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The impact of regional and catchment characteristics on long-term runoff in small agricultural catchments in Latvia

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ABSTRACT

The explanation of runoff behavior is challenging due to variable weather conditions, and catchment characteristics. The parameter equifinality in catchment-scale models turns into the uncertain distribution of water balance components even though models tend to represent total runoff well. This study aims to discuss long-term runoff and evapotranspiration (ET) variations affected by regional allocation and catchment characteristics in Latvia. The study applies the observational runoff data from drainage fields and small catchment scales. The sites represent the spatially different regions in Latvia with relatively variable yearly precipitation amounts. The robust data of surface slope gradients, the share of subsurface drainage systems, arable and grasslands, and ditch networks describes the differences in the catchment characteristics. The results reveal that higher long-term yearly average runoff and ET rates are experienced by the regions with higher yearly precipitation amounts. Simultaneously, the higher the long-term yearly average precipitation and steeper the surface slope gradient, the proportionally (%) higher is the runoff contribution into the water balance. When compared with the small catchments, the soil profiles at drainage fields might store more water after the subsurface drainage runoff is running short. Consequently, the small catchments might experience the later response of subsurface drainage runoff after the dry seasons.

Key words: evapotranspiration, precipitation, runoff, surface slope gradient, water balance

HIGHLIGHTS

- This study quantifies the impacts of regional allocation and site-specific catchment characteristics on the variations in long-term and yearly runoff and ET rates
- The results will be further practically applied for regionalization of model parameters and validation of simulated runoff and ET rates.
- Results will enable planning of appropriate nutrient mitigation measures in poorly or ungauged catchments.

INTRODUCTION

The concept of water balance is the fundament that is extensively applied for various tasks demanding a description of moisture dynamics at multiple spatiotemporal scales. Water balance and water transport affect cycling and transformations of nutrients into the soil profile and landscape. Therefore, hydrological response units (HRUs) are subdivided while interconnected within the domain of catchment modeling tools for hydrological process and nutrient transfer simulations (Neitsch *et al.* 2002; Lindström *et al.* 2010; Arheimer *et al.* 2012).

Water and nutrient balance interconnects individual catchments into the ecosystems having an essential impact on freshwater and marine ecosystems. Excessive nutrient loading is a crucial issue affecting inland and marine water quality nowadays. Excessive nutrient loading in combination with changing precipitation and air temperature patterns, as evidence of climate change, promotes degradation of marine ecosystems in terms of harmful algal blooms, hypoxia, and acidification (Griffith & Gobler 2020). Multiple nutrient mitigation measures have been tested and implemented in streams and rivers across Europe. However, individual measures may have different effects on the water quality indicators. The water quality improvements can vary due to the constructive design of the measure (Povilaitis *et al.* 2018), meanwhile being considerably affected by regional climate conditions and catchment characteristics (Carolus *et al.* 2020; Carstensen *et al.* 2020). Some of the water quality indicators may worsen after the measure is implemented. For example, the inorganic nitrogen and total phosphorus concentrations were higher while the loads were reduced at the outflow of controlled drainage in contrast to conventionally tile-drained fields (Povilaitis *et al.* 2018).

The combinations in regional climate dynamics, catchment characteristics, and land management practices are site specific and control hydrological and nutrient pathways within the catchments. Therefore, hydrological pathways should be considered when choosing appropriate nutrient mitigation measures as those considerably affect nutrient leaching (Deelstra *et al.* 2014; Jiang *et al.* 2014). The hydrological pathways might substantially affect leaching processes as the nutrient content varies within the depth of the soil profile (Povilaitis *et al.* 2018). In addition, the runoff components have different residence times into the field, thus also affecting nutrient retention (Jiang *et al.* 2014).

The hydrological processes and dynamics in terms of contribution of runoff components to streamflow reflect interactions between regional climate conditions and catchment characteristics. For example, the high share of forests in the catchment area reduces the snowmelt intensity while the other regions can experience an opposite effect (Lundquist *et al.* 2013). The increased soil moisture may reduce infiltration capacity (Jones 1976; Wu *et al.* 2016), provoking surface runoff and increasing availability of water for evaporation (Jones 1976). Wyatt *et al.* (2020) demonstrated that soil water content controls runoff partitioning and considerably affects flood possibilities. However, the flood possibilities are considerably dependent on the combining effect of existing soil moisture, snow accumulation and melt processes, and rainfall intensity. For example, runoff coefficients increase in line with rainfall intensity (Sinha *et al.* 2016). The runoff coefficients tend to be lower in relatively flat catchments. ET increases in relatively low slope gradient conditions (Boldini *et al.* 2014), while groundwater flow decreases (Richardson & Vepraskas 2000; Mu *et al.* 2015).

The components contributing to water and nutrient balance are rather known, while it is still challenging to quantify these for individual sites. In order to increase precision and details, hydrological processes are investigated at different scales (Mašíček *et al.* 2012; Mu *et al.* 2015; Mayerhofer *et al.* 2017). The experience from small-scale and modeling approaches is extensively applied for understanding processes, forecasts, and action planning requirements. However, the models should be set up and calibrated upon the existing knowledge and measurement results describing hydrological processes and runoff behavior. Otherwise, the models can represent hydrological processes inadequately and experience parameters equfinality. For example, different sets of parameters applied in the model may similarly represent streamflow (Wi *et al.* 2015; Hundecha *et al.* 2016). The parameters equifinality issue appears even in simulations of relatively well-investigated catchments, the modeling results obtained are also affected by the strategy used for model calibration (Kittel *et al.* 2020).

The streamflow data and other observational data can be applied to improve the process representation and reduce uncertainties related to parameters used in the calibration procedure. For example, the simulated ET and runoff representation in the modeling results is improved and parameters' uncertainties are reduced when observational data of vegetation biophysical parameters and ET are considered in the model calibration process (Rajib *et al.* 2018). Wagener *et al.* (2001) revealed that additional measurements such as groundwater variables and stream salinity may address equifinality problems. The application of soil moisture measurements may also substantially improve the model performance and streamflow forecasts (Wyatt *et al.* 2020).

Well-calibrated parameters can be used for building up the model domain of poorly or ungauged catchments. There are still discussions for the best practice of parameter transfer and regionalization. The model parameters can transfer between similar HRUs (Kittel *et al.* 2020), between catchments with similar characteristics (Hundecha *et al.* 2016), or between neighboring tributaries (Kittel *et al.* 2020). Our modeling experience involves the simulations of runoff and nutrient leaching processes (Abramenko *et al.* 2013; Veinbergs *et al.* 2017; Carolus *et al.* 2020). The modeling results show weaknesses such as low density of streamflow gauging network and lack of information on soil physical parameters. Our experience also indicates that the best practice for subdividing landscape characteristics into the HRUs is rather unclear. Multiple calibration approaches resulted in a very good representation of streamflow with substantially different contributions of simulated runoff components. It is challenging to estimate which set of calibrated parameters represent actual processes and are applicable for ungauged or poorly gauged catchment. It is noted that some parameters may absorb the errors caused by other parameters calibrated (Jones 1976; Kittel *et al.* 2020).

This study aims to estimate the impacts of regional allocation and site-specific catchment characteristics on the variations in long-term and yearly runoff and ET rates. The case areas represent climatically and hydrologically distinctive regions in Latvia where measurements have been carried out at the small catchments and subsurface drainage fields. The results will be further practically applied for regionalization of model parameters and validation of simulated runoff and ET rates in poorly or ungauged catchments.

MATERIALS AND PROCEDURES

During this study, runoff, ET, and precipitation rates were quantified on long-term and yearly basis. The impact of regional allocations and catchment characteristics were estimated based on the observational study results. The following set of criteria was considered to select the study sites: (1) located in different regions; (2) daily average precipitation and runoff data covered the same time period of at least twenty years; (3) scales of measurements included subsurface drainage field and small catchment. The agricultural runoff monitoring sites of Berze, Mellupite, and Vienziemite met the selected criteria, besides these sites can be considered as representative and well-investigated catchments in Latvia.

Data sets

The observational data sets of daily precipitation and runoff from 01.01.1995 to 31.12.2019 were used. The precipitation data were obtained from the meteorological stations located nearby or at the study sites, including Dobele, Mellupite, and Zoseni, as partly collected by *Latvia University of Life Sciences and Technologies* and State Limited Liability Company *Latvian Environment, Geology and Meteorology Centre* (LVGMC). The observed runoff data represents the hydrological processes at the small catchment (ditch) and drainage field (subsurface drainage system) scales. For land-use description, geospatial information was collected from the data sets of *Corine Land Cover 2012* (Geospatial information service of Latvia 2012). The surface slope gradients were determined from the digital elevation model with a spatial resolution of 30 meters by 30 meters as obtained from the *Space Shuttle Radar Topography Mission* (SRTM) (Farr *et al.* 2007). The data on water management systems were obtained from the digital cadaster of land management systems in Latvia (ZMNI 2019). Soil types were determined from the previous study (Jansons *et al.* 2011).

Site description

The monitoring stations of Berze and Mellupite (Figure 1) are situated in somewhat similar climatic conditions, while the climate at the Vienziemite monitoring station is more continental (Lauva *et al.* 2012). All stations represent a humid climate zone with four seasons, such as Winter, Spring, Summer, and Autumn. In some years, winter experiences permanent snow cover with low-flow periods, while the snow melts are often in the next year. Springs usually come with runoff maximums due to intensive snowmelts. In summers, runoff minimums are characteristic and even no runoff within small-scale streams and subsurface drainage systems due to air moisture deficits and declined groundwater tables. Autumns come with low ET rates and high flow conditions.

Each monitoring station represents both small catchment and drainage field scales of measurements. The catchment characteristics, including the area, land-use, surface slope gradients, length of stream network, subsurface drainage system's network, are the main characteristics that distinguish each monitoring station's small catchment and drainage field (Table 1).

The drainage field scale has no baseflow contribution in the total runoff compared to the small catchment scale. In contrast to Berze, the land-use is diverse, with a predominance of arable lands and forests at the Mellupite's and Vienziemite's small catchments. The share of lands with implemented subsurface drainage systems is similar at the small catchments of Mellupite and Vienziemite, while much more intense at the Berze catchment. A previous study showed that the share of forests and agricultural area was relatively stable from 1971 until 2016 at the Vienziemite small catchment (Apsīte *et al.* 2017). Land-use over the drainage fields in each monitoring station is homogenous, with subsurface drainage systems implemented in the whole contributing area. However, the Vienziemite drainage field is covered by grasslands, while arable land is present at the drainage fields of Berze and Mellupite.

The results of observations at the Berze monitoring station represent lowland conditions in the central part of Latvia that experiences one of the lowest yearly rainfall and runoff amounts and highest yearly average temperatures in the country (Lagzdins *et al.* 2012). The relatively homogenous catchment characteristics in Berze allows assessment of the impact of subsurface drainage and other specific catchment characteristics on ET and runoff generation. Mellupite represents the western and Vienziemite the eastern part of Latvia. Vienziemite is allocated in the Vidzeme region with rather hilly conditions for the Baltic countries. This results in the highest elevation

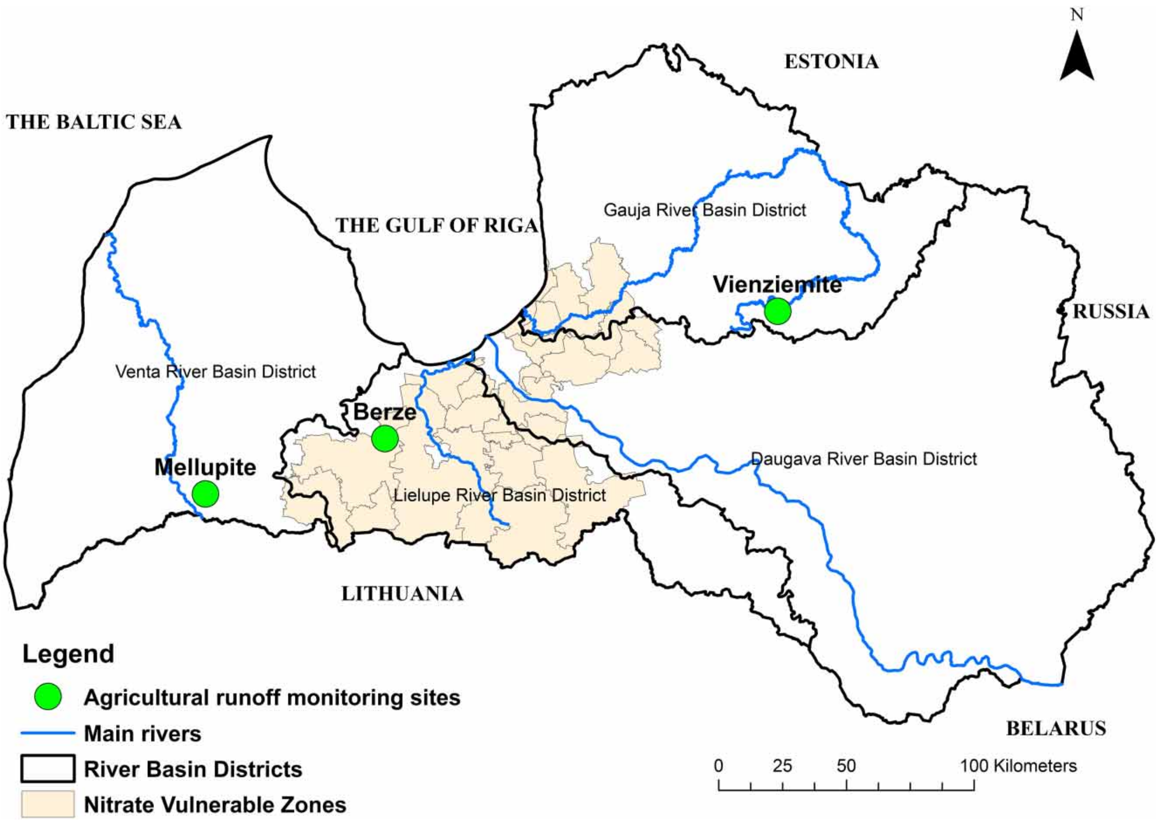

Figure 1 | Location of the agricultural monitoring sites of Berze, Mellupite, and Vienziemite.

Table 1 | Characteristics of monitoring stations

Station	Measurement scale	Area, ha	Main soil type[a]	Land-use, % Forests	Land-use, % Grass-lands	Land-use, % Arable	Subsurface drainage, %	Slope gradient, %
Berze	Small catchment	368	Calcric Cambisol Inceptsol Silty Clay Loam	2		98	98	0.55
	Drainage field	77		0	0	100	100	0.69
Mellupite	Small catchment	960	Stagnic Luvisol Loam, Clay Loam	32	68		55	0.93
	Drainage field	12		0	0	100	100	1.34
Vien-ziemite	Small catchment	592	Chromic Cambisol Sandy Loam	31	69		51	4.37
	Drainage field	67		0	100	0	69	3.7

[a]FAO soil classification (Jansons *et al.* 2011).

and surface slope gradients in contrast to Berze and Mellupite. Vienziemite experiences the highest long-term average precipitation and runoff with the lowest temperature (Lagzdins *et al.* 2012).

The monitoring activities are carried out at the Berze, Mellupite, and Vienziemite stations as part of the national agricultural runoff monitoring programme. Detailed description and assessment of hydrological processes within these catchments are essential for understanding, forecasting, and extrapolating knowledge across agriculture-dominated catchments in Latvia. This knowledge can be applied for practical planning of appropriate nutrient mitigation measures and can support setting up parameter restrictions in hydrological modeling tools.

Statistical methods

This study compares long-term water balance and runoff behavior at different temporal and measurement scales. The observed daily average runoff data were applied for the calculations described further in the text. The contribution of the long-term water balance components (1), (2), and (4) was used for the representation of both the regional specifics in the context of different allocation of monitoring stations and the impact of local catchment characteristics. However, the percentage of ET (3) and runoff (5) better demonstrate the local impact on water apportionment in the catchment. The long-term yearly average precipitation was calculated as follows:

$$\bar{P} = \frac{\sum_{i=1}^{n} P_{di}}{n_y}, \text{ mm/year} \tag{1}$$

where P_{di} is a sum of precipitations in an ith day, mm; n is the total number of days in the data set; n_y is the total number of years in the data set.

Equations (2) and (3) were applied for the long-term yearly average ET calculations.

$$ET = \bar{P} - \bar{Q}_y, \text{ mm/year} \tag{2}$$

$$ET_{\%} = \frac{(\bar{P} - \bar{Q}_y) \times 100}{\bar{P}}, \% \tag{3}$$

The long-term yearly average runoff represents the overall differences between streamflow and subsurface drainage runoff and differences caused by regional allocation. The observed long-term yearly average runoff for each drainage field and small catchment was calculated as follows:

$$\bar{Q}_y = \frac{\sum_{i=1}^{n} Q_{di}}{n_y}, \text{ mm/year} \tag{4}$$

where Q_{di} is an average runoff in an ith day, mm.

$$\bar{Q}_{y\%} = 100 - ET_{\%}, \% \tag{5}$$

The statistics of the Nash-Sutcliffe efficiency coefficient (NSE) (6) and Percent bias (7) (Moriasi *et al.* 2007) were used to compare the difference between runoff from small catchments and drainage fields in each monitoring station. The statistics were applied on a monthly average and yearly average runoff data to demonstrate relationships at different temporal scales for each monitoring station.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n} (Q_{xi}^{dr} - Q_{xi}^{sm})^2}{\sum_{i=1}^{n} (Q_{xi}^{dr} - \bar{Q}_x)^2}\right] \tag{6}$$

where Q_{xi}^{dr} is runoff from drainage field whether Q_{y_i} or Q_{m_i} was applied in calculations; Q_{xi}^{sm} is runoff from small catchment whether Q_{y_i} or Q_{mL_i} was applied in calculations; $\bar{Q}_x$ is average runoff from drainage field whether $\bar{Q}_y$ or $\bar{Q}_m$ was applied in calculations.

$$PBIAS = \left[\frac{\sum_{i=1}^{n} (Q_{xi}^{dr} - Q_{xi}^{sm}) \times 100}{\sum_{i=1}^{n} Q_{xi}^{dr}}\right] \tag{7}$$

The dominant groundwater discharge area (8) and its share in the catchment area (9) were calculated based on the methodology presented in the Latvian Building normative (Cabinet of Ministers 2015). The theoretical 60 m wide cross-sections were applied for 1.2 m deep ditches, which regulate moisture conditions at the field of loamy soils. The actual depth of the ditches was not investigated within the study sites. Therefore, Equations (8) and (9) can be utilized to generalize and demonstrate groundwater flow contribution into the streamflow.

$$A_{GW} = 0.006L, \text{ ha} \quad (8)$$

$$A_{GW} = \frac{0.6L}{A_{sc}}, \% \quad (9)$$

where L is a total stream length in the small catchment, m; A_{sc} is an area of small catchment, ha.

RESULTS AND DISCUSSION

In this study's monitoring stations, the runoff behavior is affected by seasonal meteorological forces in the relationship with different catchment characteristics and regional catchment allocation. Consequently, temporary and spatially variable hydrological partitioning might affect the runoff. We can expect profound ET and groundwater flow control over the small catchment's runoff rates during the low flow period. The subsurface drainage and surface runoff components control the runoff from drainage fields and small catchments during the relatively wet periods. The Hydrological predictions for the environment (HYPE model) developers reveal that soil types and land-use are the catchment characteristics that have a predominant impact on the hydrological processes (Arheimer *et al.* 2012; Hundecha *et al.* 2016). Furthermore, the water management systems considerably affect the migration of soil moisture(Šķiņķis 1986; van Aart *et al.* 1994; Deelstra *et al.* 2014). Regionally, the precipitations substantially affect the yearly average runoff (Merz *et al.* 2006). Meanwhile, the air temperature and precipitation relationship have been observed in monitoring sites in Latvia. Povilaitis (2015) reveals that the positive air temperatures during the winter lead to runoff increase during the winter while decreasing during the spring in Lithuania, which experiences permanent snowcover during the winters.

Long-term water balance

This study shows that regional allocation predominantly affects the long-term water balance. The highest total amount of long-term average precipitation, ET, and runoff was observed at Vienziemite (Table 2). All of the stated components were at the lowest rate at Berze. This indicates that the total amount of long-term ET and runoff is higher in the regions with relatively higher precipitation. The combined data sets from Berze, Mellupite, and Vienziemite show that a yearly precipitation increase by 1.0 mm resulted in a 0.54 mm increase in runoff and a 0.46 mm increase in ET (Figure 2). The results show that precipitation controls the total runoff and ET rates predominantly. Similarly, Kittel *et al.* (2020) accentuate that precipitation is the key factor determining the water balance. The runoff is expected to increase together with precipitation rates (Merz *et al.* 2006; Sinha *et al.* 2016). Therefore, the observed yearly average precipitation and ET amounts may be considered for validating the models in poorly and ungauged catchments.

Table 2 | Long-term water balance at the monitoring stations of Berze, Mellupite, and Vienziemite from 1995 to 2019

		Berze		Mellupite		Vienziemite	
Water balance component	**Unit**	**Small catchment**	**Drainage field**	**Small catchment**	**Drainage field**	**Small catchment**	**Drainage field**
Precipitation ($\bar{P}$)	mm	565.7		665.2		704.7	
Evapotranspiration	mm	405.4	395.3	422.4	423.6	437.7	442.8
(ET and $ET_{\%}$)	%	71.7	69.9	63.5	63.7	62.1	62.8
Runoff ($\bar{Q}_y$ and $\bar{Q}_{y\%}$)	mm	160.3	170.4	242.8	241.5	266.9	261.9
	%	28.3	30.1	36.5	36.3	37.9	37.2

However, the higher the long-term precipitation experienced at the study site, the higher the proportional runoff contribution in the water balance (Figures 3–5). As a result, a precipitation increase by 1 mm led to a 0.065% increase in runoff and decreased ET proportional contribution (%) in the water balance. Furthermore, the runoff's proportional contribution increased together with the surface slope gradient.

As a result, the runoff's proportional contribution increased, and ET decreased by 1.74%, in line with slope gradient increase by 1%. Consequently, the runoff proportion was highest (37.9%) at the Vienziemite small

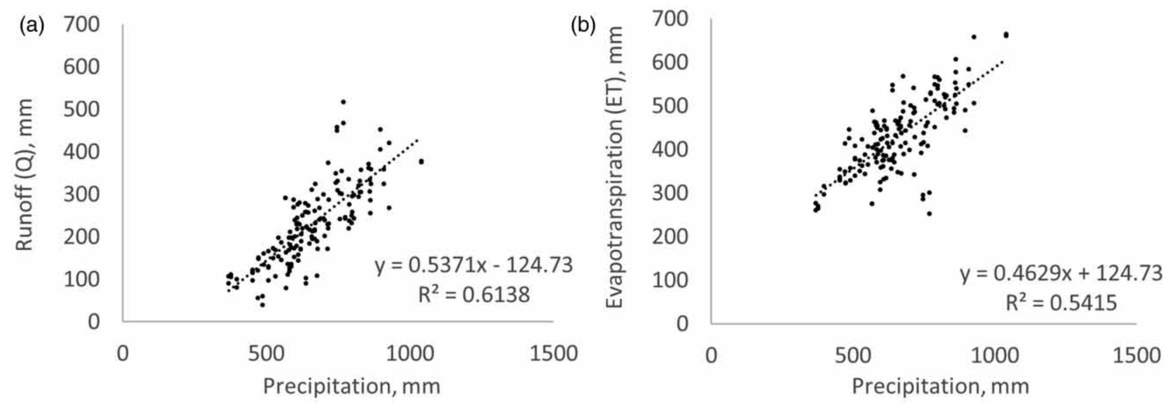

Figure 2 | The effect of yearly precipitation on water balance components in Berze, Mellupite and Vienziemite from 1995 until 2019.

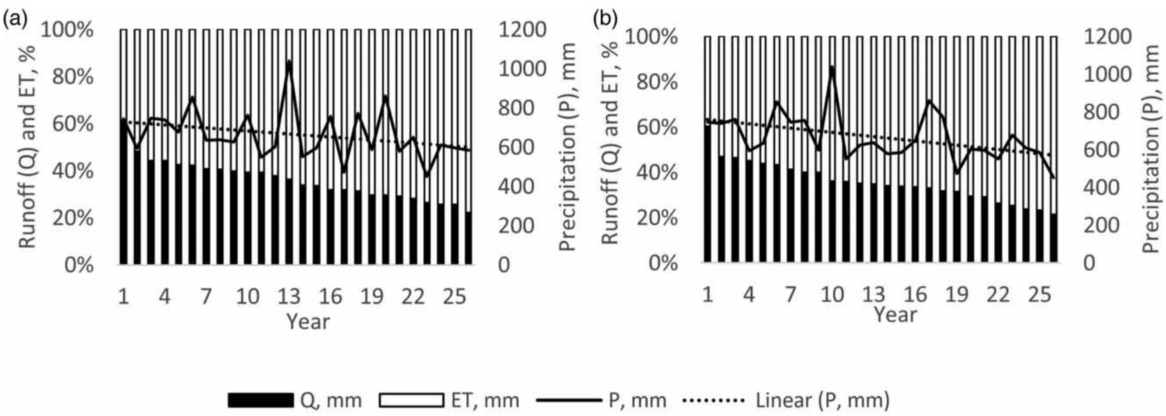

Figure 3 | The precipitation impact on water balance in Mellupite from 1995 until 2019 sorted descending according to runoff contribution: (a) small catchment; (b) drainage field.

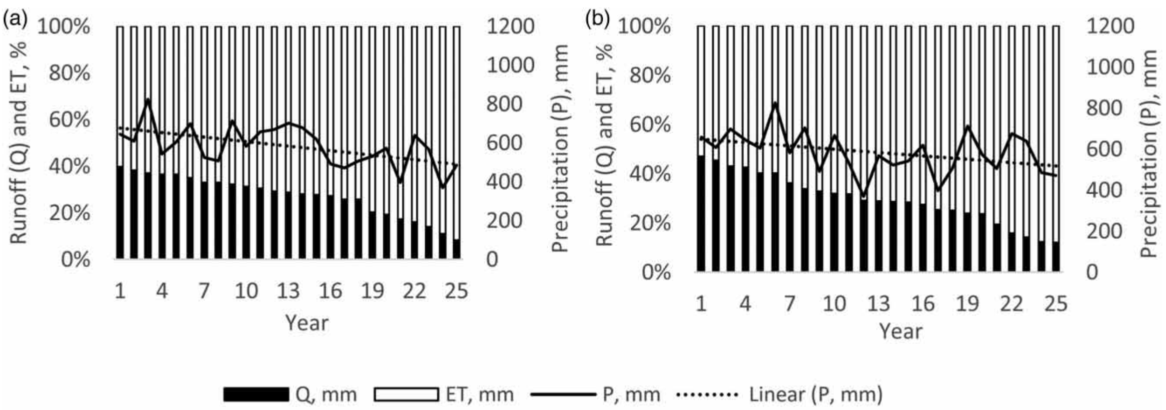

Figure 4 | The precipitation impact on water balance in Berze from 1995 until 2019 sorted descending according to runoff contribution: (a) small catchment; (b) drainage field.

catchment that experiences the highest long-term average precipitation and has the highest surface slope gradient between the sites.

Similarly to this study, the highest runoff coefficients experienced the sub-basins of highest precipitation rates at the Selke River catchment located in the central part of Germany (Sinha *et al.* 2016). It's credible that the soil moisture increases together with precipitation, which provokes surface runoff and increases groundwater-related runoff components' contribution to total runoff. In addition, the increase in surface slope gradient may increase

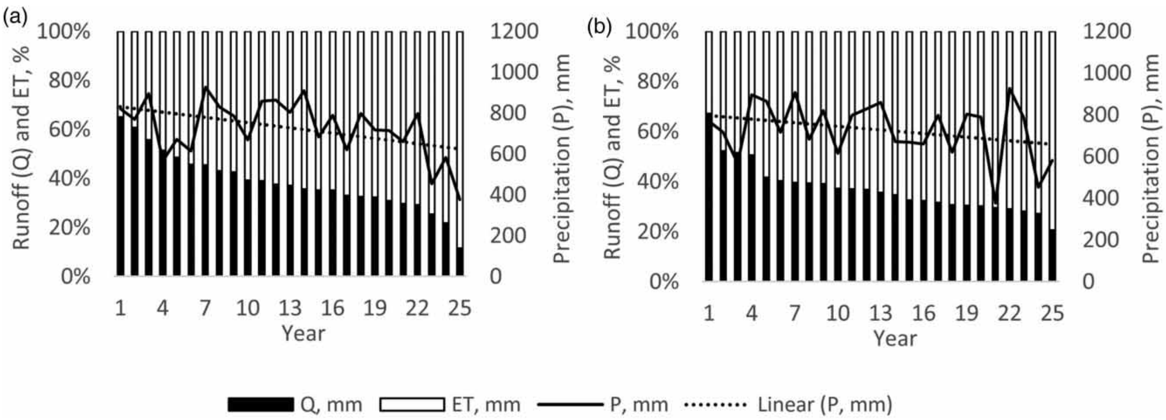

Figure 5 | The precipitation impact on water balance in Vienziemite from 1995 until 2019 sorted descending according to runoff contribution: (a) small catchment; (b) drainage field.

runoff while the ET proportional contribution in the water balance decreased due to several aspects. A high surface slope gradient in the catchment might lead to more intense groundwater flow (Richardson & Vepraskas 2000; Mu *et al.* 2015). Reduced infiltration rates were observed due to an increase in surface slope gradients (Mu *et al.* 2015), which could provoke formations of surface runoff. The increase in the surface slope gradient may indirectly reduce the ET as being caused by intensively drained soil conditions due to groundwater flow and lower soil moisture due to reduced infiltration capacity. The groundwater level controlled by the subsurface drainage ensures substantially lower surface runoff and relatively high infiltration capacity even in frozen soil conditions (Šķiņķis 1986).

However, the relief may have a site and case-specific impact on the process generation. Hintikka *et al.* (2008) noted that the increase in surface runoff was more pronounced at the lower reaches. Lotz *et al.* (2018) revealed that surface runoff might be rather affected by the land cover. The case-specific effect may appear due to combinations in initial water content in the soil, weather conditions, and snow processes. The infiltration capacity was generally affected by soil properties and moisture conditions up to 30 cm depth (Wu *et al.* 2016). ET is also pronounced from the topsoil layer up to 30 cm (Jones 1976), while soil moisture is essential for having ET. Site-specific is the relief orientation and shadowing that affect the solar radiation and the ET (Boldini *et al.* 2014).

Catchment characteristics

The historical measurements carried out in Latvia reveal that water management systems and land-use affect the runoff behavior (Šķiņķis 1986). The estimates of PBIAS (Table 3) show that the average long-term runoff is higher in the drainage field rather than in the small catchment at Berze while the difference is negligible in Mellupite. That might indicate that the existence of baseflow in the small catchment has no considerable impact on the long-term soil water balance and ET rates during the dry seasons. Jones (1976) indicates that ET is insignificant from a depth higher than approximately 1.3 m below the ground surface. Consequently, more water might store drainage fields' soil profile during the dry season, which compensates baseflow volume discharging from the small catchment. The small catchments might experience a later response of subsurface drainage runoff next after the dry periods.

In contrast to Berze, the PBIAS indicates lower long-term average runoff from the drainage field than from the small catchment at Mellupite and Vienziemite. The grassland cover, comparatively high surface slope gradient

Table 3 | Statistical differences between the runoff from small catchment and drainage field within the period from 1995 to 2019

	Berze		Mellupite		Vienziemite	
Period	**NSE**	**PBIAS, %[a]**	**NSE**	**PBIAS, %[a]**	**NSE**	**PBIAS, %[a]**
Monthly	0.77	6.28	0.80	−0.55	0.77	−1.91
Yearly	0.60		0.82		0.45	

[a]Negative value shows higher runoff from small catchment than from drainage field.

and relatively large groundwater discharge area (Table 4) most likely explain these results at Vienziemite. The individual studies demonstrate lower average runoff coefficients in grasslands than in arable lands during the vegetation period (Liu *et al.* 2006; Zhao *et al.* 2014). However, in contrast to arable lands, runoff coefficients in grasslands are temporarily more variable and higher during storm events (Liu *et al.* 2006). Compared to arable lands, grasslands can experience from 20 to 40% higher surface runoff during the snowmelts (Šķiņķis 1986).

Table 4 | The area of small catchments and area contributing to groundwater flow into streams

Small catchment	Catchment area, ha	Stream length, m	Groundwater recharge area	
			ha	% of catchment
Berze	367	2,399	14.4	3.9
Mellupite	964	5,850	35.1	3.6
Vienziemite	592	6,177	37.1	6.3

At Vienziemite, in contrast to Berze and Mellupite, total runoff might have a comparatively high contribution from storm runoff and melting snow due to relatively high precipitation rates and intensive formations of the snowpack. The minor runoff difference between the small catchment and drainage field at Melupite could cause a relatively high share of tile-drained grasslands over the small catchment. While more intensive infiltration and subsurface flow exist within grassland's vegetation period compared to bare soils (Zhao *et al.* 2014), the subsurface drainage systems intensify the subsurface flow (Šķiņķis 1986; van Aart *et al.* 1994). According to seasonal specifics in Latvia, additional studies are recommended to estimate the runoff behavior in tile-drained grasslands.

Also, the estimates of NSEs indicate that temporarily the runoff behaves somewhat differently in terms of measurement scale. The flow patterns in drainage fields differ from the small catchment, and mostly it is apparent on a yearly average time scale. The pattern differences are most likely related to differences in hydrological pathways that affect the hydrographs' pulses. The NSE's discrepancies of monthly average runoff data are similar between the monitoring stations. The lower NSEs within the yearly average runoff data could indicate the cumulative effect of the runoff discrepancies. As the NSEs demonstrate good agreement, the linear regression can consider to predict the runoff from one to another measurements scale.

The groundwater flow contribution might affect the runoff behavior differences between monitoring scales. Compared to the Berze and Mellupite stations, the groundwater flow contribution might be much higher in the Vienziemite small catchment. In the Vienziemite small catchment, an estimated groundwater recharge area is 1.6 and 1.7 times larger than in Berze and Mellupite, respectively (Table 4). Furthermore, groundwater flow could be higher due to comparatively high surface slope gradients at Vienziemite, similarly found by Ward & Robinson (2000).

CONCLUSIONS

This study reveals that the regional and local differences between long-term and yearly runoff and ET amounts are predominantly controlled by precipitation amounts. The impact of precipitation is rather a case than site-specific. However, the slope gradient may substantially affect the runoff and ET proportional contribution in the water balance. The following conclusions are drawn within this study:

(1) The regions with higher precipitation rates experience higher runoff and ET amounts. Precipitation increase by 1.0 mm results in a 0.54 mm increase in runoff and 0.46 mm increase in ET;
(2) The runoff's proportional contribution (%) increases, and ET decreases by 0.065% in the water balance with a 1 mm precipitation increase. In other words, the runoff coefficients increase in agreement with the precipitation rates.
(3) A higher surface slope gradient results in higher runoff and lower ET proportional contribution in the water balance. The proportional contribution of runoff increase and ET decreased by 1.74% in line with slope gradient increase by 1%;
(4) The runoff data from the small catchment scale can apply to predict the runoff at the drainage field scale by considering the linear regression. The accuracy of predicted runoff is very good (NSE=0.77…0.80 and

PBIAS=−1.91…6.28) monthly, while from poor to good at a yearly temporal scale (NSE=0.45…0.82 and PBIAS=−1.91…6,28).

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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