Hydro-meteorological trends in an Austrian low-mountain catchment

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Abstract: While the ongoing climate change is well documented, the impacts exhibit a substantial variability, both in direction and magnitude, visible even at regional and local scales. However, the knowledge of regional impacts is crucial for the design of mitigation and adaptation measures, particularly when changes in the hydrological cycle are concerned. In this paper we present hydro-meteorological trends based on observations from a hydrological research basin in Eastern Austria between 1979-2019. The analysed state variables include the air temperature, the precipitation, and the catchment runoff. Additionally, trends for the catchment evapotranspiration were derived. The analysis shows that while the mean annual temperature was decreasing and annual temperature minima remained constant, the annual maxima were rising. The long-term trends indicate a shift of precipitation to the summer with minor variations observed for the remaining seasons and at an annual scale. Observed precipitation intensities mainly increased in spring and summer between 1979-2019. The catchment evapotranspiration, computed based on catchment precipitation and outflow, showed an increasing trend for the observed time period.

Keywords: hydrological research basin; precipitation; temperature; long-term trends; climate change; evapotranspiration

1. Introduction

It is well documented that the climate is changing [1–3]. Impacts are seen as globally rising temperatures [2,4] with a reduced number of cold days and nights and an increased number of warm days and nights [4], an altered depth [5–7] and duration of snow and ice cover [6–8], changing precipitation [4,9–11] and river flow regimes [12–14], or an increased number of extreme events [2,4,15].

However, the magnitude and impact direction of climate change observations and projections vary significantly at the global and regional scale [16,17]. To give some examples, a runoff decrease was observed for the Chinese Wuding basin [18] or the Three-River-Headwaters region [19] while an increase in runoff was reported for the Chinese Kaidu basin [20] and the North-Eastern USA [21].

While there is a consensus on global warming [2] supported by many studies (e.g. [18,22]) some areas experienced decreasing mean, maximum, or minimum temperatures 1951-2002 [23].

Precipitation observations indicate minor global changes despite a large, compensating variability with a decrease observed in the subtropics, the Mediterranean [24], southern Asia and Africa and increases observed in North America, South America and Eurasia [11,25]. Furthermore, a seasonal shift of precipitation (e.g. [22,26]) and runoff has been reported (e.g. [13]).

Several studies report increasing evapotranspiration trends for most of the Northern hemisphere (e.g. [22,27–30]) while China experienced decreasing evapotranspiration rates over the past 50 years [31]. Some of these studies confirm the trend that dry areas become drier and wet areas become wetter, while some contradict [25,32].
The validation of observations is one of the most important tasks during hydrological assessments as faulty data obviously provoke wrong analysis results and conclusions. At the same time, particularly the validation of precipitation measurements is very demanding due to the spatial and temporal variability of rainfall and its stochastic nature. An appropriate validation strategy depends on several factors, such as the spatial distribution of stations, the recording and analysis frequency or the type of measurement device. While there is no standardized procedure that is generally applicable, validation strategies commonly comprise the following steps: (i) identification of documented defects, (ii) device specific boundaries, (iii) climatological boundaries, (iv) temporal variability, (v) intra-stational validation, and (vi) inter-stational variability [33,34].

The literature shows that the impact of climate change is widely acknowledged. At the same time it is obvious that the impacts highly vary at a regional and even local scale. However, this knowledge is crucial to develop measures to mitigate and counteract hydrological climate change impacts. In this paper we present and analyse the hydro-meteorological data from an hydrological research catchment in Styria, Eastern Austria, that is monitored since 1979. Analysed climate variables include precipitation, air temperature, river flow, and evapotranspiration.

2. Materials and methods

2.1. Hydrological research catchment Pöllau

The hydrological research basin (HRB) Pöllau was established in 1978 [35,36] and is currently operated by the Institute of Urban Water Management and Landscape Water Engineering at Graz University of Technology in cooperation with the Department 14 of the Federal State Styria. The decision to establish an HRB in the Pöllau sub-basin was based on a number of reasons: (i) the confining arched mountain ridge allows a clear delineation of the catchment, (ii) the loamy soils are characterized by low storage capacities minimizing the influence of subsurface flow on catchment hydrology, and (iii) the climate of the catchment with heavy storm events in the summer and relatively dry winters is representative for the Eastern alpine foothills [37]. The catchment covers 58.3 km² and is located in Styria, Austria, about 60 km north-east of the city of Graz (Figure 1). The elevation of the catchment ranges from 398-1279 m and the catchment land-cover is dominated by forest (ca. 44.6%) and grass- and cropland (ca. 51.5%) with a low degree of impervious areas (ca. 1.3%) [38]. The land-cover changes in the catchment are minor since the start of the observations in 1979.

The catchment comprises two main sub-catchments that are monitored: (i) the sub-catchment Saifenbach/Dürre Saifen covering 23 km² (monitored 1997-2005 and since 2018) and (ii) the sub-catchment Prätisbach covering 21 km² (monitored since 1980). Additionally, the discharge at the joint catchment outlet of the both sub-catchments is monitored since 1980. Characteristic catchment properties are given in Table 1.
Figure 1. Overview of the catchment Pöllau (discharge measurement A) with the sub-catchment Prättisbach (discharge measurement B) in the West and the sub-catchment Dürre Saifen (discharge measurement D) in the East and the locations of the precipitation measurements.

Table 1. Overview of the catchment properties.

| Property                      | Value                                      |
|-------------------------------|--------------------------------------------|
| Area                          | 58.3 km²                                   |
| Land-use                      | forest 44.2%, grass- and cropland 51.5%, settlement 4.3% |
| Stream density                | 1.87 km km⁻² or 0.0019 m m⁻²               |
| Geology                       | Crystalline basement rock 82.7%, tertiary hill country 12.7%, quaternary deposits 4.3% |
| Elevation range               | 398-1279 m.a.s.l                           |
| Discharge characteristics     | Qₘᵢₙ 0.04 m³s⁻¹; Qₘₐₓ 92.14 m³s⁻¹; Qₘₑᵃₙ 0.49 m³s⁻¹; Mean runoff coefficient 0.31 (1979-2004) |

2.2. Data

The first precipitation measurement in the HRB Pöllau was installed in 1979 (1, see Figure 1 and Table 2). During the following year (1980) additional five precipitation gauges were installed and two stream gauges (the catchment outlet A and the sub-catchment B) were constructed and taken into operation. The precipitation monitoring at the meteorological station (7) started in 1982 whereas the observation of climate variables started in 1991. The stream gauge C started operation in 1988 but was destroyed during a massive flood in 1997. The gauge was then reconstructed in 2000 but after another flood damage in 2007 not taken into operation anymore. The stream gauge D was constructed in 1997 but due to the challenging measurement location, monitoring was abandoned in 2005. The gauge was reconstructed 500 m upstream in 2018 and is, together with the gauges A and B currently operating.

The currently operated precipitation gauges are rather symmetrically distributed over the catchment area and located at elevations between 420-1040 m.a.s.l. Initially, all 7 precipitation gauges were tipping buckets with a resolution of 0.1 mm. Since the year 2011 6 stations have been equipped with rain scales (type Ott Pluvio², [39]) operated at a 1 min recording interval. The currently operated stream gauges monitor the entire catchment.
outflow \((A)\) and the two main sub-catchments (Figure 1). The stream gauges are equipped with pressure sensors, calibrated with rating curves, and record at a 10-15 min interval.

Table 2. Stations, altitude (m.a.s.l), measured variables: WL (water level), WT (water temperature), \(P\) (precipitation), \(T\) (air temperature), \(p\) (air pressure), \(rH\) (relative humidity), \(Ra\) (solar radiation), \(ST\) (soil temperature), \(SM\) (soil moisture), \(WS\) (wind speed), \(WD\) (wind direction), and data availability.

| Station | Altitude | Observed variables | Data availability |
|---------|----------|-------------------|------------------|
| A       | 398      | WL, WT            | 1980-             |
| B       | 415      | WL, WT            | 1980-             |
| C       | 418      | WL, WT            | 1988-1997, 2000-2007 |
| D       | 455      | WL, WT            | 1997-2005, 2018-  |
| 1       | 424      | \(P\)             | 1979-             |
| 2       | 729      | \(P\)             | 1980-             |
| 3       | 740      | \(P\)             | 1980-             |
| 4       | 800      | \(P\)             | 1980-             |
| 5       | 740      | \(P\)             | 1980-             |
| 6       | 1040     | \(P\)             | 1980-             |
| 7       | 525      | \(P, T, p, rH, Ra, ST, SM, WS, WD\) | 1980-             |

2.3. Data validation

To exclude as much doubtful data as possible from the subsequent analysis the available measurements were first validated on a daily basis according to the following procedure: (i) identification of documented defects, (ii) device specific boundaries, (iii) climatological boundaries, (iv) temporal variability, (v) intra-stational validation, and (vi) inter-stational variability [33,34].

Figure 2. Scatter of daily recordings of each station against each station (Pearson correlation 0.91).

The validation steps (i)-(vi) were applied for the rainfall and discharge observations. The comparison of daily precipitation observations after validation shows a good correlation (Pearson correlation 0.91) allowing the conclusion that the seven stations mostly recorded similar values (Figure 2). The discharge measurements were validated using cumulative sums of the available gauges. An inter-stational validation for the temperature data was not directly possible, as this variable is recorded at only one location within the
catchment. However, the general observed pattern was compared with regionally available temperature observations for consistence.

2.4. Data analysis

The long-term hydrological trends and their significance were computed using the non-parametric modified Mann-Kendall test [40] to reduce the influence of serial correlation. Additionally, the Theil-Sen robust estimate was computed [41,42] to evaluate the magnitude of the trend. This approach has been successfully used to assess climate developments in numerous earlier studies (e.g. [43–46]) and was therefore applied in the current study.

The long-term trend of the air temperatures was analyzed based on the mean annual temperatures on the one hand and on seasonal mean temperatures recorded at the climate station 7 on the other hand. The seasons were defined as spring (March, April, May), summer (June, July, August), autumn (September, October, November) and winter (December, January, February). The seasonal trends were computed as annual trends might be balanced by seasonal changes.

The conducted precipitation analyses comprised the long-term trend of annual and seasonal (seasons as defined above), precipitation depths as well as the long-term trends of precipitation intensities for different durations (60 min, 120 min, 240 min). The precipitation depth was analyzed as the catchment mean sum (mean of the station recordings that fulfilled the validation criteria).

The long-term trends for the catchment discharge were analysed for the gauge A while the remaining gauges were utilized for data validation only.

As for the precipitation and the temperature the long-term flow trends were also analysed at a seasonal scale to identify temporal shifts in the stream flow behaviour.

The catchment water balance was computed based on the observed precipitation and the observed runoff to assess the long-term development of the evapotranspiration in the catchment. The computation includes a number of simplifications: (i) groundwater outflow of the catchment is not considered (no data available), (ii) land-cover changes are not considered, and (iii) only years are taken into account, where the available data allows for the computation of annual runoff values. The simplifications yield in the following water balance:

$$ET = P - R$$

where $ET$ is the evapotranspiration [mm], $P$ is the observed catchment precipitation [mm], and $R$ is the observed catchment runoff [mm].

3. Results

3.1. Temperature trends

The mean annual air temperature at the climate station 7 between 1991-2019 is 9.8°C with the maximum annual mean recorded in 1995 (11.5°C) and the minimum annual mean recorded in 1991 (7.6°C). The long-term development of the mean annual temperature shows a negative trend with decreasing annual mean air temperature recordings (Figure 3).

While the development of the annual minima shows no significant trend, annual temperature maxima were increasing between 1991-2019. The mean annual minimum 1991-2019 is -13.4°C with the lowest recording in 2009 (-19.2°C) and the highest recording in 2015 (-8.3°C). The mean annual maximum 1991-2019 is 32.5°C with the lowest recording in 1997 (29.1°C) and the highest recording in 2003 and 2016 (37.4°C) (Figure 3).
The mean winter temperature between 1991-2019 is 0.3°C shows a decreasing trend with the lowest value recorded in 2009 (-3.2°C) and the highest recording in 1994 (2.7°C). Both the winter minima (mean of -13.4°C with the lowest recording in 2009 (-19.2°C) and the highest recording in 2015 (-8.3°C)) and maxima 1991-2019 (mean of 16.5°C with the lowest recording in 1996 (10.6°C) and the highest recording in 2011 (20.3°C)) show no significant trend (Figure 4 top left).

The mean spring temperature between 1991-2019 is 10.0°C shows a similarly decreasing trend as observed for the winter. The lowest mean was recorded in 2009 (7.6°C) and the highest recording in 1995 (12.1°C). The trend of the spring minima is decreasing around a mean minimum of -5.5°C with the lowest recording in 2018 (-16.3°C) and the highest record observed in 2011 (-1.2°C). The trend of the spring maxima 1991-2019 is also decreasing around 27.0°C with the lowest recording in 1991 (23.1°C) and the highest recording in 1999 (30.9°C) (Figure 4 top right).

The mean temperature during the summer between 1991-2019 shows no trend staying at 19.9°C with the lowest recording in 2008 (17.5°C) and the highest recording in 2003 (22.2°C). The trend of the summer minima is also not significant at 6.3°C with the lowest recording in 2006 (2.7°C) and the highest recording in 2019 (12.7°C). The trend of the summer maxima 1991-2019 is increasing around 35.5°C with the lowest recording in 1997 (29.1°C) and the highest recording in 2003 and 2016 (37.4°C) (Figure 4 bottom left).

The trend of the mean autumn temperature 1991-2019 is not significant around 9.8°C with the lowest recording in 2008 (6.0°C) and the highest recording in 1995 (13.4°C). The
trend of the autumn minima is decreasing around -4.9°C with the lowest recording in 2008 (-9.8°C) and the highest recording in 1995 (1.0°C). The trend of the autumn maxima 1991-2019 is increasing around 25.7°C with the lowest recording in 2010 (22.7°C) and the highest recording in 2015 (31.5°C) (Figure 4 bottom right). A comprehensive summary of the observed temperature trends including statistical trend properties is given in Table 3.

3.2. Precipitation trends

3.2.1. Precipitation depth

The mean annual precipitation shows no significant trend between 1979-2019 around 608.9 mm with the maximum mean recorded in 2014 (807.2 mm) and the minimum recorded in 2001 (364.3 mm). The annual maximum at a single station was recorded in 1996 at 829.2 mm and the annual minimum in 2001 at 340.4 mm.

![Figure 5](preprints sums.pdf)  
**Figure 5.** Annual precipitation of the 7 stations (25% and 75% percentile, mean (green), median (orange)) and trend 1979-2019 (dashed line).

The seasonal precipitation 1979-2019 shows an increasing trend for the summer (June, July, August) while no significant trend was detected for the spring (March, April, May), the autumn (September, October, November), and the winter (December, January, February) 1979-2019 (Figure 6).

![Figure 6](preprints sums.pdf)  
**Figure 6.** Precipitation of the 7 stations (25% and 75% percentile, mean (green), median (orange)) and trend 1979-2019 (dashed line) for winter (top left), spring (top right), summer (bottom left), and autumn (bottom right).

The mean winter precipitation in the catchment 1979-2019 was 73.3 mm with the highest recording in 2013 (139.5 mm) and the lowest recording in 1998 (16.3 mm) (Figure 6 top left). The mean precipitation falling in the winter season accounted for 12% of the mean annual precipitation 1979-2019.
The mean spring precipitation accounted with 151.9 mm for 25% of the mean annual precipitation 1979-2019. The largest spring precipitation was recorded in 1985 (272.5 mm) and the smallest in 2003 (66.7 mm) (Figure 6 top right).

The mean summer precipitation shows a clearly increasing trend around 222.0 mm accounting for 36% of the mean annual precipitation 1979-2019. The largest summer precipitation was recorded in 2018 (416.4 mm) and the smallest value was recorded in 1984 (99.1 mm) (Figure 6 bottom left).

The mean autumn precipitation 1979-2019 was around 168.2 mm accounting for 27% of the mean annual precipitation. The largest autumn precipitation was recorded in 1993 (273.5 mm) and the smallest precipitation in 2019 (78.7 mm) (Figure 6 bottom right).

3.2.2. Precipitation intensities

The precipitation intensities for a duration of 60 min intensities showed no significant trend at an annual level as well as for the summer and autumn season. However, an increasing trend was detected for the winter and spring 1979-2019. The annual intensities for a duration of 120 min showed no significant trend as well as for the winter and autumn while the spring and summer experienced increasing intensities (Figure 7). The trend for a longer duration of 240 min was not significant for the winter and autumn as well as annually. However, as for the duration of 120 min, intensities were increasing for the spring and summer. A comprehensive summary of the observed precipitation trends including statistical trend properties is given in Table 3.

3.3. River flow trends

The annual mean flow 1981-2016 at the catchment outlet shows a decreasing trend around 1.10 m³s⁻¹ with the maximum mean flow observed in 1998 (3.01 m³s⁻¹) and the minimum mean flow observed in 2016 (0.12 m³s⁻¹) (Figure 8 left).
The observed mean annual minimum flow was increasing 1981-2016 around 0.11 m$^3$s$^{-1}$ with the smallest recording in 2002 (0.03 m$^3$s$^{-1}$) and the largest recording in 2014 (0.24 m$^3$s$^{-1}$) (Figure 8 left). The observed mean annual maximum flow showed no significant trend 1981-2016 around 31.10 m$^3$s$^{-1}$ with the largest observation in 1992 (92.14 m$^3$s$^{-1}$) and the smallest observation in 2015 (5.61 m$^3$s$^{-1}$) (Figure 8 right).

The mean winter flow 1981-2016 shows, as already observed for the annual flow, a decreasing trend around 0.51 m$^3$s$^{-1}$ with the lowest observation in the winter 2016 (0.12 m$^3$s$^{-1}$) and the largest observation in the winter 1992 (1.99 m$^3$s$^{-1}$). The minimum winter flow showed no significant trend 1981-2016 around 0.14 m$^3$s$^{-1}$ with the lowest flow occurring in 2002 (0.03 m$^3$s$^{-1}$) and the highest minimum observed in 2014 (0.35 m$^3$s$^{-1}$). The maximum winter flow also remained constant 1981-2016 at 4.11 m$^3$s$^{-1}$ with the highest flow recorded in 1992 (34.28 m$^3$s$^{-1}$) and the lowest maximum in 1984 (0.58 m$^3$s$^{-1}$) (Figure 9 top).

The mean spring flow 1981-2016 was decreasing around 0.88 m$^3$s$^{-1}$ with the lowest mean in 2002 (0.13 m$^3$s$^{-1}$) and the largest mean recorded in 1994 (5.62 m$^3$s$^{-1}$). The mean minimum spring flow shows no trend at 0.17 m$^3$s$^{-1}$ with the lowest flow occurring in 2014 (0.03 m$^3$s$^{-1}$) and the highest minimum observed in 2002 (0.05 m$^3$s$^{-1}$). The mean maximum spring flow was increasing 1981-2016 around 8.27 m$^3$s$^{-1}$ with the largest recording in 1994 (42.42 m$^3$s$^{-1}$) and the smallest recording in 1993 (0.91 m$^3$s$^{-1}$) (Figure 9 2nd from top).

The mean summer flow 1981-2016 remained constant around 1.64 m$^3$s$^{-1}$ with the largest summer mean flow observed in 1997 (8.07 m$^3$s$^{-1}$) and the lowest mean in the summer 2001 (0.19 m$^3$s$^{-1}$). The summer minimum shows no trend 1981-2016 at 0.20 m$^3$s$^{-1}$ with the lowest observation in 2003 (0.04 m$^3$s$^{-1}$) and the highest in 1986 (1.30 m$^3$s$^{-1}$). The summer maximum increased 1981-2016 around 26.57 m$^3$s$^{-1}$ with the largest summer flow in 1992 (92.14 m$^3$s$^{-1}$) and the lowest maximum in 1984 (0.76 m$^3$s$^{-1}$) (Figure 9 3rd from top).

*Figure 9.* Mean (black), minimum (blue) and maximum (red) flow at Saifenbach and linear trends 1981-2016 for the winter (top), spring (2nd from top), summer (3rd from top), and autumn (bottom).
The mean autumn flow showed no trend 1981-2016 around $1.08 \text{ m}^3\text{s}^{-1}$ with the lowest mean recorded in 2001 ($0.16 \text{ m}^3\text{s}^{-1}$) and the largest mean occurring in 1998 ($4.35 \text{ m}^3\text{s}^{-1}$). The autumn minimum decreased around $0.19 \text{ m}^3\text{s}^{-1}$ with the smallest flow recorded in autumn 1992 ($0.06 \text{ m}^3\text{s}^{-1}$) and the largest minimum in 1982 ($0.40 \text{ m}^3\text{s}^{-1}$). The maximum autumn flow remained constant 1981-2016 around $13.04 \text{ m}^3\text{s}^{-1}$ with the smallest maximum in autumn 2008 ($0.73 \text{ m}^3\text{s}^{-1}$) and the largest autumn flow in 1998 ($60.81 \text{ m}^3\text{s}^{-1}$) (Figure 9 bottom). A comprehensive summary of the observed runoff trends including statistical trend properties is given in Table 3.

### 3.4. Water balance and evapotranspiration

Particularly in the 1990’s the flow measurements at A have large gaps preventing the computation of annual flow volumes. Thus, 22 years were available to assess the evapotranspiration based on precipitation and catchment runoff (Figure 10). The mean runoff fraction of the water balance 1981-2016 was 55% showing a decreasing trend. It is to be noted though that less data was available for the time period 1981-2000 (6 years) than for the period 2001-2016 (16 years). The highest runoff fraction was observed in the year 1999 with 92% while the lowest fraction occurred in 2016 with only 10%. In absolute values the catchment runoff ranged between 67-743 mm with a mean of 338 mm per year.

Based on long-term precipitation and runoff trends the actual evapotranspiration fraction was increasing 1981-2016 around a mean of 45% with a minimum of 8% in 1999 and a maximum of 90% in 2016. In absolute numbers the actual evapotranspiration in the catchment was 1981-2016 around 265 mm with a minimum of 51 mm in 1999 and a maximum of 629 mm in 2016.

![Figure 10. Annual water balance as the runoff (red) fraction of the precipitation (blue). The dashed lines mark the long-term trend of the runoff fraction (red) and the evapotranspiration fraction 1981-2016. Missing years did not provide sufficient runoff data for a cumulative annual runoff value.](Water balance.pdf)
Table 3. Summary of the climate variable trends for the catchment Pöllau.

| Assessment period | Variable                  | Unit          | Y-W trend | p-value | T-S slope |
|-------------------|---------------------------|---------------|-----------|---------|-----------|
| Annual            | mean air temperature     | [C]           | decrease  | 1.4e-03 | -3.1e-02  |
|                   | minimum air temperature  | [C]           | no trend  | 2.3e-01 | 2.7e-02   |
|                   | maximum air temperature  | [C]           | increase  | 1.2e-03 | 6.3e-02   |
|                   | precipitation depth      | [mm]          | no trend  | 9.3e-02 | 6.0e-01   |
|                   | precipitation intensity  | [mm / 60 min] | no trend  | 5.7e-01 | 4.0e-04   |
|                   | precipitation intensity  | [mm / 120 min]| no trend  | 4.3e-01 | 5.0e-03   |
|                   | precipitation intensity  | [mm / 240 min]| no trend  | 5.9e-01 | 7.0e-03   |
|                   | mean river flow          | [m³s⁻¹]       | decrease  | 4.2e-03 | -2.4e-02  |
|                   | minimum river flow       | [m³s⁻¹]       | increase  | 5.2e-03 | 1.0e-03   |
|                   | maximum river flow       | [m³s⁻¹]       | no trend  | 7.3e-01 | -1.1e-01  |
| Winter            | mean air temperature     | [C]           | decrease  | 1.1e-02 | -3.7e-02  |
|                   | minimum air temperature  | [C]           | no trend  | 2.2e-01 | -1.5e-02  |
|                   | maximum air temperature  | [C]           | no trend  | 6.5e-01 | 2.8e-02   |
|                   | precipitation depth      | [mm]          | no trend  | 4.5e-01 | -1.5e-01  |
|                   | precipitation intensity  | [mm / 60 min] | increase | 5.5e-04 | 1.7e-02   |
|                   | precipitation intensity  | [mm / 120 min]| no trend  | 5.8e-02 | 9.0e-03   |
|                   | precipitation intensity  | [mm / 240 min]| no trend  | 1.8e-01 | 1.4e-02   |
|                   | mean river flow          | [m³s⁻¹]       | decrease  | 3.2e-03 | -5.0e-03  |
|                   | minimum river flow       | [m³s⁻¹]       | no trend  | 4.6e-01 | 3.0e-04   |
|                   | maximum river flow       | [m³s⁻¹]       | no trend  | 1.8e-01 | -9.0e-03  |
| Spring            | mean air temperature     | [C]           | decrease  | 2.6e-05 | -4.7e-02  |
|                   | minimum air temperature  | [C]           | decrease  | 1.1e-02 | -4.6e-02  |
|                   | maximum air temperature  | [C]           | decrease  | 3.0e-04 | -9.9e-02  |
|                   | precipitation depth      | [mm]          | no trend  | 3.4e-01 | 2.8e-01   |
|                   | precipitation intensity  | [mm / 60 min] | increase | 3.1e-04 | 1.1e-02   |
|                   | precipitation intensity  | [mm / 120 min]| increase | 7.1e-03 | 2.5e-02   |
|                   | precipitation intensity  | [mm / 240 min]| increase | 1.0e-02 | 4.9e-02   |
|                   | mean river flow          | [m³s⁻¹]       | decrease  | 1.1e-03 | -9.0e-03  |
|                   | minimum river flow       | [m³s⁻¹]       | no trend  | 2.4e-01 | -9.0e-04  |
|                   | maximum river flow       | [m³s⁻¹]       | increase  | 3.0e-02 | 3.6e-02   |
| Summer            | mean air temperature     | [C]           | no trend  | 7.9e-01 | -1.0e-03  |
|                   | minimum air temperature  | [C]           | no trend  | 2.3e-01 | -3.4e-02  |
|                   | maximum air temperature  | [C]           | increase  | 7.5e-05 | 6.3e-02   |
|                   | precipitation depth      | [mm]          | increase  | 2.5e-06 | 2.1e00    |
|                   | precipitation intensity  | [mm / 60 min] | no trend  | 1.3e-01 | 3.4e-03   |
|                   | precipitation intensity  | [mm / 120 min]| increase | 0.0e00  | 5.2e-02   |
|                   | precipitation intensity  | [mm / 240 min]| increase | 1.6e-05 | 5.4e-02   |
|                   | mean river flow          | [m³s⁻¹]       | no trend  | 2.0e-01 | -1.1e-02  |
|                   | minimum river flow       | [m³s⁻¹]       | no trend  | 1.5e-01 | -1.5e-03  |
|                   | maximum river flow       | [m³s⁻¹]       | increase  | 4.4e-02 | 3.6e-01   |
| Autumn            | mean air temperature     | [C]           | no trend  | 8.5e-01 | -5.0e-03  |
|                   | minimum air temperature  | [C]           | decrease  | 6.2e-03 | -6.9e-02  |
|                   | maximum air temperature  | [C]           | increase  | 1.0e-03 | 6.4e-02   |
|                   | precipitation depth      | [mm]          | no trend  | 5.0e-01 | -2.8e-01  |
|                   | precipitation intensity  | [mm / 60 min] | no trend  | 7.9e-01 | -8.1e-17  |
|                   | precipitation intensity  | [mm / 120 min]| no trend  | 2.1e-01 | -5.0e-03  |
|                   | precipitation intensity  | [mm / 240 min]| no trend  | 7.8e-01 | -4.2e-04  |
|                   | mean river flow          | [m³s⁻¹]       | no trend  | 1.6e-01 | 7.3e-03   |
|                   | minimum river flow       | [m³s⁻¹]       | increase  | 8.0e-03 | 1.7e-03   |
|                   | maximum river flow       | [m³s⁻¹]       | no trend  | 2.8e-01 | 2.9e-02   |
4. Discussion

The mean annual air temperature in the catchment Pöllau was decreasing since 1991 while the annual minima remained constant and maxima were increasing. While the development of minima and maxima is a common consequence of ongoing climate change (e.g. [47,48]), the decreasing long-term development of the annual mean temperature in Pöllau is less often confirmed by the literature (e.g. [23]) as clearly more often rising temperatures are reported (e.g. [15,18,22,49]). It is to be noted that the observed time series in Pöllau covers approximately 30 years and is thus rather short for temperature change detection. It might therefore well be that the time period analysed coincided with a period where warming in the catchment did not occur (see e.g. [50]). This assumption is also confirmed by reports and studies addressing climate change in Austria (e.g. [51–53]).

The reported climate change induced perturbations to precipitation patterns are far more diverse than for the air temperature. Increasing [11,25] and decreasing precipitation rates [23,24] were reported as well as areas were no change was detected [22,23,54]. The mean annual precipitation in Pöllau remained constant between 1979-2019. This observation is confirmed by the Austrian APCC report [51] which reports increasing precipitation for the Austrian alpine areas and a decrease for South-East Austria since the beginning of observations. The catchment Pöllau falls in between these two areas in the Eastern alpine foothills. The seasonal precipitation analysis indicates a shift towards the summer season, for which an increasing trend was observed. The remaining seasons (spring, autumn, winter) showed no significant trend concerning the fallen precipitation 1979-2019. Seasonal shifts in precipitation have been reported also by earlier studies (e.g. [9,10]) but it is to be noted that especially the climate change induced impact on precipitation shows obvious regional differences [51]. The precipitation intensities for the analyzed durations were increasing for the spring and summer. While the summer precipitation depth 1979-2019 was also increasing it remained constant for spring allowing the assumption of a reduction of events and at the same time a higher event precipitation. For the winter and autumn no significant trends were detected as already observed for the precipitation depth in these seasons.

The mean river flow at the gauge A decreased annually as well as for spring and summer, while the minimum flow increased annually and for the autumn and the maximum flow increased for the spring and summer. At the same time the precipitation depth increased only during the summer season and analyzed precipitation intensities during spring and summer. The rather opposite trends for the precipitation depth and the mean river flow indicate that more water is evapotranspirated in the catchment during the warm season and the increasing flow maxima during spring and summer can be due to increasing precipitation intensities at the same seasons. Based on the observed catchment precipitation and runoff the annual catchment evapotranspiration increased between 1981-2016. It is to be noted though that only river flow was used to compute the catchment outlet as subsurface flow data was not available. Despite the simplifications of the used approach this observations are confirmed by several studies reporting similar evapotranspiration trends for the Northern hemisphere [22,27–30].

5. Conclusions

The presented analyses of hydro-meteorological variables observed in a hydrological research basin in Eastern Austria mostly confirm the results of earlier studies and allows the following conclusions:

- The mean annual air temperature in the catchment was decreasing 1991-2019 and while the annual minima remained constant, the annual maxima increased;
- The catchment precipitation showed an increasing trend only for the summer season, while no significant trend was seen for the remaining seasons and the annual precipitation;
- The analyzed precipitation intensities increased for the spring and summer mostly with no significant trends observed for the remaining time periods;
The impact of increasing precipitation intensities is seen in larger river flow maxima during spring and summer;

The computed water balance of precipitation and runoff shows an increase in catchment evapotranspiration especially during spring and summer;

It is to be noted that the datasets used for the analysis cover approximately 30 (temperature) and 40 (precipitation and runoff) years and are thus rather short for climate change detection;

The computed catchment water balance to assess the evapotranspiration is simplified and does not take subsurface flows into account;

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