998; WMO 1997; Schöniger et al. 2003). The equation of the water balance is:

precipitation = runoff (Q) + evapotranspiration (E) + storage changes (dS).

Water balance is an open system (Hong et al. 2006) where the inputs and outputs of water are calculated. The main systems input in the World is precipitation and the main output is evapotranspiration (Ritter 2006). As we will reveal, this does not apply for Slovenia.

In the process of this water balance calculation for Slovenia, the water storage changes were not considered. We presumed that this element can be neglected due to longterm period (Kolbezen et al. 1998; Frantar et al. 2005; Berezovskaya et al. 2005). Thus storage changes are very important in yearly water balance calculations (Koczot et al. 2004; Sloto et al. 2005; Neff et al. 2005).

The equation used in our analysis is simplified and presumes equilibrium of precipitation, evapotranspiration and runoff:

precipitation (P) = runoff (Q) + evapotranspiration (E).

The main goals of analysis are to confirm the results of the calculated raster layers for the precipitation and evapotranspiration (made from point source data layers) with the (direct) runoff measurements on water gauging stations; and to derive the raster layer of 1971–2000 runoff with the use of the two layers mentioned above. Water balance elements were compared and corrected with the use of the water balance error method. The use of (measured) runoff results confirmed the regularity of precipitation and evapotranspiration rasters. This enabled us to make the raster water balance analysis of Slovenia (Figures 1, 3, 5).

2.1 Precipitation

Precipitation is defined as atmospheric water condensating or sublimating from air, falling towards the surface and eventually falling on the ground surface (DIN 1996, cited after Schöniger et al. 2003). Precipitation is the most important climate element of hydrological system (Fürst 2006) because it is the sole input of the water cycle in natural conditions (Van Abs. et al. 2000). There are various forms of precipitation uniformly presented as a liquid water eqvivalent (Frantar et al. 2006a; Fürst 2006).

Precipitation measurements are recorded in many different locations of Earths surface.

A total of over 200 measurement sites were selected: 193 measurement sites were selected with more than 25 years of data, 8 with less with 29 sites located in Austria and Croatia. The foreign stations are important due to the high relief energy in border areas and due to the watersheds lying outside of the state of Slovenia (Frantar et al. 2006d).

Appropriate values of measurements are gained by transferring point locations into the space (Schöniger et al. 2003) and with the systematic error corrections (WMO 1994; Fürst 2006). Systematic errors are mostly the result of wind, wetting, evaporation, spills or snow problems during the measurement (WMO 1994). The raw precipitation data was corrected using the dynamic correction model (Forland et. al. 1996; Nespor et al. 1999) that considers precipitation type, intensity and wind speed on a daily basis for a single precipitation event (Frantar et al. 2006a). The average correction factors gained in this analysis are very similar to the factors in described in the analysis of water balance 1961–1990 (Kolbezen et al. 1998).

2.2 Evapotranspiration

Evapotranspiration is of great importance to the water balance. It is the process of the physical transformation of water with temperatures under the dew point from solid or liquid state into gaseous state (Schöniger et al. 2003). Evapotranspiration combines the evaporation from the earth's surface and the transpiration from plants (Allen 1998; WMO 1994; Schöniger et al. 2003; Fürst 2006).

Reference evapotranspiration for period 1971–2000 was calculated using modified Hargreas method (Allen 1998) for 37 meteorological stations.

Data for minimum and maximum air temperatures and geoposition of the stations was used.

The Hargreas method was pounded with daily linear regression coefficients according to the Penman-Montheith method (Allen 1998). The reference evapotranspiration holds for grass surfaces with enough water in the soil. Therefore our data was corrected with the land cover type factors of the Corine Land Cover database (Frantar et al. 2006d). Evapotranspiration is locally very variable according to the land cover type (Jones 1997).

2.3 Runoff

In the water balance equation, the runoff is seen as the most accurately measured element. Under ideal conditions, all the water from the watershed is drained through one single measuring profile of a water gauging station. Therefore, only the water gauging stations of proper quality may be used in analysis. Out of over 700 stations, the ones with the defined standard time and space characteristics were used. With this process of multiple comparisons of water balance elements, the hydrometrical units as a basis of water balance accounts were obtained. A hydrometrical unit is a surface delineated with the watershed divides, with known inputs on upstream water gauging stations and outflows on downstream water gauging station(s) (Frantar 2003). The results of water balance elements in one hydrometrical unit allow comparison between different hydrometrical units (Fürst 2006). With this process, the accuracy of the calculated precipitation and evapotranspiration values is confirmed or disproved by comparison with the measured runoff data. With enough conformity between the water balance elements, the raster data map of the mean annual runoff in mm can be made using climatological method with $Q = P - E$ equation (Jones 1997).

3 Water balance of Slovenia

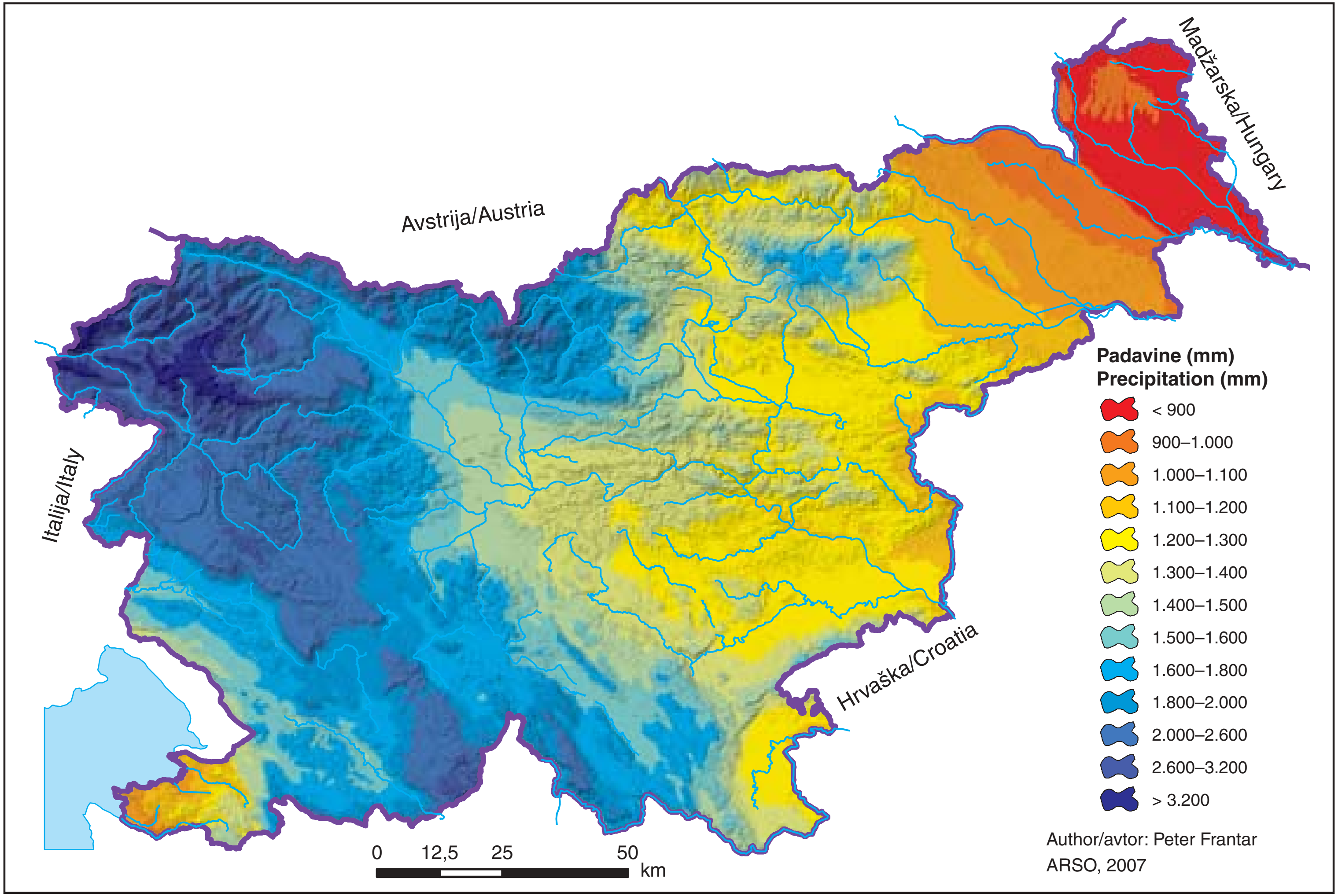
3.1 Precipitation

Mean annual precipitation in period 1971–2000 in Slovenia was 1579 mm. The spatial distribution is also highly dependable upon the relief also in Slovenia (figure 1) (Schöniger et al. 2003; WMO 1994). Due to orographic effect the amount of precipitation increases from the sea towards inland, with maximums on the Dinaric-alpine mountain ridge. Highest mean precipitation (over 2600 mm) is found on the southwestern side of Julian Alps and Mount Sneznik.

In other locations in the Julian Alps, the Karavanke region and in the high Dinaric plateau ridge, there is annually from 2000 to 2600 mm of precipitation. In the Kamnik-Savinja Alps, there is also a slightly smaller local maximum. On the coast, the amount of precipitation is from 1100 to 1200 mm. Towards the northeast, behind the Dinaric plateau ridge, the precipitation decreases according to the distance from the sea and the altitude.

Higher amounts of precipitation are found only in Pohorje and Gorjanci region (up to 1800 mm).

Figure 1: Mean annual precipitation in period 1971–2000 in mm (Dolinar 2006). ➤


Avstrija/Austria
Madžarska/Hungary
Italija/Italy
Hrvaška/Croatia
Padavine (mm)
Precipitation (mm)
< 900
900–1.000
1.000–1.100
1.100–1.200
1.200–1.300
1.300–1.400
1.400–1.500
1.500–1.600
1.600–1.800
1.800–2.000
2.000–2.600
2.600–3.200
> 3.200
0
12,5
25
50
km
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ARSO, 2007

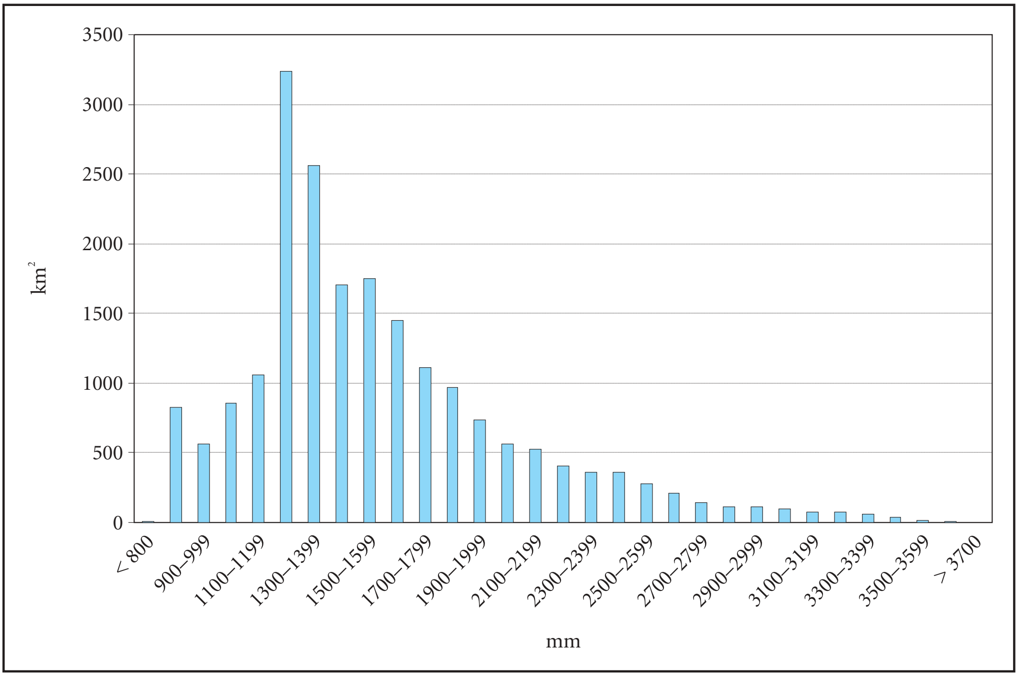


Figure 2: Area covered by precipitation classes in Slovenia.

In the Ljubljana basin, the precipitation amount decreases from north to south, from 1800 mm to 1300 mm. Highest altitudes of the Posavsko mountains have up to 1400 mm of precipitation. From here to lower altitudes, and towards the north- and the south-east, the amount decreases to about 1200 mm.

The Drava and the Ptuj lowlands receive between 1100 and 1200 mm precipitation yearly and precipitation decreases towards the northeast of state where the mean annual amounts average below 900 mm.

3.2 Evapotranspiration

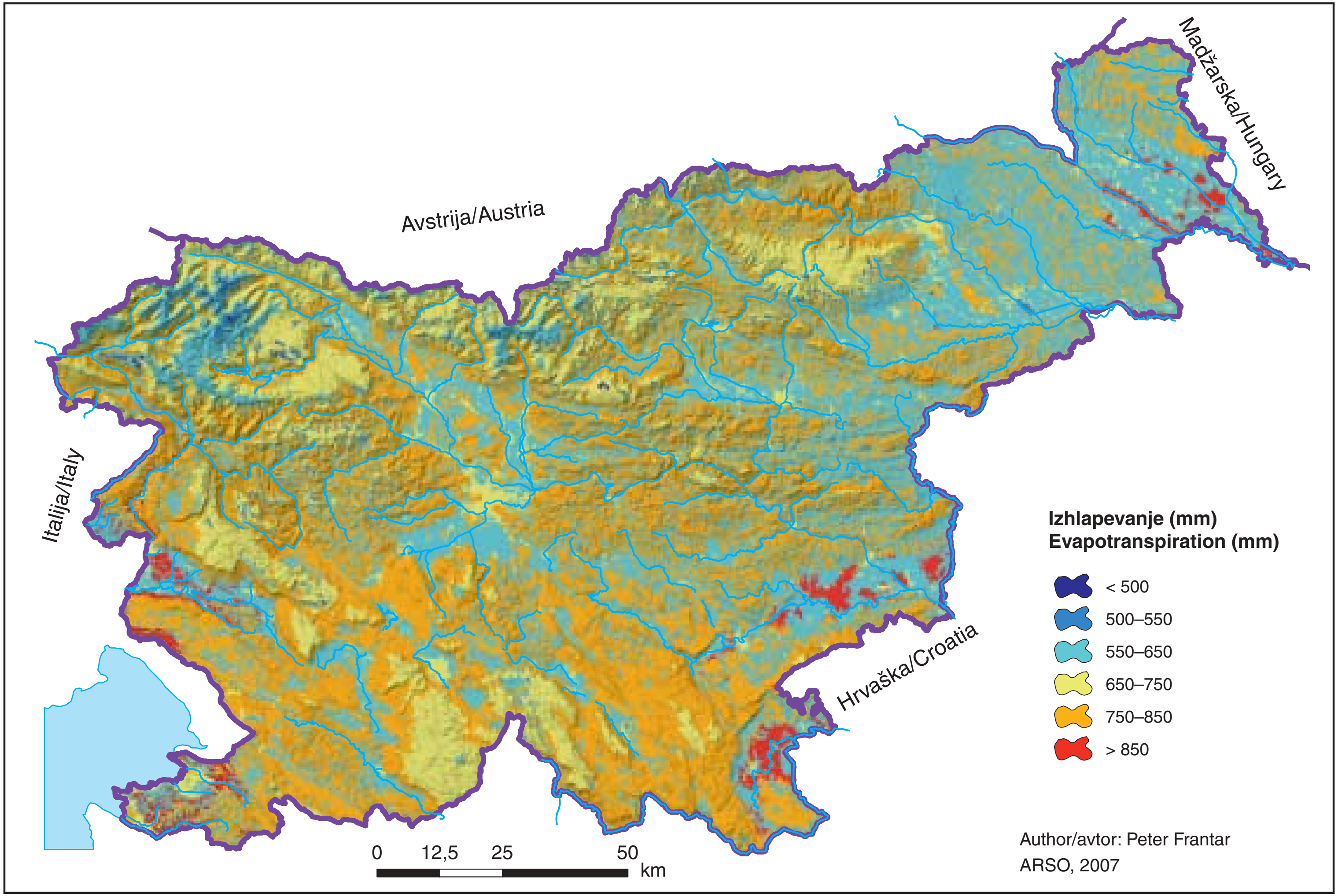
The evapotranspiration variability in space is the lowest of any water cycle element in Slovenia (figure 4). The total range of mean annual evapotranspiration in the period 1971–2000 is from 458 to 879 mm with a mean value of 717 mm.

The spatial distribution is very crumbled and is highly dependant on the altitude and the type of land cover (figure 3). The highest evapotranspiration (rate) in Slovenia is over 850 mm. In the east, this is found in the forested areas of Pomurje, in parts of the Krško-Brežice basin and in parts of the Bela Krajina region. In the west of state, high evapotranspiration is found on the coastal area of the Koper hills, in parts of the Vipava hills and in the western Karst areas.

The average values of Slovenia's evapotranspiration are spatially very crumbled due to the various types of relief and land cover.

Very low evapotranspiration, less than 600 mm, is found in small patches of the mountains and hills. Slightly larger areas of very low evapotranspiration are only found on the southeast of Pohorje mountains, around the Bled area, on tops of the Julian Alps, in the Postojna-Pivka basin, in the Brkini region and in the areas of east Notranjska and west Dolenjska regions. In general evapotranspiration rates decrease from the south towards the northwest and the northeast.

Figure 3: Mean annual evapotranspiration in period 1971–2000 in mm (Kurnik 2006). ➤


Avstrija/Austria
Madžarska/Hungary
Italija/Italy
Hrvaška/Croatia
Izhlapevanje (mm)
Evapotranspiration (mm)
< 500
500–550
550–650
650–750
750–850
> 850
0
12,5
25
50
km
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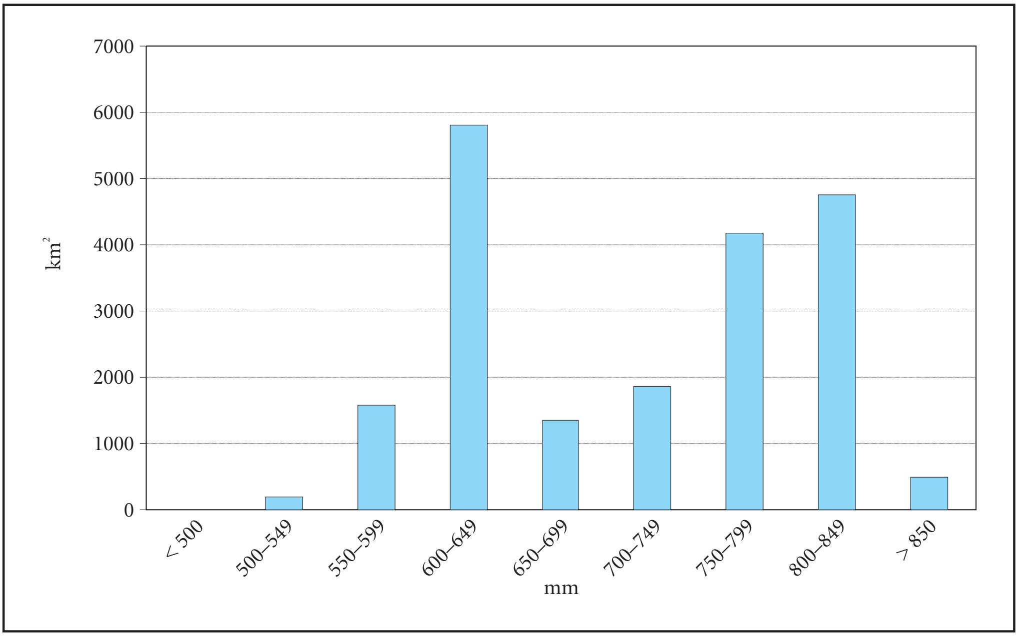


Figure 4: Area covered by evapotranspiration classes in Slovenia

3.3 Runoff

The physio-geographical diversity of Slovenia is greatly dependant on the runoff variability. Runoff amounts decrease from the Alpine-Dinaric mountains between the Julian Alps and Mount Sneznik towards the southwest and northeast. Mean annual runoff in the period 1971–2000 in Slovenia was 862 mm. This amount is highly dependant on orography – in general higher altitudes have higher runoff as nearby lower altitudes.

The highest annual runoffs (over 2000 mm) are in central parts of the Julian Alps, in the highest parts of Trnovski gozd and Mount Sneznik. These are the »wettest« regions of Slovenia with fast above and underground precipitation drainage.

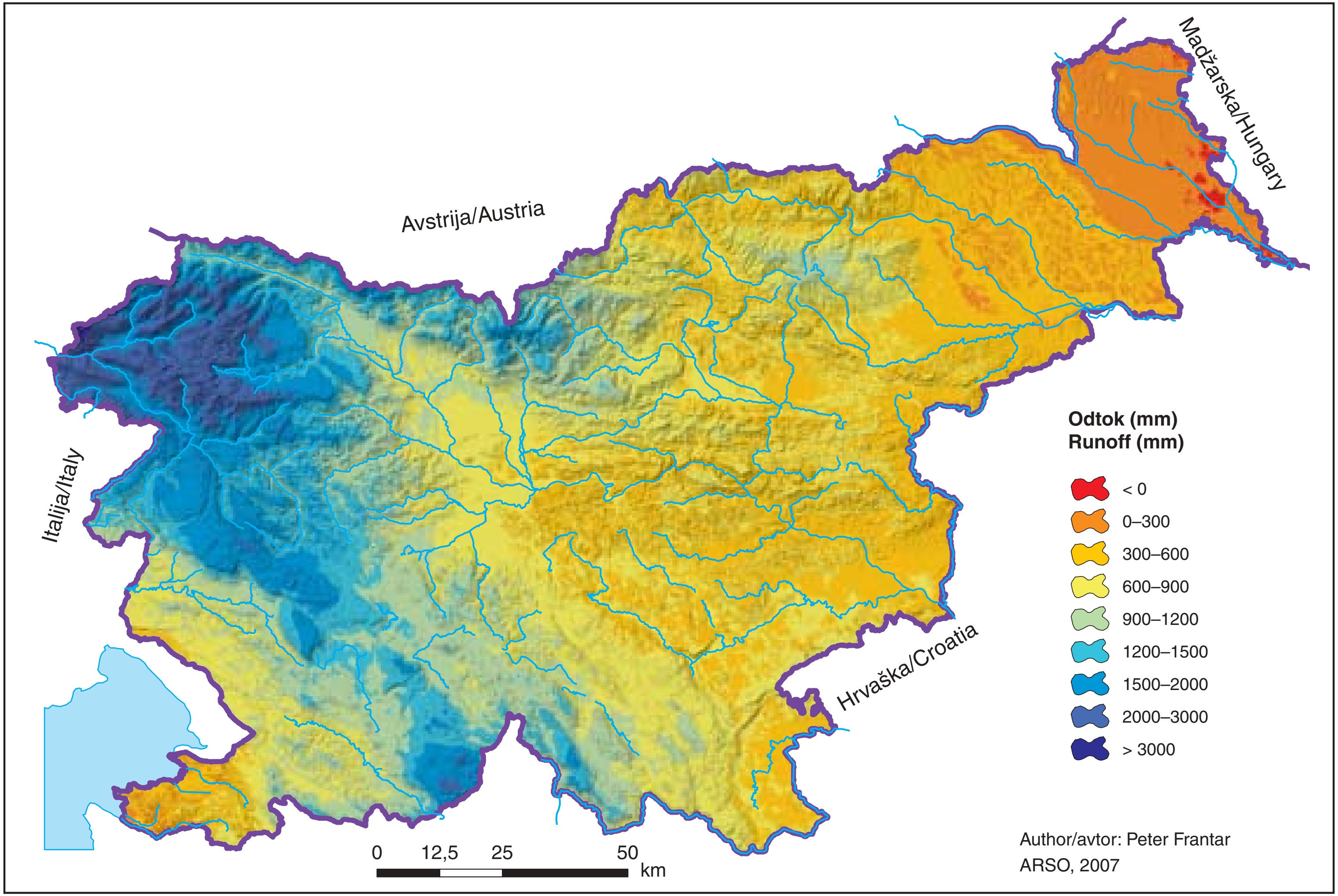
Smaller areas of such high runoff are also found in the highest parts of the Karavanke Mountains and the Kamnik-Savinja Alps. Runoff here averages from 1500 to 2000 mm annually in the subalpine parts of Julian Alps and the western Dinaric plateaus from Banjšice to Mount Sneznik.

Areas with 1200 to 1500 mm runoff are found in western Slovenia in the hills around the Alps, in the hilly regions around the Škofjeloško and Idrijsko regions, in the northern part of the Goriška Brda region, in the western Dinaric plateaus fringes, in the Javorniki mountains and in the Gotenica region.

Averages of 900 to 1200 mm annual runoff are found in the area from the southern Goriška Brda region to Slavnik in the south, from the Dolina region to the eastern Kamnik-Savinja Alps, from the eastern Škofjeloško hill region to the Kočevska Mala mountain, Roga and Pohorje.

The runoff from 600 to 900 mm is found in the southwestern regions of Vipavska brda region, in Kras, in parts of Brkini region and in the eastern part of the Koper coastal region. The largest area with 900 to 1200 mm runoff is in central Slovenia and extends from the Suha Krajina region on the south over to the Ljubljana basin and on to the Pohorje and Kozjak regions. Low runoffs of between 300 and 600 mm are common in the Koper coastal region, in eastern Slovenia from the Bela krajina region to the Slovenske gorice area. The lowest annual runoffs of 300 mm annually are in the Pomurje region. In some places here, the evapotranspiration is greater than the precipitation.

Figure 5: Mean annual runoff in period 1971–2000 in mm calculated with climatological equation Q = P – E. ➤


Avstrija/Austria
Madžarska/Hungary
Italija/Italy
Hrvaška/Croatia
Odtok (mm)
Runoff (mm)
< 0
0–300
300–600
600–900
900–1200
1200–1500
1500–2000
2000–3000
> 3000
0
12,5
25
50
km
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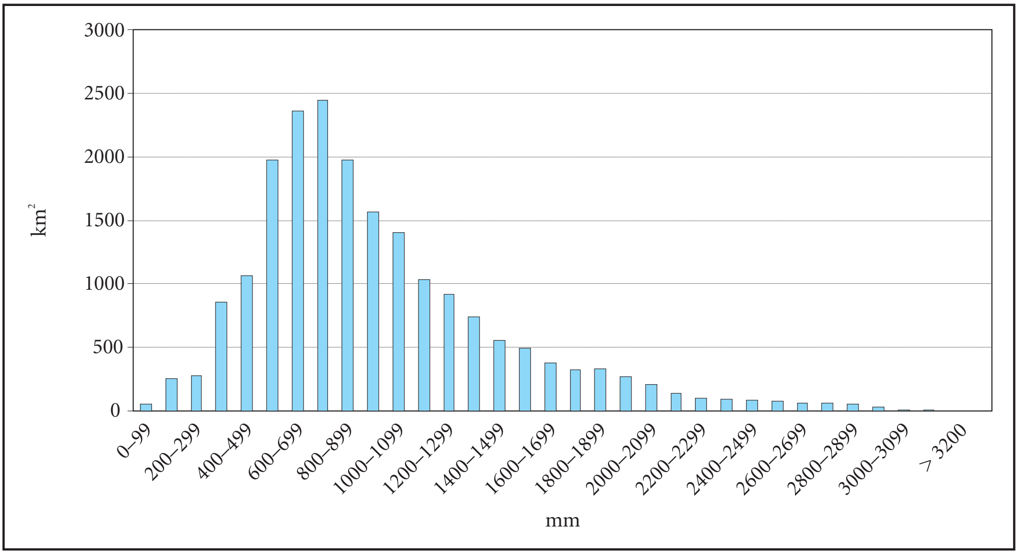

Figure 6: Area covered by runoff classes in Slovenia.

4 Water balance in main river basins

Water balance results show a great variability in the climatogeographical and hydrogeographical conditions in Slovenia's river basins. In this chapter, the precipitation, the evapotranspiration and the runoff in main river basins are presented.

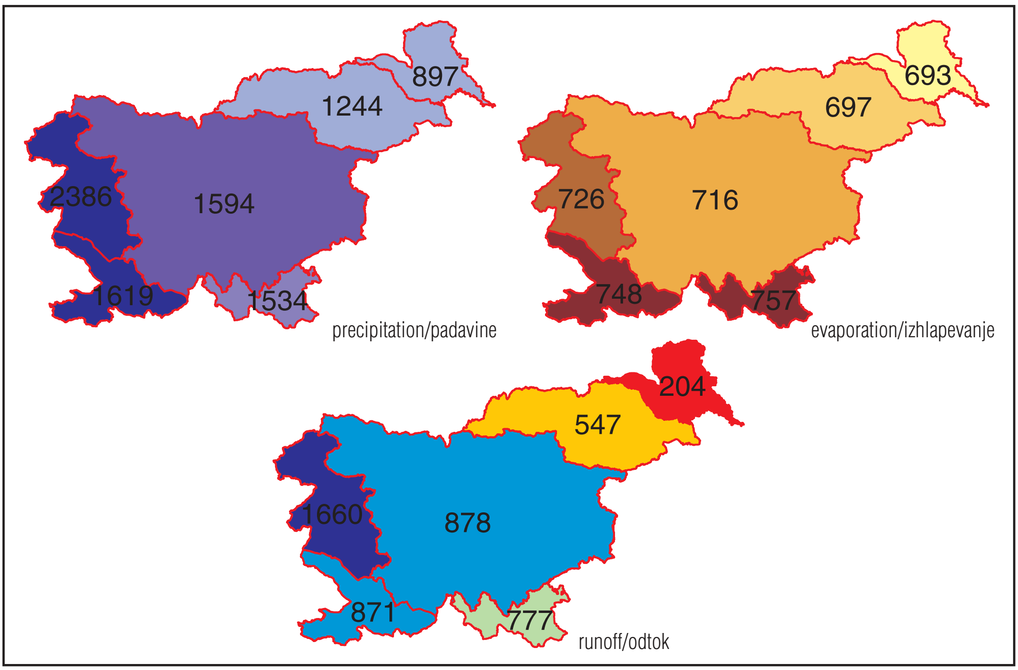

Figure 7: Water balance elements in mm in the main river basins.

4.1 Mura river basin (Pomurje)

This is the region with the least water quantities in Slovenia. On average there is 897 mm of precipitation, 693 mm of evapotranspiration and 204 mm of runoff annually.

On the left side of Mura river, the precipitation amount is under 900 mm and in the most eastern part of the river, it is under 850 mm. The highest precipitation of slightly more than 1000 mm is found on the Mura river's right side in the Slovenske gorice area. Evapotranspiration has a very low variation with a value of 693 mm on average; the highest evapotranspiration occurs in the forest areas. From these two water balance components, we can easily see the consequence: low runoff values. The runoff values here are the lowest in the state, decreasing from 300 mm on the right side of Mura river towards the east. In some places, the evapotranspiration is greater than the precipitation-runoff difference as the plants derive their water from shallow underground aquifers that gain water from transit streams (Mura river).

4.2 Drava river basin (Podravje)

The Slovenian part of river Drava drainage basin has more variety than the Mura river basin. The Drava river basin can be divided in three regions: the Slovenske gorice, the southern lowlands including the Drava valley and the mountainous northern part of the Pohorje and Karavanke Mountains.

On average, there is 1244 mm of precipitation, 697 mm of evapotranspiration and 547 mm of runoff, annually. In the entire region, the precipitation is over 1000 mm annually. The lowest values are found in the Slovenske gorice area (around 1000 in south and 1100 in north) and the lowland areas of Haloze and the summits of Pohorje (around 1200 mm).

From here, the amount of precipitation increases towards the higher parts of the Pohorje and Karavanke Mountains to over 1600 mm annually. Evapotranspiration in the Podravje is the lowest with less than 650 mm annually, in the Slovenske gorice area, in the lowlands and in the highest parts in the Pohorje region and in the Meža springs area. For most of the area of the river basin, evapotranspiration rates average around 700 mm annually. The highest values of over 800 mm annually are found in Haloze. The runoff spatial distribution is similar. It is lowest in the east (300 mm annually) and the highest in mountain tops of Pohorje and Karavanke Mountains with over 1100 mm of runoff annually.

4.3 Sava river basin (Posavje)

The Posavje region has on average 1594 mm of precipitation, 716 mm of evapotranspiration and 878 mm of runoff annually. The spatial distribution of precipitation in Posavje ranges widely. In the most wettest parts of the Julian Alps, in the spring watershed area of the Sava Bohinjka river, there is over 3000 mm of precipitation on average per year. From here, precipitation amounts decrease rapidly towards the north and the east. Over 2500 mm of precipitation annually are found only in nearby places: in Vrata valley, on Pokljuka plateau and in parts of the Jelovica plateau.

Most of the Julian Alps' plateaus, the Karavanke Mountains, the Kamnik-Savinja Alps and parts of the subalpine mountains and the Javorniki mountrains have from 2000 to 2500 mm of precipitation annually. Towards the east, the central part of Posavje area gets »only« on average 1400 and 1800 mm annually, and most of the eastern part of the Sava river basin receives even less than 1400 mm precipitation annually. The lowest amount of annual precipitation is found in the Sotla river watershed (less than 1200 mm annually). The lowest evapotranspiration rates in Posavje area is found in two areas: in the high mountain Alps (with under 550 mm annually) and in the Sotla river watershed (with around 650 mm annually).

Evapotranspiration rates for most of Posavje area is between 650 and 850 mm annually, it is less in the north and more in south. In specific, local areas (the Krško-Brežice basin) there are evapotranspiration rates annually of over 850 mm. Posavje's runoff distribution is similar to the precipitation distribution. The highest runoff of over 2500 mm occurs in the alpine and subalpine areas. Towards east, this amount decreases to 300 to 600 mm of annually.

4.4 Kolpa river basin (Pokolpje)

The Slovenian part of the Kolpa river basin has 1534 mm of precipitation, 757 mm of evapotranspiration and 777 mm of runoff annual average. The highest precipitation amounts are found on in the west, in parts of Mt. Snežnik and in the Kočevje region – over 2000 mm annually. The central Kolpa area has on average around 1700 mm and the eastern area, around 1300 mm of precipitation annually. Evapotranspiration in the Kolpa river basin is high, from 650 mm to over 850 mm annually. Runoff is the highest in the upper Kolpa watershed – over 1600 mm. It decreases rapidly towards east – the lowest values are in central Bela krajina region with around 400 mm of annual runoff.

4.5 Soča river basin

Posočje is the wettest region in Slovenia. Average annual values are: precipitation 2386 mm, evapotranspiration 726 mm, runoff 1660 mm. Precipitation amounts decrease from the north to the south of the region. The highest altitudes have over 3000 mm annually, with the summits of the Julian Alps receiving over 3500 mm annually.

The alpine valleys have less precipitation – between 2300 and 2700 mm annually – due to earlier precipitation that falls over southern mountain ridges. The southwestern ridge of the high Dinaric plateaus from Kambreško, Banjšice to Trnovski gozd region have around 2300 mm annually. The subapline mountains, behind the for-mentioned plateaus, and on Mount Nanos have less precipitation: 2000 to 2300 mm annually. Less than 2000 mm of precipitation occurs in the Goriška Brda area and in parts of the Vipava valley. The lowest precipitation of 1500 mm annually is found in the lower Vipava valley and in the Vipavska brda area. Evapotranspiration is the highest in the southern parts of this area with over 850 mm and decreases in amount towards the north according to altitude. In high Julian Alps, there is only 550 mm of annual evapotranspiration.

There are high differences in runoff. In the Kanin area, the runoff is over 3000 mm annually while most of the Alps have runoffs higher than 2000 mm annually (valleys excluded). Over 1500 mm annually of runoff occurs in the Dinaric plateaus and central regions. In the foothills and the hinterland of the Dinaric plateaus, runoff values decrease. In the Idrijca valley, there is 1100 mm of runoff annually and in the Vipavska brda area, the amount decreases to 650 mm of annual runoff.

4.6 Adriatic sea watershed without the Soča river basin

The smallest hydrographical part of Slovenia includes the (Notranjska) Reka river basin and its direct Adriatic sea tributaries. On average, there is 1619 mm of precipitation, 748 mm of evapotranspiration and 871 mm of runoff annually. Highest precipitation values are found in the Snežnik region, with over 2500 mm. From here, it decreases towards west to 1100 mm annually in the coastal areas and 1500 mm annually in the Karst region.

Evapotranspiration is the highest in parts of the Koper coastal region and in the southwest Karst (over 850 mm annually). Towards the north and the east, the evapotranspiration decreases, with the lowest values in the Snežnik mountain area – under 700 mm annually. On the contrary, runoff is the highest in the east (Snežnik mountain area), with over 2000 mm annually and decreases towards west to the Koper coastal region where the runoff is from 200 to 400 mm annually.

5 Conclusion

Overall, Slovenia is a wet country from a world point of view. The World land masses have on average 750 mm of precipitation, 480 mm of evapotranspiration and 270 mm of runoff per year – as described by Global Water Balance (Global Water Balance, 2006; Fürst, 2006).

In Slovenia, these values are much higher. In the period 1971–2000, the average annual precipitation is 1579 mm, evapotranspiration 717 mm and runoff 862 mm.

In addition, the runoff coefficient of Slovenia at over 55% compared to the average World runoff coefficient with 36% (Schöniger et al. 2003, cited after Baumgartner et al. 1996) which also shows that Slovenia is wet country.

Direct comparison of water balance of Slovenia in the 1971–2000 period with the period 1961–90 (Kolbezen et al. 1998) reveals that in the period 1971–2000, the precipitation amount was almost the same, the evapotranspiration increased and the runoff decreased. For the period 1971–2000, evapotranspiration increased by 11% and runoff values decreased by 6%.

Table 1: Water balance of Slovenia in 1961–1990 and 1971–2000 in mm (Kolbezen et al. 1998).

	1961–1990	1971–2000
precipitation	1567	1579
evapotranspiration	650	717
calculated runoff (Q = P – E)	917	862
runoff coefficient	58,5%	54,5%

Climate changes do also affect the water amounts. Better data to determine the effects of climate on water quantities would be yearly and decade water balance analyses for longer period. Most of the temperature and the hydrologic-storm climate change indicators (Houghton et al. 2001) reveal climate changes have occurred in Slovenia after the year 1990 (Nadbath 1999; Gabrovec 1998; Frantar 2004). From any viewpoint, the water resources are becoming more precious.

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Geografski pregled vodne bilance Slovenije 1971–2000 po glavnih porečjih

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IZVLEČEK: Pregled hidrogeografskih značilnosti vodne bilance Slovenije v obdobju 1971–2000 zajema tri glavne elemente vodnega kroga: padavine, izhlapevanje in odtok. Rezultati kažejo na njihovo prostorsko razporeditev in na močno soodvisnost vseh treh glavnih elementov vodne bilance po glavnih porečjih. Najbolj namočeno je Posočje, najmanj pa Pomurje. Povprečno je v Sloveniji v obdobju 1971–1990 padlo 1579 mm padavin, izhlapelo 717 mm in odteklo 862 mm. V primerjavi z obdobjem 1961–1990 je količina padavin ostala približno enaka, povečalo se je izhlapevanje, odtok pa se je zmanjšal. Količina razpoložljivih vodnih virov v Sloveniji se zmanjšuje.

KLJUČNE BESEDE: hidrogeografija, vodna bilanca, padavine, izhlapevanje, odtok, porečja, Slovenija

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Vsebina

1 Uvod

Voda je na Zemlji prisotna v treh fizikalnih stanjih: tekočem, plinastem in trdnem. Najdemo jo v vseh treh za človeka pomembnih okoljih: ozračju, morju in na kopnem. Voda lahko menja vsa okolja in agregatna stanja tako v prostoru kot času, in je dinamičen medij (WMO 1994; Jones 1997).

Vodna bilanca je razdelitev hidroloških procesov vodnega kroga na temelju sistemske analize, ki jih obravnavamo v določenem času in prostoru. Hidrološki sistem je celota elementov in njihovih medsebojnih odnosov ter značilnosti, ki so del velikega naravnega vodnega kroga na omejenem območju (Fürst 2006; Schöniger in ostali 2003; Neff in ostali 2004). V zasnovi enostaven sistem se pokaže ob izračunavanju za zelo zapletenega (Davie 2004). V članku bomo predstavili vodno bilanco oziroma elemente vodnega kroga po glavnih slovenskih porečjih.

2 Metoda izračuna elementov vodne bilance

Enačba za izračun vodne bilance temelji na teoriji vodnega kroga, kjer voda kroži med ozračjem in površjem Zemlje (Van Abs in ostali, 2000; Kolbezen in ostali 1998; WMO 1997; Schöniger in ostali 2003). Enačba vodne bilance je:

padavine (P) = odtok (Q) + izhlapevanje (E) + sprememba vodnih zalog (dS).

Vodna bilanca je odprt sistem (Hong in ostali 2006), v katerem lahko izračunamo dotoke in odtoke vode. Na Zemlji so poglavitni dotok padavine, poglavitni »odtok« pa je izhlapevanje (Ritter 2006), kar za Slovenijo ne drži. Pri izračunu vodne bilance za obdobje 1971–2000 nismo upoštevali sprememb vodnih zalog, saj smo predpostavili, da je ta člen bilance zaradi povprečenja v dolgoletnem obdobju zanemarljiv (Kolbezen in ostali 1998; Frantar in ostali 2005; Berezovskaya in ostali 2005), za letno bilanco pa je ta člen zelo pomemben (Koczot in ostali 2004; Sloto in ostali 2005; Neff in ostali 2005). Uporabili smo poenostavljeno enačbo vodne bilance, ki predpostavlja ravnovesje padavin z odtokom in evapotranspiracijo:

padavine (P) = odtok (Q) + evapotranspiracija (E).

Temeljni cilj našega dela je z uporabo rezultatov elementa vodne bilance odtoka v obdobju 1971–2000 in na podlagi 100-metrskega digitalnega rasterskega sloja podatkov potrditi ustreznost rezultatov izračunanih padavin in izhlapevanja ter z uporabo bilančne enačbe določiti povprečni letni odtok v Sloveniji. Posamezne elemente vodne bilance smo primerjali med seboj in jih popravili s pomočjo izračuna bilančne napake. Z upoštevanjem rezultatov odtoka smo tako potrdili pravilnost izračunanih vrednosti padavin in izhlapevanja, s čimer je možna rastrska »bilančna« analiza v Sloveniji (slike 1, 3, 5).

2.1 Padavine

Padavine so definiciji atmosferska voda, ki po kondenzaciji in sublimaciji izhaja iz zraka in se zaradi težnosti premika proti tlem oziroma pade na tla (DIN 1996, citirano po Schöniger in ostali 2003). Padavine so najpomembnejši podnebni element hidrološkega sistema (Fürst 2006), saj so v krogu v naravnih pogojih edini dotok vodnega kroga (Van Abs et al. 2000). Oblika padavin je različna, v vodnobilančnih izračunih pa jih podajamo v ekvivalentih tekoče vode (Frantar in ostali 2006a; Fürst 2006).

Z meritvami padavin, ki potekajo na izbranih točkah na površini Zemlje, dobimo točkovne vrednosti. Izbranih je bilo 193 merilnih mest z vsaj 25 leti delovanja, osem meteoroloških postaj s krajšimi nizi v Sloveniji in 29 postaj iz Avstrije in Hrvaške. Te so pomembne zlasti na razgibanem mejnem reliefu, kjer je prostorska spremenljivost padavin zelo velika in zaradi hidroloških razvodnic (Frantar in ostali 2006d). Uporabno vrednost za bilanco smo dobili z ekstrapolacijo točkovnih vrednosti (Schöniger in ostali 2003) in s popravki meritev zaradi sistematične napake meritve (WMO 1994; Fürst 2006). Sistematične napake so v največji meri posledica napačnih meritev zaradi vetra, omočenosti ombrometra, izhlapevanja, izlitja ali transporta snega (WMO 1994). Točkovne podatke smo korigirali z dinamičnim korekcijskim modelom (Forland in ostali 1996; Nespor in ostali 1999), ki upošteva vrsto padavin ter intenziteto in hitrost vetra na dnevni ravni za vsak padavinski dogodek posebej (Frantar in ostali 2006a). Pridobljeni povprečni korekcijski faktorji za postaje so podobni, kot sta jih izračunala Pristov in Kolbezen (Kolbezen in ostali 1998) za povprečne padavine v obdobju med 1961 in 1990.

2.2 Izhlapevanje

Ocena izhlapevanja ima za hidrološko bilanco izreden pomen. Izhlapevanje je fizikalni prehod vode s temperaturami pod rosiščem iz trdnega ali tekočega v plinasto stanje (Schöniger in ostali 2003). Evapotranspiracija je pojem, ki povezuje prehajanje vode v obliki vodne pare z zemeljske površine (evaporacijo) in iz rastlin (transpiracijo) (Allen 1998; WMO 1994; Schöniger in ostali 2003; Fürst 2006).

Referenčno evapotranspiracijo za obdobje 1971–2000 so izračunali po modificirani Hargreasovi metodi (Allen 1998) za 37 klimatoloških postaj na osnovi minimalne in maksimalne temperature zraka in lege postaje. Za slovensko klimatsko območje so Hargreasovo metodo utežili z linearnimi regresijskimi koeficienti glede na dnevne vrednosti evapotranspiracije po Penman-Montheithovi metodi (Allen 1998). Izračun velja za topli del leta in dobro namočena tla porašča s travo, zato so vrednosti korigirane, da smo dobili dejansko evapotranspiracijo. Za korekcijo smo uporabili podatke o rabi tal iz baze Corine Land Cover (Frantar in ostali 2006d). Evapotranspiracija na površju je namreč zelo odvisna od vrste rabe tal (Jones 1997).

2.3 Odtoki

Odtoki so praviloma najzanesljiveje merjen člen vodne bilance. Na dobrih vodomernih postajah namreč vsa voda z vodozbirnega območja odteče skozi en sam profil, zato je zelo pomembna izbira ustreznih in kakovostnih vodomernih postaj. Med več kot 700 vodomernimi postajami smo izbrali take, ki delujejo ustrezno časovno obdobje in imajo primerno geografsko lego. Po večkratnem pregledu in usklajevanju členov vodne bilance smo določili tako imenovana hidrometrična zaledja, ki so osnovna enota za izdelavo vodne bilance. Hidrometrično zaledje je območje, ki je omejeno z razvodnicami, ter za katerega poznamo dotoke (na primer pretok na gorvodnih vodomernih postajah) in odtoke (Frantar 2003). Na podlagi rezultatov na območju posameznega hidrometričnega zaledja lahko primerjamo posamezne elemente vodnega kroga (Fürst 2006), s čimer lahko potrdimo pravilnost izračunanih vrednosti padavin in izhlapevanja z izmerjenim odtokom. Tako lahko izdelamo zemljevid povprečnega letnega odtoka v mm po tako imenovani klimatološki metodi z uporabo enačbe $Q = P - E$ (Jones 1997).

3 Bilanca Slovenije

3.1 Padavine

V Sloveniji je v obdobju 1971–2000 padlo letno povprečno 1579 mm padavin. Prostorska porazdelitev padavin je močno povezana z reliefom (slika 1) (Schöniger in ostali 2003; WMO 1994). Zaradi orografskega učinka se količina padavin povečuje od morja proti notranjosti Slovenije in doseže višek na dinarsko-alpski pregradi. Največ padavin (nad 2600 mm) pade na jugozahodni strani grebenov Julijskih Alp in Snežnika. Drugod v Julijskih Alpah, Karavankah in na robnih visokih dinarskih planotah pade povprečno letno med 2000 in 2600 mm padavin. Nekoliko manjši krajevni višek padavin je tudi v Kamniško-Savinjskih Alpah. Ob obali Jadranskega morja je letna količina padavin med 1100 in 1200 mm. Proti severovzhodu, za dinarsko pregrado se z oddaljenostjo od morja in orografskih pregrad količina padavin hitro zmanjšuje. Večja količina padavin pade le še na Pohorju in Gorjancih (do 1800 mm). V Ljubljanski kotlini količina padavin pada od severa proti jugu in je med 1300 mm na jugovzhodu kotline in 1800 mm na skrajnem severu kotline. V višjih predelih Posavskega hribovja pade letno do 1400 mm padavin, v nižjih predelih Posavskega hribovja, na Koroškem, Štajerskem do Maribora, na Dolenjskem in v Beli krajini pa pade med 1200 in 1300 mm padavin. Od Dravsko-Ptujskega polja, kjer dobijo letno med 1100 in 1200 mm padavin, se proti severovzhodu količina padavin še zmanjšuje. Na skrajnem severovzhodu države ne preseže 900 mm.

Slika 1: Povprečna letna količina padavin v obdobju 1971–2000 v mm (Dolinar 2006).
Glej angleški del prispevka.

Slika 2: Velikost površja glede na količino padavin po razredih v Sloveniji.
Glej angleški del prispevka.

3.2 Izhlapevanje

Regionalne razlike so med elementi vodnega kroga v Sloveniji najmanjše pri izhlapevanju (slika 4). Letno izhlapevanje v obdobju 1971–2000 je bilo med 458 in 879 mm oziroma povprečno 717 mm. Izhlapevanje je predvsem odvisnost od nadmorske višine in vrste rabe tal (slika 3).

Največje izhlapevanje, nad 850 mm, imajo posamezna gozdnata območja v Pomurju, določeni predeli Krško-Brežiške ravnine in del Bele Krajine. Na zahodu države so taka priobalna območja Koprskega gričevja, predeli Vipavskih brd ter zahodni kraški rob. Vmesni pasovi količine izhlapevanja so zelo razdrobljeni zaradi raznolike rabe tal. Majhno izhlapevanje z vrednostmi pod 600 mm, je na manjših območjih gorskega in hribovitega sveta, večje pa na jugovzhodnem robu Pohorja, v Blejskem kotu, v visokogorju Julijcev, v območju Postojnsko-Pivške kotlinice, v Brkinih in na območju vzhodne Notranjske ter zahodne Dolenjske. Splošna značilnost je, da se izhlapevanje zmanjšuje od južne Slovenije proti severozahodu in severovzhodu države.

Slika 3: Povprečna letno izhlapevanje v obdobju 1971–2000 v mm (Kurnik 2006).
Glej angleški del prispevka.

Slika 4: Površina glede na količino izhlapevanja po razredih v Sloveniji.
Glej angleški del prispevka.

3.3 Odtok

Naravnogeografska pestrost Slovenije se kaže v veliki variabilnosti odtoka. Odtok pada od alpsko-dinarskega pasu med Julijci in Snežnikom proti jugozahodu in severovzhodu. Povprečni letni odtok v obdobju 1971–2000 je bil 862 mm. Glavna geografska značilnost razporeditve odtoka je, da količina pada od severozahoda proti jugu in vzhodu države. Razporeditev je odvisna od reliefa – višji predeli imajo praviloma večji odtok, medtem ko je ta v okoliškem nižje ležečem svetu precej manjši.

Letno v povprečju največ vode (več kot 2000 mm) odteče iz osrednjega dela Julijcev, najvišjih predelov Trnovskega gozda in Snežnika. To so najbolj namočeni predeli Slovenije, kjer je hiter podzemski in površinski odtok padavin. Poleg teh imajo več kot 2000 mm odtoka letno še najvišji predeli Karavank in Kamniško-Savinjskih Alp. Med 1500 in 2000 mm odtoka letno imajo predalpska hribovja Julijcev ter zahodne dinarske planote od Banjšic do Snežnika. Območja z odtokom med 1200 in 1500 mm so v zahodni Sloveniji: predgorja Julijskih Alp, Karavank in Kamniško-Savinjskih Alp, Škofjeloško in Idrijsko hribovje, severni del Goriških Brd, obrobje zahodnih dinarskih planot, Javorniki in območje Goteniške gore.

Pas med 900 in 1200 mm odtoka letno obsega območja od južnih Brd do Slavnika, območja od Doline do vzhodnih Kamniško-Savinjskih Alp in prek vzhodnih delov Škofjeloškega hribovja vse do Kočevske Male gore ter Roga in Pohorja.

Med 600 in 900 mm odtoka imajo pokrajine na jugozahodu: Vipavska brda, Kras, del Brkinov in vzhodni del Koprskega primorja. Največje območje s takim odtokom je v osrednji Sloveniji, od Suhe krajine na jugu prek Ljubljanske kotline vse do Pohorja in Kozjaka.

Nizki odtoki z vrednostmi med 300 in 600 mm prevladujejo v Koprskem primorju in v vzhodni Sloveniji od Bele krajine do Slovenskih goric. Vrednosti odtoka pod 300 mm so v Pomurju, kjer ponekod izhlapevanje presega količino padavin.

Slika 5: Povprečni letni odtok v obdobju 1971–2000 v mm izdelana na podlagi bilančnega računa P – ETP.
Glej angleški del prispevka.

Slika 6: Površina glede na količino odtoka po razredih v Sloveniji.
Glej angleški del prispevka.

4 Bilanca po glavnih porečjih

Rezultati vodnobilančnih elementov kažejo na veliko pestrost klimatogeografskih in hidrogeografskih razmer v slovenskih porečjih. V tem poglavju smo v obravnavanih glavnih porečjih opisali padavine, izhlapevanje in odtoke.

Slika 7: Elementi vodne bilance po porečjih v mm.
Glej angleški del prispevka.

4.1 Pomurje

Pomurje je regija z najmanjšimi količinami vode v Sloveniji. V povprečju imamo tu 897 mm padavin, izhlapi 693 mm in odteče 204 mm vode letno. Na levem bregu Mure je padavin povsod manj kot 900 mm, na skrajnem vzhodnem delu celo manj kot 850 mm. Največ jih imajo Slovenske gorice, kjer je ponekod tudi več kot 1000 mm padavin letno. Povprečno izhlapi 693 mm, količina je enaka v vsem Pomurju. Izhlapevanje je odvisno od rabe tal – največ vode izhlapi iz gozdnatih območij. Zaradi visokega izhlapevanja in majhne količine padavin so tu najnižji odtoki v državi. Okrog 300 mm vode odteče z desnega brega Mure, od tam pa količina pada proti vzhodu. Marsikje v Pomurju je izhlapevanje celo večje kot razlika padavin in odtoka, kar je razumljivo, saj tu prevladujejo plitvi vodonosniki.

4.2 Podravje

Slovenski del Podravja zajema bolj raznolike pokrajine kot Pomurje. Območje lahko razdelimo na Slovenske gorice, nižinski južni del desnega brega Drave z njeno dolino ter hribovit severni del s Pohorjem in zahodnimi Karavankami.

Tu pade povprečju letno 1244 mm padavin, izhlapi 697 mm in odteče 547 mm vode. Povsod v Podravju imamo nad 1000 mm padavin. Najmanj jih je v Slovenskih goricah, kjer jih je v južnem delu okrog 1000 mm, v severnem pa okoli 1100 mm. Območje nižinskega dela Dravsko-Ptujskega polja, Haloz in obronkov Pohorja ima več kot 1200 mm padavin. Količina padavin odtod rasteta proti višjim delom Pohorja in zahodnih Karavank, kjer jih je nad 1600 mm. Izhlapevanje je najmanjše na območju Slovenskih goric in Dravskega polja ter v najvišjih delih predelih porečja Drave – na Pohorju in v povirju Meže, kjer izhlapi manj kot 650 mm letno. Drugod izhlapi več kot 700 mm, največ ponekod v Halozah in sicer več kot 800 mm. Odtoki kažejo podobno sliko – najmanjši so na vzhodnem delu (okrog 300 mm letno), največji pa v višjih predelih Pohorja in Karavank, kjer presežejo 1100 mm letno.

4.3 Posavje

V Posavju je v obdobju 1971–2000 na leto povprečno padlo 1594 mm padavin, izhlapelo 716 mm in odteklo 878 mm vode. Padavinska slika Posavja je zelo raznolika. V najbolj namočenih predelih Julijcev, v povirju Save Bohinjke pade več kot 3000 mm padavin. Količina padavin se od tod naglo zmanjšuje proti severu in vzhodu. Več kot 2500 mm padavin je tako le še v dolini Vrat, na Pokljuki in delno na Jelovici. Večina planot Julijskih Alp, Karavanke in Kamniško-Savinjske Alpe ter deli predalpskega hribovja in Javornikov imajo med 2000 in 2500 mm padavin. Količina odtod pada proti vzhodu, tako da prejme osrednji del Posavja med 1400 in 1800 mm padavin, velik vzhodni del pa manj kot 1400 mm. Najmanj padavin v Posavju je v Posotelju – pod 1200 mm na leto. Izhlapevanje je v Posavju najmanjše v visokogorskem Alpskem svetu (manj kot 550 mm letno) in ob Sotli (okoli 650 mm letno). Iz Posavja povečini izhlapeva med 650 in 850 mm letno, manj na severu in več na jugu. Na manjših območjih izhlapi več kot 850 mm (Krško-Brežiško polje). Odtok je v Posavju razporejen podobno kot padavine. Največ odteče iz alpskih (več kot 2500 mm) in predalpskih območij, odtod pa količina pada proti vzhodu, kjer je odtoka za 300–600 mm.

4.4 Pokolpje

V slovenskem delu Pokolpja v povprečju pade 1534 mm padavin, izhlapi 757 mm, odteče pa 777 mm vode letno. Na zahodu, to je na robu Snežnika in na Kočevskem je več kot 2000 mm letno. Osrednji del ima okrog 1700 mm padavin, porečje Lahinje pa okrog 1300 mm. Izhlapevanje je zelo visoko, od 650 do več kot 850 mm letno. Odtok je največji v zgornjem delu porečja Kolpe, več kot 1600 mm, od tod pa se proti vzhodu zmanjšuje. Najmanjši je v osrednji Beli krajini, kjer odteče zgolj okoli 400 mm vode letno.

4.5 Posočje

Posočje je naše najbolj namočeno porečje. V povprečju pade tu 2386 mm padavin, izhlapi v 726 mm in odteče 1660 mm vode letno. Količina padavin pada od severa proti jugu porečja. Njegovi najvišji deli imajo več kot 3000 mm padavin letno, visokogorski predeli Julijcev celo več kot 3500 mm. V alpskih dolinah je padavin že med 2300 in 2700 mm, saj se del padavin zaustavi že na južnejših visokogorskih pregradah. Jugozahodni rob visokih dinarskih planot od Kambreškega, Banjšic do Trnovskega gozda prejme okrog 2300 mm. V predalpskem hribovju ter na Nanosu je padavin že manj, to je med 2000 in 2300 mm na leto. Pod 2000 mm padavin je v Goriških brdih in v zgornji Vipavski dolini. Najmanj padavin imajo spodnja Vipavska dolina in Vipavska brda, in sicer okoli 1500 mm letno. Izhlapevanje je največje na jugu Posočja, kjer na določenih območjih izhlapi več kot 850 mm letno. Izhlapevanje pada proti severu skladno z nadmorsko višino in je v visokogorju Julijskih Alp le še okrog 550 mm letno. Velike razlike so v odtoku. Na Kaninskem pogorju odteče več kot 3000 mm vode, v večini posoških Julijskih Alp pa je odtok večji od 2000 mm (z izjemo dolin). Več kot 1500 mm odteče z dinarskih pregrad in iz osrednjega dela Posočja. V dolini Idrijce letno odteče približno 1100 mm vode, v Vipavskih brdih pa le še 650 mm letno.

4.6 Povodje jadranskih rek brez Posočja

Najmanjši hidrogeografski del Slovenije so porečja Notranjska Reka in rek, ki se izlivajo neposredno v Jadransko morje. Povprečno pade letno 1619 mm padavin, izhlapi 748 mm in odteče pa 871 mm vode. Največ padavin ima okolica Snežnika, in sicer več kot 2500 mm. Od tam količina pada proti zahodu, tako da ima obala Jadranskega morja približno 1100 mm padavin, zahodni Kras pa okrog 1500 mm. Izhlapevanje je največje ponekod v Koprskih brdih in na jugozahodu Krasa (več kot 850 mm). Proti severu in vzhodu se izhlapevanje zmanjšuje, in je na Snežniku manjše od 700 mm letno. Odtoki so največji v okolici Snežnika (nad 2000 mm) in se od tam proti zahodu zmanjšujejo. V Koprskem primorju so le med 200 in 400 mm letno.

5 Sklep

Slovenija je v svetovnem merilu nadpovprečno namočena dežela. Na celinah pade povprečno 750 mm padavin, izhlapi 480 mm in odteče 270 mm (Global Water Balance 2006; Fürst 2006). V Sloveniji je v obdobju 1971–2000 padlo povprečno letno 1579 mm padavin, izhlapelo je 717 mm, skupni izmerjeni odtok pa je bil 862 mm. Da je Slovenija še vedno dobro namočena kaže odtočni količnik, ki je v Sloveniji (55 %) večji kot je povprečni odtočni količnik na Zemlji, ki je 36 % (Schöniger in sotali 2003, citirano po Baumgartner in ostali 1996).

Preglednica 1: Vodna bilanca Slovenije v obdobjih 1961–1990 in 1971–2000 v mm (Kolbezen et al. 1998).

	1961–1990	1971–2000
padavine	1567	1579
izhlapevanje	650	717
odtok – izračunan (Q = P – E)	917	862
odtočni količnik	58,5 %	54,5 %

Primerjava naših izračunov z vodo bilanco Slovenije za obdobje 1961–1990 (Kolbezen in ostali 1998) kaže, da so bile obdobju 1971–2000 količine padavin skoraj enake, povečalo se izhlapevanje in zmanjšal odtok. Izhlapevanje je večje za enajst, odtok pa je manjši za šest odstotkov.

Podnebne spremembe se odražajo tudi v količini vode. Večina tako temperaturnih kot tudi hidrološko-nevihtnih indikatorjev podnebnih sprememb (Houghton in ostali 2001) kaže na spremembe v Sloveniji zlasti po letu 1990 (Nadbath 1999; Gabrovec 1998; Frantar 2004). Smiselno bi bilo izdelati vodno bilanco za daljše obdobje, in sicer po posameznih desetletjih in letih. V vsakem pogledu postaja voda vse dragocenejša naravna dobrina.

6 Literatura

Glej angleški del prispevka.