

Article

Hydro-meteorological trends in an Austrian low-mountain catchment

Gerald Krebs^{1,2} , David Camhy¹  and Dirk Muschalla¹ 

¹ Institute of Urban Water Management and Landscape Water Engineering, Graz University of Technology, Austria; gerald.krebs@tugraz.at; david.camhy@tugraz.at; d.muschalla@tugraz.at

² Institute of Hydraulic Engineering and Water Resources Management, Graz University of Technology, Austria; gerald.krebs@tugraz.at

* Correspondence: gerald.krebs@tugraz.at; Tel.: +43 316 873 8159

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].



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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.

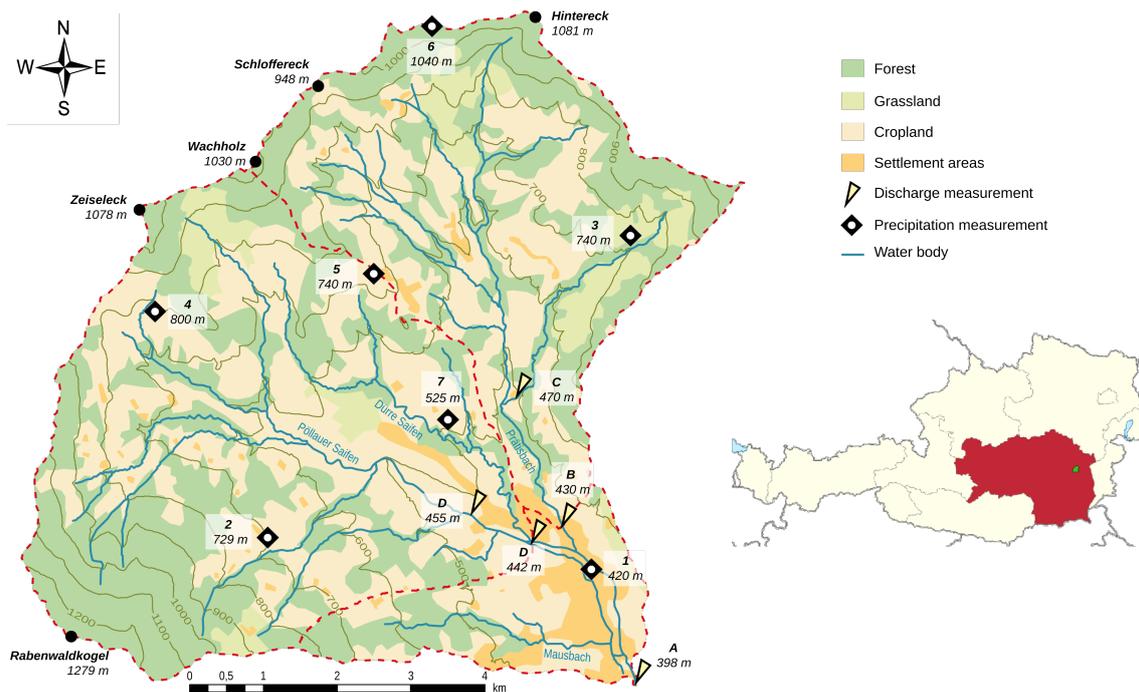


Figure 1. Overview of the catchment *Pöllau* (discharge measurement *A*) with the sub-catchment *Prätisbach* (discharge measurement *B*) in the West and the sub-catchment *Dürre Saifen* (discharge measurement *D*) in the East and the locations of the precipitation measurements.

Table 1. Overview of the catchment properties.

| | |
|---------------------------|--|
| Area | 58.3 km ² |
| 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 | Q_{min} 0.04 m ³ s ⁻¹ ; Q_{max} 92.14 m ³ s ⁻¹ ; Q_{mean} 0.49 m ³ s ⁻¹ ; Mean runoff coefficient 0.31 (1979-2004) |

1 2.2. Data

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

13 The currently operated precipitation gauges are rather symmetrically distributed
 14 over the catchment area and located at elevations between 420-1040 m.a.s.l. Initially, all 7
 15 precipitation gauges were tipping buckets with a resolution of 0.1 mm. Since the year 2011
 16 6 stations have been equipped with rain scales (type Ott *Pluviso*², [39]) operated at a 1 min
 17 recording interval. The currently operated stream gauges monitor the entire catchment

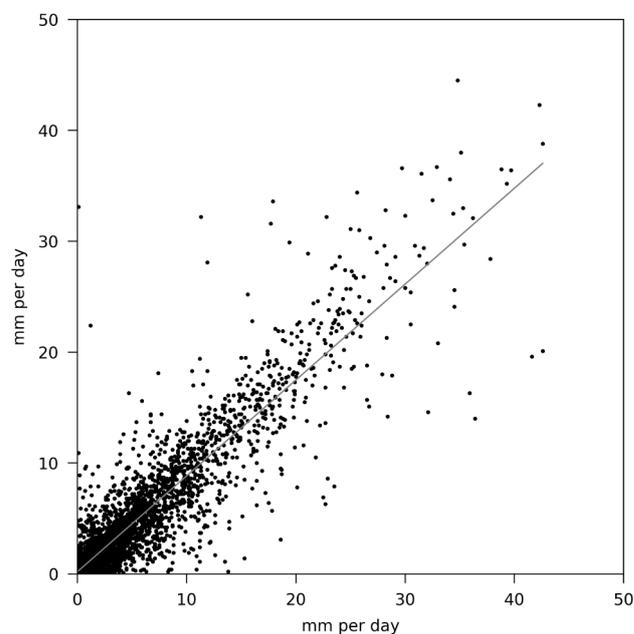
18 outflow (A) and the two main sub-catchments (Figure 1). The stream gauges are equipped
19 with pressure sensors, calibrated with rating curves, and record at a 10-15 min interval.

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 | <i>WL, WT</i> | 1980- |
| B | 415 | <i>WL, WT</i> | 1980- |
| C | 418 | <i>WL, WT</i> | 1988-1997, 2000-2007 |
| D | 455 | <i>WL, WT</i> | 1997-2005, 2018- |
| 1 | 424 | <i>P</i> | 1979- |
| 2 | 729 | <i>P</i> | 1980- |
| 3 | 740 | <i>P</i> | 1980- |
| 4 | 800 | <i>P</i> | 1980- |
| 5 | 740 | <i>P</i> | 1980- |
| 6 | 1040 | <i>P</i> | 1980- |
| 7 | 525 | <i>P, T, p, rH, Ra, ST, SM, WS, WD</i> | 1980- |

20 2.3. Data validation

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



correlation.pdf

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

26 The validation steps (i)-(vi) were applied for the rainfall and discharge observations.
27 The comparison of daily precipitation observations after validation shows a good corre-
28 lation (Pearson correlation 0.91) allowing the conclusion that the seven stations mostly
29 recorded similar values (Figure 2). The discharge measurements were validated using
30 cumulative sums of the available gauges. An inter-stationary validation for the temperature
31 data was not directly possible, as this variable is recorded at only one location within the

32 catchment. However, the general observed pattern was compared with regionally available
33 temperature observations for consistence.

34 2.4. Data analysis

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

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

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

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

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

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

$$ET = P - R \quad (1)$$

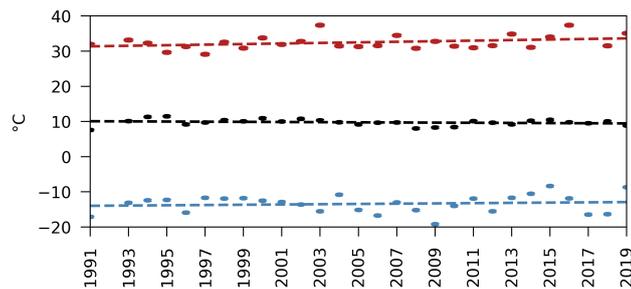
62 where *ET* is the evapotranspiration [mm], *P* is the observed catchment precipitation [mm],
63 and *R* is the observed catchment runoff [mm].

64 3. Results

65 3.1. Temperature trends

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

70 While the development of the annual minima shows no significant trend, annual
71 temperature maxima were increasing between 1991-2019. The mean annual minimum
72 1991-2019 is -13.4C with the lowest recording in 2009 (-19.2C) and the highest recording in
73 2015 (-8.3C). The mean annual maximum 1991-2019 is 32.5C with the lowest recording in
74 1997 (29.1C) and the highest recording in 2003 and 2016 (37.4C) (Figure 3).

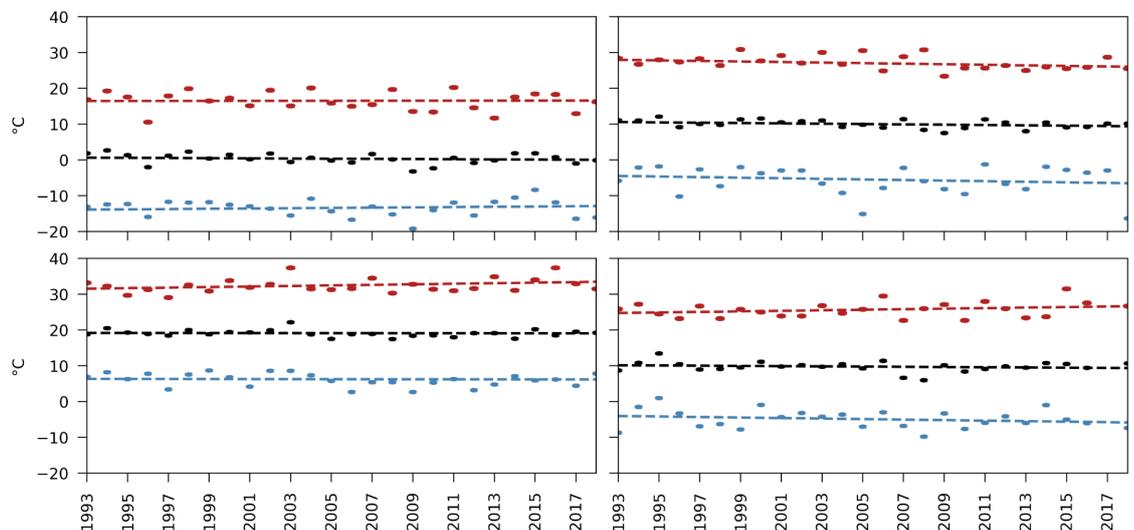


air temperature.png

Figure 3. Annual mean (black), maxima (red) and minima (blue) of the air temperature and their trends 1979-2019.

75 The mean winter temperature between 1991-2019 is 0.3C shows a decreasing trend
 76 with the lowest value recorded in 2009 (-3.2C) and the highest recording in 1994 (2.7C).
 77 Both the winter minima (mean of -13.4C with the lowest recording in 2009 (-19.2C) and the
 78 highest recording in 2015 (-8.3C)) and maxima 1991-2019 (mean of 16.5C with the lowest
 79 recording in 1996 (10.6C) and the highest recording in 2011 (20.3C)) show no significant
 80 trend (Figure 4 top left).

81 The mean spring temperature between 1991-2019 is 10.0C shows a similarly decreasing
 82 trend as observed for the winter. The lowest mean was recorded in 2009 (7.6C) and the
 83 highest recording in 1995 (12.1C). The trend of the spring minima is decreasing around a
 84 mean minimum of -5.5C with the lowest recording in 2018 (-16.3C) and the highest record
 85 observed in 2011 (-1.2C). The trend of the spring maxima 1991-2019 is also decreasing
 86 around 27.0C with the lowest recording in 1991 (23.1C) and the highest recording in 1999
 87 (30.9C) (Figure 4 top right).



air temperature.pdf

Figure 4. Mean (black), maxima (red) and minima (blue) of the air temperature and the trend 1979-2019 for the winter (top left), spring (top right), summer (bottom left), and autumn (bottom right).

88 The mean temperature during the summer between 1991-2019 shows no trend staying
 89 at 19.9C with the lowest recording in 2008 (17.5C) and the highest recording in 2003 (22.2C).
 90 The trend of the summer minima is also not significant at 6.3C with the lowest recording in
 91 2006 (2.7C) and the highest recording in 2019 (12.7C). The trend of the summer maxima
 92 1991-2019 is increasing around 35.5C with the lowest recording in 1997 (29.1C) and the
 93 highest recording in 2003 and 2016 (37.4C) (Figure 4 bottom left).

94 The trend of the mean autumn temperature 1991-2019 is not significant around 9.8C
 95 with the lowest recording in 2008 (6.0C) and the highest recording in 1995 (13.4C). The

96 trend of the autumn minima is decreasing around -4.9C with the lowest recording in
 97 2008 (-9.8C) and the highest recording in 1995 (1.0C). The trend of the autumn maxima
 98 1991-2019 is increasing around 25.7C with the lowest recording in 2010 (22.7C) and the
 99 highest recording in 2015 (31.5C) (Figure 4 bottom right). A comprehensive summary of
 100 the observed temperature trends including statistical trend properties is given in Table 3.

101 3.2. Precipitation trends

102 3.2.1. Precipitation depth

103 The mean annual precipitation shows no significant trend between 1979-2019 around
 104 608.9 mm with the maximum mean recorded in 2014 (807.2 mm) and the minimum recorded
 105 in 2001 (364.3 mm). The annual maximum at a single station was recorded in 1996 at 4
 106 (829.2 mm) and the annual minimum in 2001 at 7 (340.4 mm).

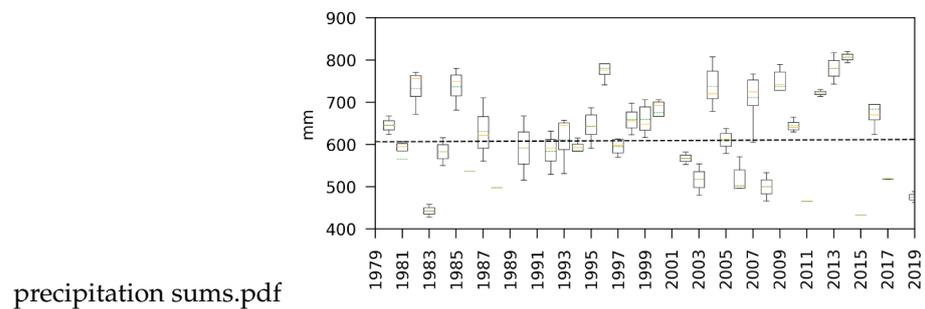


Figure 5. Annual precipitation of the 7 stations (25% and 75% percentile, mean (green), median (orange)) and trend 1979-2019 (dashed line).

107 The seasonal precipitation 1979-2019 shows an increasing trend for the summer (June,
 108 July, August) while no significant trend was detected for the spring (March, April, May),
 109 the autumn (September, October, November), and the winter (December, January, February)
 110 1979-2019 (Figure 6).

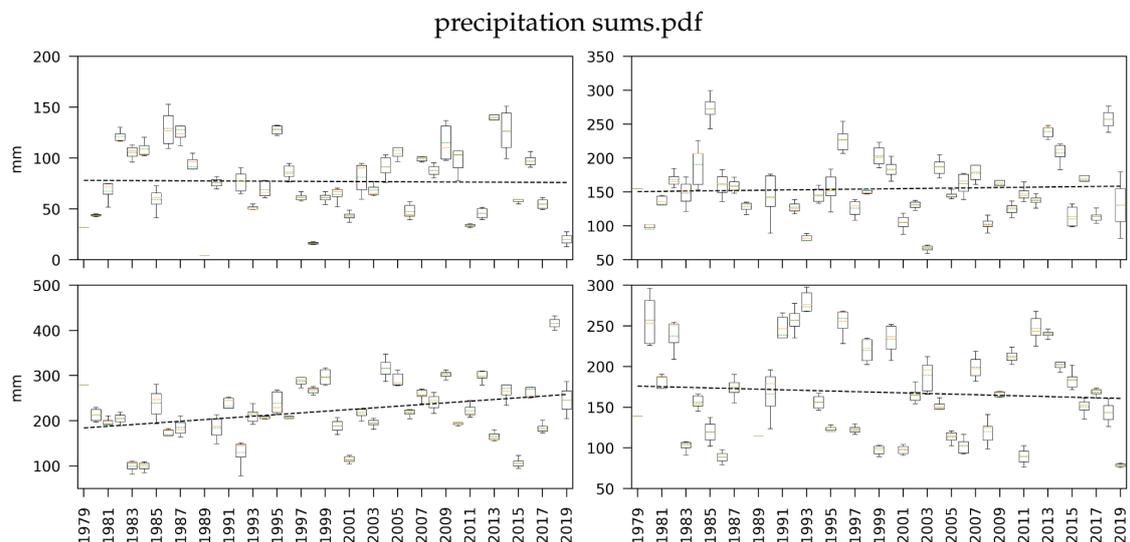


Figure 6. Precipitation of the 7 stations (25% and 75% percentile, mean (green), median (orange)) and trend 1979-2019 (dashed line) for winter (top left), spring (top right), summer (bottom left), and autumn (bottom right).

111 The mean winter precipitation in the catchment 1979-2019 was 73.3 mm with the
 112 highest recording in 2013 (139.5 mm) and the lowest recording in 1998 (16.3 mm) (Figure
 113 6 top left). The mean precipitation falling in the winter season accounted for 12% of the
 114 mean annual precipitation 1979-2019.

115 The mean spring precipitation accounted with 151.9 mm for 25% of the mean annual
 116 precipitation 1979-2019. The largest spring precipitation was recorded in 1985 (272.5 mm)
 117 and the smallest in 2003 (66.7 mm) (Figure 6 top right).

118 The mean summer precipitation shows a clearly increasing trend around 222.0 mm
 119 accounting for 36% of the mean annual precipitation 1979-2019. The largest summer
 120 precipitation was recorded in 2018 (416.4 mm) and the smallest value was recorded in 1984
 121 (99.1 mm) (Figure 6 bottom left).

122 The mean autumn precipitation 1979-2019 was around 168.2 mm accounting for 27%
 123 of the mean annual precipitation. The largest autumn precipitation was recorded in 1993
 124 (273.5 mm) and the smallest precipitation in 2019 (78.7 mm) (Figure 6 bottom right).

125 3.2.2. Precipitation intensities

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

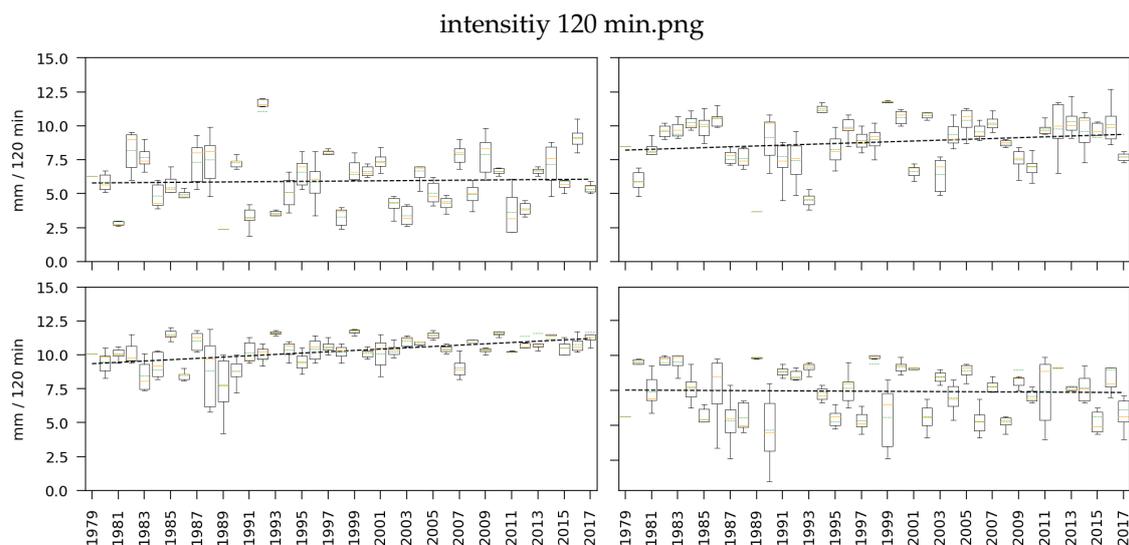


Figure 7. Seasonal maximum precipitation intensities for 120 minutes of the 7 stations (25% and 75% percentile, mean (green), median (orange)) and the trend 1979-2017 (dashed line).

135 3.3. River flow trends

136 The annual mean flow 1981-2016 at the catchment outlet A shows a decreasing trend
 137 around $1.10 \text{ m}^3 \text{ s}^{-1}$ with the maximum mean flow observed in 1998 ($3.01 \text{ m}^3 \text{ s}^{-1}$) and the
 138 minimum mean flow observed in 2016 ($0.12 \text{ m}^3 \text{ s}^{-1}$) (Figure 8 left).

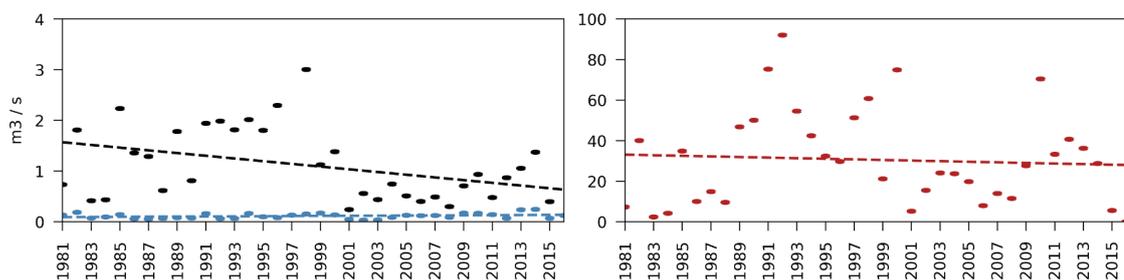
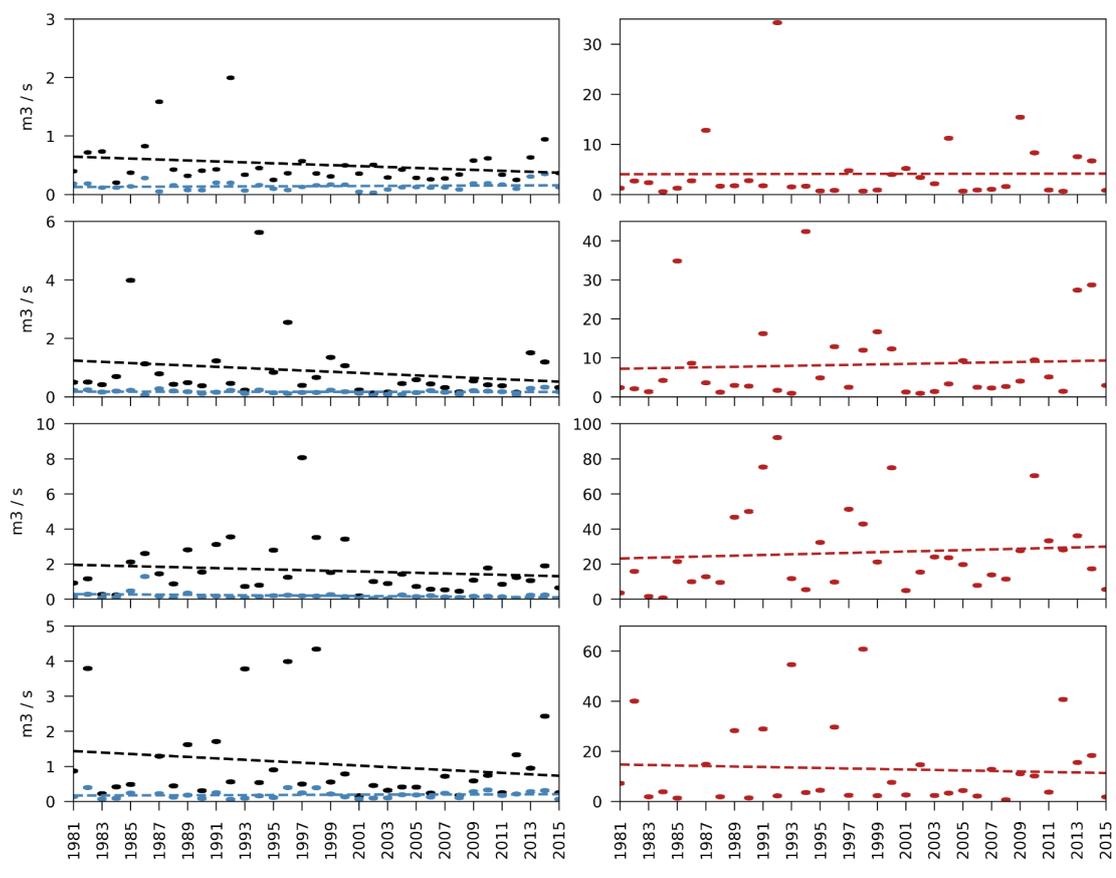


Figure 8. Annual mean (black), minimum (blue) and maximum (red) flow at Saifenbach and linear trends 1981-2016.

139 The observed mean annual minimum flow was increasing 1981-2016 around 0.11
 140 m^3s^{-1} with the smallest recording in 2002 ($0.03 \text{m}^3\text{s}^{-1}$) and the largest recording in 2014
 141 ($0.24 \text{m}^3\text{s}^{-1}$) (Figure 8 left). The observed mean annual maximum flow showed no signifi-
 142 cant trend 1981-2016 around $31.10 \text{m}^3\text{s}^{-1}$ with the largest observation in 1992 ($92.14 \text{m}^3\text{s}^{-1}$)
 143 and the smallest observation in 2015 ($5.61 \text{m}^3\text{s}^{-1}$) (Figure 8 right).

144 The mean winter flow 1981-2016 shows, as already observed for the annual flow, a
 145 decreasing trend around $0.51 \text{m}^3\text{s}^{-1}$ with the lowest observation in the winter 2016 (0.12
 146 m^3s^{-1}) and the largest observation in the winter 1992 ($1.99 \text{m}^3\text{s}^{-1}$). The minimum winter
 147 flow showed no significant trend 1981-2016 around $0.14 \text{m}^3\text{s}^{-1}$ with the lowest flow in
 148 2002 ($0.03 \text{m}^3\text{s}^{-1}$) and the largest minimum in 2014 ($0.35 \text{m}^3\text{s}^{-1}$). The maximum winter
 149 flow also remained constant 1981-2016 at $4.11 \text{m}^3\text{s}^{-1}$ with the highest flow recorded in
 150 1992 ($34.28 \text{m}^3\text{s}^{-1}$) and the lowest maximum in 1984 ($0.58 \text{m}^3\text{s}^{-1}$) (Figure 9 top).



flow.pdf

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).

151 The mean spring flow 1981-2016 was decreasing around $0.88 \text{m}^3\text{s}^{-1}$ with the lowest
 152 mean in 2002 ($0.13 \text{m}^3\text{s}^{-1}$) and the largest mean recorded in 1994 ($5.62 \text{m}^3\text{s}^{-1}$). The mean
 153 minimum spring flow shows no trend at $0.17 \text{m}^3\text{s}^{-1}$ with the lowest flow occurring in 2014
 154 ($0.33 \text{m}^3\text{s}^{-1}$) and the highest minimum observed in 2002 ($0.05 \text{m}^3\text{s}^{-1}$). The mean maximum
 155 spring flow was increasing 1981-2016 around $8.27 \text{m}^3\text{s}^{-1}$ with the largest recording in 1994
 156 ($42.42 \text{m}^3\text{s}^{-1}$) and the smallest recording in 1993 ($0.91 \text{m}^3\text{s}^{-1}$) (Figure 9 2nd from top).

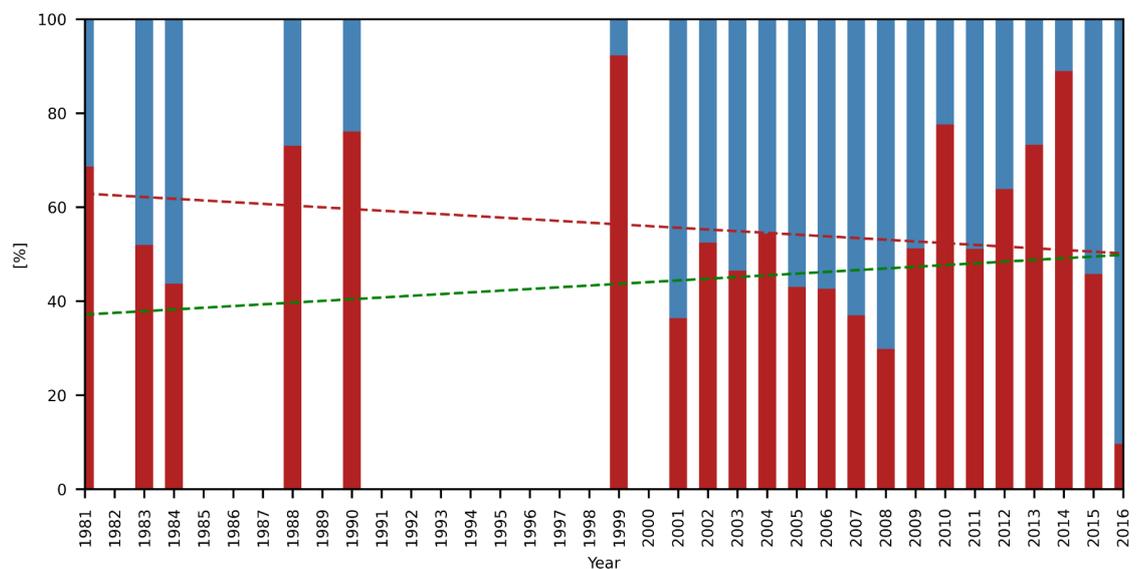
157 The mean summer flow 1981-2016 remained constant around $1.64 \text{m}^3\text{s}^{-1}$ with the
 158 largest summer mean flow observed in 1997 ($8.07 \text{m}^3\text{s}^{-1}$) and the lowest mean in the
 159 summer 2001 ($0.19 \text{m}^3\text{s}^{-1}$). The summer minimum shows no trend 1981-2016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

163 The mean autumn flow showed no trend 1981-2016 around $1.08 \text{ m}^3 \text{ s}^{-1}$ with the lowest
 164 mean recorded in 2001 ($0.16 \text{ m}^3 \text{ s}^{-1}$) and the largest mean occurring in 1998 ($4.35 \text{ m}^3 \text{ s}^{-1}$).
 165 The autumn minimum decreased around $0.19 \text{ m}^3 \text{ s}^{-1}$ with the smallest flow recorded in
 166 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
 167 autumn flow remained constant 1981-2016 around $13.04 \text{ m}^3 \text{ s}^{-1}$ with the smallest maximum
 168 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
 169 bottom). A comprehensive summary of the observed runoff trends including statistical
 170 trend properties is given in Table 3.

171 3.4. Water balance and evapotranspiration

172 Particularly in the 1990's the flow measurements at A have large gaps preventing
 173 the computation of annual flow volumes. Thus, 22 years were available to assess the
 174 evapotranspiration based on precipitation and catchment runoff (Figure 10). The mean
 175 runoff fraction of the water balance 1981-2016 was 55% showing a decreasing trend. It is to
 176 be noted though that less data was available for the time period 1981-2000 (6 years) than
 177 for the period 2001-2016 (16 years). The highest runoff fraction was observed in the year
 178 1999 with 92% while the lowest fraction occurred in 2016 with only 10%. In absolute values
 179 the catchment runoff ranged between 67-743 mm with a mean of 338 mm per year.

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



Water balance.pdf

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.

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 | [m ³ s ⁻¹] | decrease | 4.2e-03 | -2.4e-02 |
| | minimum river flow | [m ³ s ⁻¹] | increase | 5.2e-03 | 1.0e-03 |
| | maximum river flow | [m ³ s ⁻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 | [m ³ s ⁻¹] | decrease | 3.2e-03 | -5.0e-03 |
| | minimum river flow | [m ³ s ⁻¹] | no trend | 4.6e-01 | 3.0e-04 |
| | maximum river flow | [m ³ s ⁻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 | [m ³ s ⁻¹] | decrease | 1.1e-03 | -9.0e-03 |
| | minimum river flow | [m ³ s ⁻¹] | no trend | 2.4e-01 | -9.0e-04 |
| | maximum river flow | [m ³ s ⁻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 | [m ³ s ⁻¹] | no trend | 2.0e-01 | -1.1e-02 |
| | minimum river flow | [m ³ s ⁻¹] | no trend | 1.5e-01 | -1.5e-03 |
| | maximum river flow | [m ³ s ⁻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 | [m ³ s ⁻¹] | no trend | 1.6e-01 | 7.3e-03 |
| | minimum river flow | [m ³ s ⁻¹] | increase | 8.0e-03 | 1.7e-03 |
| | maximum river flow | [m ³ s ⁻¹] | no trend | 2.8e-01 | 2.9e-02 |

185 4. Discussion

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

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

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

227 5. Conclusions

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

- 231 • The mean annual air temperature in the catchment was decreasing 1991–2019 and
232 while the annual minima remained constant, the annual maxima increased;
- 233 • The catchment precipitation showed an increasing trend only for the summer sea-
234 son, while no significant trend was seen for the remaining seasons and the annual
235 precipitation;
- 236 • The analyzed precipitation intensities increased for the spring and summer mostly
237 with no significant trends observed for the remaining time periods;

- 238 • The impact of increasing precipitation intensities is seen in larger river flow maxima
- 239 during spring and summer;
- 240 • The computed water balance of precipitation and runoff shows an increase in catch-
- 241 ment evapotranspiration especially during spring and summer;
- 242 • It is to be noted that the datasets used for the analysis cover approximately 30 (tem-
- 243 perature) and 40 (precipitation and runoff) years and are thus rather short for climate
- 244 change detection;
- 245 • The computed catchment water balance to assess the evapotranspiration is simplified
- 246 and does not take subsurface flows into account;

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 249 Krebs; Methodology, Gerald Krebs and David Camhy; Project administration, Gerald Krebs and
 250 Dirk Muschalla; Supervision, Dirk Muschalla; Validation, Gerald Krebs, David Camhy and Dirk
 251 Muschalla; Visualization, Gerald Krebs; Writing – original draft, Gerald Krebs; Writing – review
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