WATER BALANCE OF SLOVENIA 1971 – 2000

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Abstract

The water is becoming more and more valuable natural resource. The increasing water demand and climate changes are making water a precious and not always available resource. For the purpose of knowing more about water cycle in Slovenia, about hydrological characteristics of drainage basins, precipitation and evaporation, the water balance is the most appropriate way to make a full overview. The article presents the methodology and the results of the Water balance project of Slovenia.
The geographical position of Slovenia is the juncture of 4 main European georegions: The Alps, the Panonian Basin, the Mediteranean and the Dinaric Mountains, and this is what makes the territory very diverse also from a hydrological point of view. Our major watershed divides the precipitation runoff into two watershed areas – the Adriatic Sea and the Black Sea. Due to this watershed almost all the Slovenia's rivers have headwaters in our territory.
Water balance is calculation of water inputs and outputs in a ceratin area. The basic elements of the water balance include all the inflows and outflows for a given basin and serve for the computation of the water regime of a catchment area. It is defined by the parameters precipitation (P), evaporation (E), discharge (Q) and the change of the water reserves (dS).
Main results of the water balance elements for the period 1971 – 2000 for Slovenia are: Average annual precipitation in Slovenia is 1579 mm, average annual evapotranspiration is 717 mm and calculated runoff 862 mm. Compared to water amounts in the World, where the average precipitation is 750 mm, evapotranspiration is 480 mm and runoff is 270 mm, Slovenia is very watery country. Also the runoff coefficient with 55 % is much higher as 36 % of the World. The major questions remain if we are capable to live with this water amounts within the boundaries of sustainable development and what will be the effects of climate change to water balance.

Keywords: *water balance, precipitation, evaporation, runoff, hydrogeography, Slovenia.*

1 WATER BALANCE METHODOLOGY

The water balance calculation is based on the circulation of water. It assesses the quantities of water in a certain area and over a certain time period. It must consider all the inflows and outflows as well as changes in storage. For simple systems, such as a container or water reservoir with measurable inflow and outflow, the balance is straightforward and easily understood. The small water cycle schematic, where the main "inflow" is precipitation and the main "outflow" is evaporation, is also straightforward (Ritter, 2006). The water balance of a selected area, such as a country, region, etc., is much more complicated. Such a balance is invariably a simplified depiction of the actual conditions that covers the essential water balance elements and accurately portrays the relations between them.

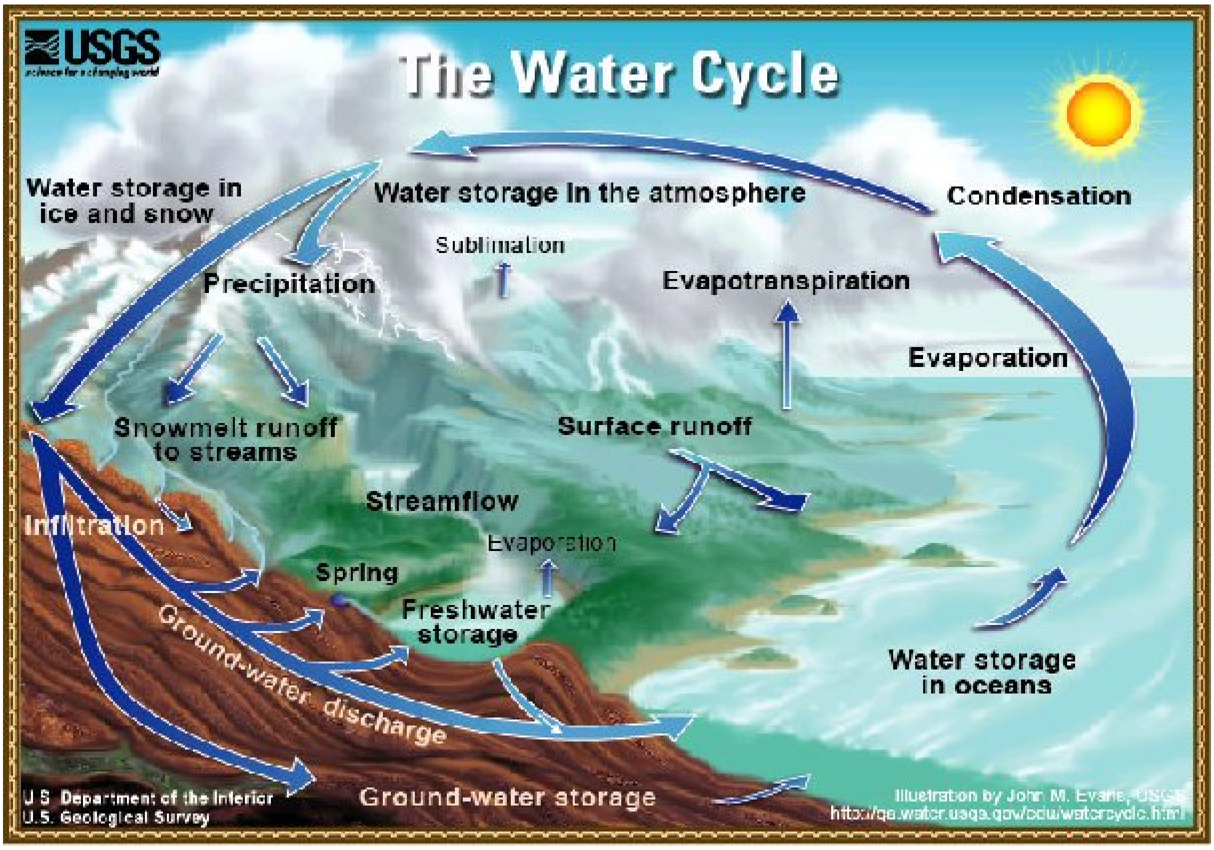

Figure 1: The circulation of water on Earth
Source: http://ga.water.usgs.gov/edu/watercyclehi.html

The basic water balance equation is based on the circulation of water between the atmosphere and the surface of the Earth (Van Abs et al., 2000, Kolbezen et al., 1998):

Precipitation (P) = Runoff (Q) + Evaporation (E) + Changes in the storage (dS)

According to the definition, precipitation is atmospheric water that exits from the air either by condensation or sublimation and falls to or towards the ground because of gravity (DIN 1996 according to Schöniger et al., 2003). The term evaporation signifies the transfer of water into vapour from areas of open water, while transpiration means the transfer through vegetation. The term evaporation here encompasses both forms, which are together called evapotranspiration. When analysing the water balance, we must limit ourselves to the analysis of the areas – to hydrometric catchment areas – whose runoff can be measured as the water flow rate (Q) of the water gauging station.

In addition to precipitation, it is necessary to consider other inflows of water (Q_i) when dealing with the water balance of a selected area. The equation is thus as follows:

$$P\ (\text{precipitation}) + Qi\ (\text{inflow}) = Qo\ (\text{runoff}) + E\ (\text{evaporation}) + dS\ (\text{changes in the storage})$$

In the balance for the 1971–2000 period we have not taken into account changes in water storage (dS) as we assume that these can be neglected over a long-time period (Frantar et al., 2005).

For the main building block of the water balance the hydrometric catchment area was used. This area is delimited by the water divide of balance cross-sections. Aside from precipitation, the headwater hydrometric catchment areas do not have other inflows. The precipitation surplus that does not evaporate and simply flows out of them and is measured as a discharge (Q). Intermediate hydrometric catchment areas receive water from both precipitation and inflow from the upstream hydrometric catchment area. The correct spatial delimitation of the hydrometric catchment area is therefore very important.

We analysed and reconciled the water balance elements of precipitation, evaporation and runoff for the selected areas. The runoffs derived from the discharges at water gauging stations (Q) were compared with the runoffs calculated using the water balance equation. The correctness of the relationships between the elements of the water balance was reviewed with the help of balance error analysis.

2 PRECIPITATION

In the 1971-2000 reference period, we measured the quantities of precipitation at 394 stations. We used data from stations with at least 25 years of operation within the period treated for the analysis. To achieve a greater spatial coverage with the stations, we included 8 additional meteorological stations with shorter time series. Finally, there were 201 precipitation stations included in the analysis. For the calculation of the spatial distribution of precipitation we also used measurements from totalizer rain gauges in 18 locations in the Julian Alps, the Karavanke Mountains and the Dinaric Alps available for the period treated. In addition to data from the stations in the territory of Slovenia, we also had at our disposal data on the daily precipitation from 29 stations located in Austria, Croatia and Italy.

The quantities of precipitation are measured in Slovenia using the Hellman rain gauge. These measurements are partially underestimated because of various effects: evaporation, the wetting of the walls of the Hellman rain gauge and the effect of the wind blowing the precipitation away from the rain gauge (WMO, 1994). For the purpose of calculating the water balance, we corrected the precipitation measured, considering the effect of the wind, the precipitation intensity and the wetting of the Hellman rain gauge (Nespor et al., 1999; Dolinar et al., 2006). The missing data was interpolated on a daily and monthly level based on the values from neighbouring stations. The average correction factors for the precipitation stations are similar to those calculated for the 1961-1990 period (Kolbezen et al., 1998). Differences occurred at some of the individual precipitation stations, but no systematic deviations could be observed.

The differences between the corrected and measured precipitation values are highest in the mountainous regions and the smallest in western and south-western Slovenia.

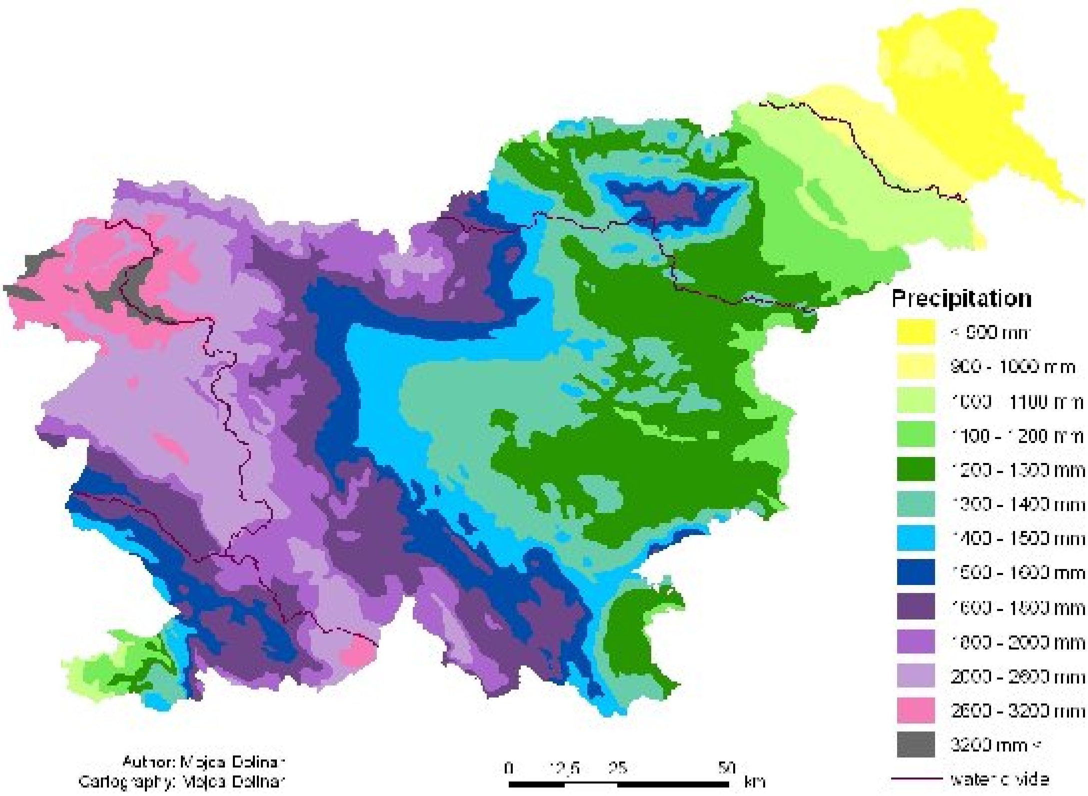

Figure 2: Precipitation in period 1971-2000

3 EVAPORATION

Evaporation or evapotranspiration (ETP) is the transfer of water in the form of water vapour from the water surface, the ground and through plant stomata into the atmosphere (Allen, 1998). Evapotranspiration is a process that combines evaporation from un-vegetated ground and water surfaces with the transpiration from plants. We have calculated the actual, real evaporation for the 1971-2000 period, which is given in the average height of the water column in mm.

The real evapotranspiration depends on the variety of plant, the phenological phase of the plant, the ground moisture available to the plants and the meteorological conditions, among which the air temperature affects evaporation the most, followed by relative air humidity, wind speed and solar radiation.

The calculation of the real evaporation was performed for 37 climatological stations using the modified Hargreas method balanced for Slovenia with linear regression coefficients concerning their daily value of potential evaporation according to the Penman-Monteith method (Allen, 1998). This calculation applies to the warm part of the year and to well-wetted ground covered with grass. Because of the difference in evapotranspiration from different types of land cover (forest, farmland, etc.), the values obtained for potential evaporation are then corrected by using standard correction coefficients for individual layers of land cover with respect to the potential evaporation.

The calculated average annual values of the real evaporation for individual meteorological stations vary from 355 mm at the station on Kredarica to 845 mm at the Bilje pri Novi Gorici station. Evaporation is strongly affected by elevation, so it also depends on the geographical position of the station. Using interpolation, we produced a map of the spatial distribution of the average evaporation.

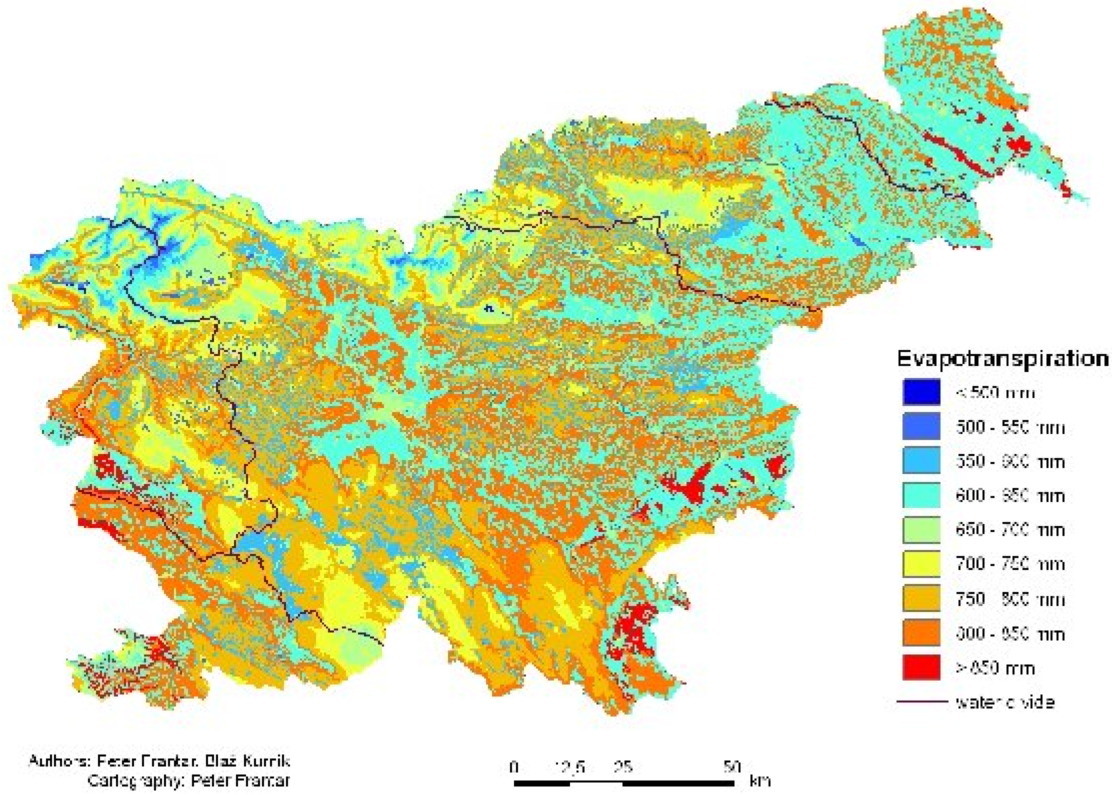

Figure 3: Evapotranspiration in period 1971-2000

4 RUNOFF

Runoff is the term that describes or represents the movement of a certain part of precipitated water into channelled streams or the discharge of water within it (Davie, 2004; Van Abs. et al. 2000). The surplus precipitation that does not evaporate or is not used for transpiration, which instead flows away, is the runoff. When this surplus is large enough, the runoff is collected into streams, which represent the majority of the runoff from a certain catchment area. In places where the majority of the runoff is collected the runoff can be measured as the discharge. In general, measured discharges are the most reliably measured elements of the water cycle. In suitably located water gauging stations, water from a certain catchment area runs through the cross-section of the water gauging station.

The characteristics of a discharge at a certain point are a reflection of the entire catchment area (WMO, 1994). Because of this, knowledge of the physical-geographical space, especially of the gauging profiles and divides is of key importance, as it is only in this way that we can obtain comparable data and analyse smaller river basin units. Discharge data are linked to the space via the hydrometric catchment areas.

Data gaps cause difficulties in the analysis of hydrological data. When reviewing the data on discharges for the 1971-2000 period, it was found that 65 water gauging stations had complete data sets. On other stations, data gaps were supplemented with the use of a statistical method – with the Pearson linear correlation coefficient based on the mean monthly averages of the 1961-2001 period.

Specific Runoff in the 1971-2000 Period

The specific runoff shows how many mm of water runs off per year on average. The average runoff can be estimated based on the measured values from the discharges at individual water gauging stations or using the water balance equation – precipitation minus evaporation ($Q = P – E$). In Slovenia the runoffs measured are very similar to those calculated using the water balance formula, which indicates the correctness of the calculations of precipitation and evapotranspiration. The prevailing characteristic of the specific discharge in Slovenia is that it is highest in the upstream part and gradually decreases downstream (Kolbezen et al, 1998).

The most important effect on the specific runoff has the climate or, more precisely, the precipitation, which is also reflected in the geographical distribution. The quantity of the specific runoff decreases as you move from the Alps and the Dinaric belt toward the north-east and south-west, which is also shown by the chart of specific runoffs that was produced based on the water balance equation using precipitation and evaporation data.

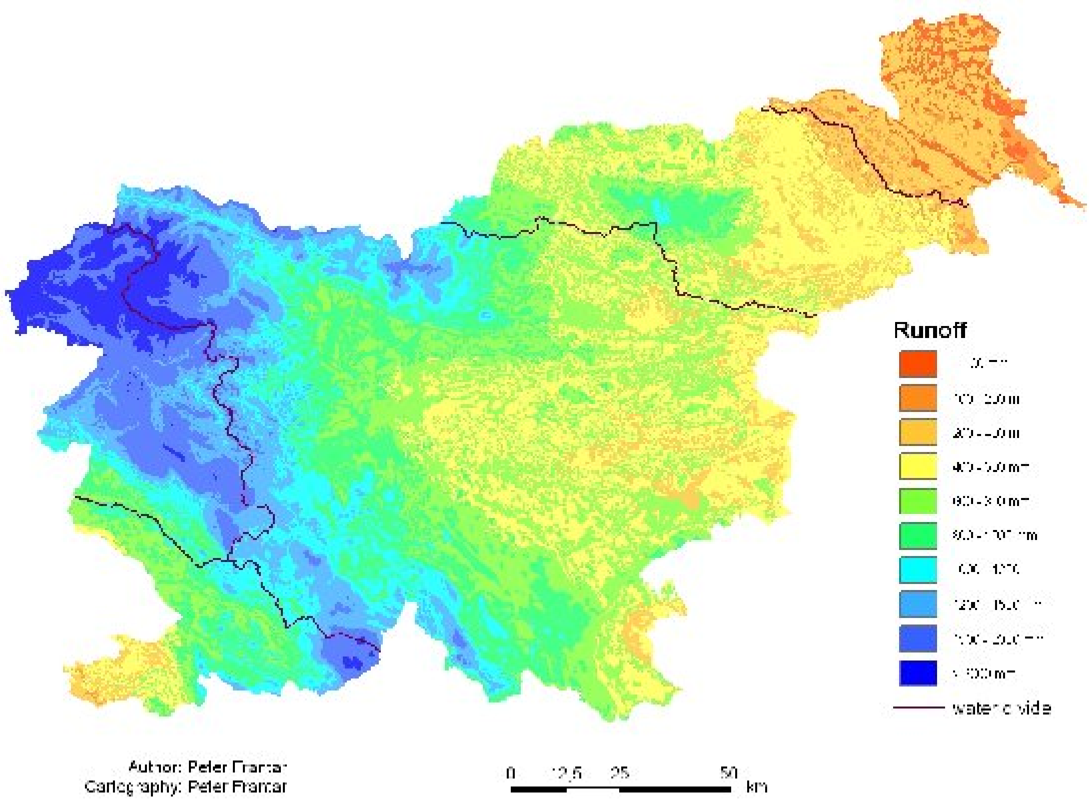

Figure 4: Runoff in period 1971-2000

5 OVERVIEW OF THE WATER BALANCE BY RIVER BASINS

The results of the water balance elements indicate a great variety of climatic-geographical and hydrogeographical conditions in individual areas.

Pomurje (The River Basin of the Mura River)

Pomurje has the least water in Slovenia. On average, there is 897 mm of precipitation, 693 mm of evaporation and 204 mm of runoff annually in the entire Pomurje. Throughout the left bank of the Mura, there is less than 900 mm of precipitation, while in the eastern-most part there is less than 850 mm. The most precipitation in the river basin occurs in the Slovenske gorice area. The annual evaporation quantity is 693 mm and has only slight geographical deviation – the situation being similar throughout Pomurje. The result of this evaporation and precipitation are the low runoff values – with the lowest values in the country. The average annual runoff is around 300 mm from the right bank of the Mura, though the runoff decreases as you move eastwards.

Podravje (The Drava River Basin)

The Slovenian part of the Drava river basin encompasses a more varied landscape than Pomurje. On average, there is 1244 mm of precipitation in the entire Podravje area, where 697 mm evaporate and 547 mm of water run off annually. Throughout Podravje, the measured annual quantities of precipitation are in excess of 1000 mm.

Here the least precipitation is in Slovenske gorice. The quantity of precipitation increases from here towards the higher-lying parts of Pohorje and the western Karavanke Mountains, where there is more than 1600 mm of precipitation. Evaporation is lowest in the area of Slovenske gorice and the Dravsko polje, as well as in the highest reaches of the Drava river basin – on Pohorje and in the Karavanke Mountains. In the remaining area evaporation exceeds 700 mm annually, with the highest occurring in individual areas of Haloze – more than 800 mm. The runoffs show a similar picture – they are lowest (around 300 mm per year) in the eastern part, and the highest of the higher reaches of Pohorje and the Karavanke Mountains, where they reach more than 1100 mm per year.

Posavje (The Sava River Basin)

Posavje is the largest river basin. In the entire Posavje area, without the Kolpa River basin, there was an average of 1594 mm of precipitation, 716 mm of evaporation and 878 mm of runoff per year in the 1971-2000 period. In the wettest areas of the Julian Alps, in the western parts of the catchment areas of the Savica, Bohinjska Bistrica and Mostnica, there is more than 3000 mm of precipitation. The quantity drops from here towards the east, so that the central area of Posavje exhibits between 1400 and 1800 mm of precipitation. The least precipitation in Posavje occurs in Posotelje region. Evaporation in this river basin is the lowest in the high-mountain Alpine area and in Posotelje region. In general, between 650 and 850 mm of water evaporate from Posavje annually, with less evaporation observed in the north and more in the south. The runoff in Posavje is distributed similar to the precipitation. The most water runs off from the Alpine and pre-Alpine areas, with the quantity dropping from here towards the east.

Pokolpje (The Kolpa River Basin)

Pokolpje is a part of Posavje as the Kolpa discharges into the Sava River in Croatia. It is a karstic river basin. In the Slovenian part of Pokolpje, there is an average of 1534 mm of precipitation, 757 mm of evaporation and 777 mm of water run off annually. The most precipitation is in the west. Evaporation is very high – from 650 to up to over 850 mm per year, and is strongly dependent on the vegetation and the surface exposure. The runoff is highest in the upper part of the Kolpa river basin, with more than 1600 mm, and drops rapidly from here towards the east. The least runoff occurs in central Bela krajina, where only around 400 mm of water run off annually.

Posočje (Soča River Basin)

Posočje is our most water-abundant river basin. In the entire Posočje, there is an average of 2386 mm of precipitation, 726 mm of evaporation and 1660 mm of runoff annually. The highest parts experience over 3000 mm precipitation per year. From there the precipitation drops towards the south where the lowest precipitation occurs in the Lower Vipava Valley and in the Vipavska brda areas - around 1500 mm annually. Evaporation in Posočje is highest in the southern areas and the amount drops as you move towards the north in accordance with the elevation. Great differences occur in terms of runoff. In the majority of the Alps in Posočje the runoff is over 2000 mm (with the exception of the valley areas), but in the Vipavska brda the quantity drops to a mere 650 mm per year.

The Catchment Area of the Adriatic Rivers without Posočje

The smallest hydrogeographical area of Slovenia is represented by the Reka River - with its catchment area that flows into the Adriatic via the Karst - and the area of small rivers and streams that drain directly into the Slovenian sea. In the entire Primorje area with Karst, there is an average of 1619 mm of precipitation, while 748 mm of water evaporates and 871 mm of water run off annually. The most precipitation falls in the surroundings of Mount Snežnik. The quantity drops towards the west. The coastal areas receive a good 1000 mm of precipitation and the western Karst around 1500 mm of precipitation annually. Evaporation is highest in individual parts of the Koper coastal area and in the south-western part of the Karst. Towards the north and east, the quantity of evaporation drops, being lowest in the Snežnik mountain chain – below 700 mm annually. The runoffs are highest in the eastern-most part (surroundings of Mount Snežnik), where more than 2000 mm of water runs off. Runoffs decrease from there towards the west. The groundwater runoff in the Karst is between 500 and 750 mm, with the lowest being in the Koper coastal area – between 200 and 500 mm annually.

6 OVERVIEW

On the territory of Slovenia in the 1971-2000 period, there was an average of 1579 mm of annual precipitation, 717 mm of evaporation and the 862 mm of runoff.

Table 1 : The water balance – a comparison of periods (source for the 1961-90 period: Kolbezen et al, 1998) for the territory of the Republic of Slovenia

In mm	1961-1990	**1971-2000**
Precipitation	1567	1579
Evaporation	650	717
Runoff – calculated according to the equation Q = P – E	917	862
Runoff coefficient	58.5%	54.5%

A direct comparison with the 1961-1990 reference period water balance (Kolbezen et al., 1998) shows that the quantities of precipitation were almost the same in the 1971-2000 period, but that the quantity of evaporation has increased and runoff has decreased. It shows a significant change in the evaporation and runoffs. Evaporation is higher by 11%, and the runoff is lower by 6%.

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