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EVOLUTION OF WATER LEVELS IN THE RIVER LIELUPE: A PERSPECTIVE FOR JELGAVA CITY

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Abstract
The River Lielupe is a critical hydrological and ecological resource for Jelgava City, significantly influencing agricultural productivity, urban development, biodiversity, and disaster risk management. However, long-term fluctuations in water levels pose pressing challenges, particularly increased flood risks during wet periods and more severe low-flow conditions during droughts. This study undertakes a comprehensive analysis of multi-decadal daily water level data recorded at the Jelgava gauge station, employing robust statistical approaches to identify clear patterns and trends. By systematically examining seasonal and annual variations and investigating potential climatic and anthropogenic drivers, our results reveal significant increases in both mean and minimum water levels, accompanied by a discernible decline in maximum levels. These shifts indicate evolving hydrological dynamics, likely driven by changing precipitation regimes, increasing land-use intensification, alterations in upstream land management practices, and ongoing river regulation efforts. The findings underscore the growing urgency for adaptive water resource management strategies tailored specifically to the basin. Recommended actions include the development of advanced flood protection infrastructures, sustainable water-use frameworks, comprehensive ecosystem-based planning, and strategic and well-informed policymaking. These strategies are essential to enhance the long-term resilience, sustainability, and ecological functionality of the Lielupe basin amidst ongoing climatic variability, urbanization pressures, and broader environmental change.
Keywords: hydrology, flood risk, adaptive management.

Introduction

The River Lielupe is considered a vital environmental and socio-economic resource for Jelgava City. Its water levels are influenced by factors ranging from agricultural activities and urban infrastructure planning to flood control measures and drought mitigation strategies (Krapesch et al., 2011; Miller et al., 2014). Over time, its hydrological regime has been modified by natural variability, climatic shifts, and human interventions (Itoshiro et al., 2021; Guo et al., 2022).

Variations in river form are quantified, and the factors influencing channel and valley responses to extreme floods, such as gradient, channel and floodplain morphology, and sediment availability, are analysed. These insights are essential for understanding the impacts on the river's hydrological regime (Bertoldi et al., 2010; Krapesch et al., 2011; Saha et al., 2019). Accurate hydrological simulations and river flow forecasts are recognised as key tools for managing water resources, assessing water demand, and planning irrigation (Ge et al., 2018; Guo et al., 2022).

The effects of climate change and human activities, including urbanisation and dam construction, on river hydrology have been widely studied (Allen & Pavelsky, 2015; Zhang et al., 2016; Feng et al., 2020). Structural and non-structural measures, such as flood-limited water level operations, are explored to mitigate extreme weather impacts and support sustainable water management (Li et al., 2012; Wei et al., 2016).

Large dams, such as the Three Gorges Dam on the Yangtze River, have significantly impacted downstream hydrology and river ecosystems (Zhang et al., 2016). Channel modifications for flood control have also been shown to harm freshwater ecosystems and associated species (Usuda et al., 2010; Wu et al., 2018).

Long-term hydrological data analysis is regarded as critical for identifying trends and understanding processes driving water resource changes (Krapesch et al., 2011; Miller et al., 2014). These assessments provide essential guidance for developing evidence-based water management and climate adaptation strategies (Itoshiro et al., 2021; Guo et al., 2022).

This study examines historical water level data from the Jelgava gauge station on the River Lielupe. Trends, seasonal and annual patterns, and climatic and anthropogenic factors influencing the changes are investigated (Bertoldi et al., 2010; Saha et al., 2019). The findings aim to inform urban planning, agricultural management, flood risk reduction, and environmental conservation in the Lielupe basin (Ge et al., 2018; Feng et al., 2020).

The aim of this study is to analyse historical water level records from the River Lielupe at Jelgava, to identify long-term trends and the driving processes, and to apply these insights to project future conditions, thereby supporting sustainable water resource management and policy development within the basin.

Materials and Methods

Daily water level measurements recorded at the Jelgava gauge station were utilised to generate key metrics, including daily maximum, mean, and minimum levels. Seasonal patterns were characterised by aggregating data by month to identify intra-annual variability, while annual statistics enabled the detection of long-term trends.

Linear regression and the non-parametric Mann–Kendall test were applied to assess trend significance and direction. The resultant findings were visually represented through time-series plots, boxplots, and other graphical tools, enabling straightforward interpretation of temporal variability. Collectively, these methods ensured a rigorous and transparent approach to identifying and understanding underlying hydrological patterns.

Results and Discussion

Seasonal water level variability

Distinct seasonal patterns emerged from the analysis, revealing the natural hydrological cycle of the River Lielupe (Figure 1). Peak water levels occurred in March and April, primarily driven by snowmelt and spring runoff from the catchment. In contrast, the lowest water levels were observed in July and August due to lower rainfall, higher evapotranspiration, and increased agricultural water use.

During autumn, partial recovery in water levels was noted, with secondary peaks in November and December. This recovery is attributed to enhanced precipitation and storm runoff during this period. The cyclical nature of these seasonal variations underscores the predictable nature of hydrological changes in the River Lielupe basin.

Pronounced seasonal peaks during March and April have been confirmed, primarily influenced by snowmelt and spring runoff from the catchment area. A sharp rise in the seasonal component has consistently been observed during this period, thereby highlighting the dominant role of snowmelt processes in shaping river discharge.

Figure 1

Seasonal decomposition of Maximal water levels in the River Lielupe at Jelgava

The seasonal decomposition of water level data isolated these recurring patterns and confirmed the dominant role of snowmelt processes in shaping river discharge during spring. A sharp rise in the seasonal component was consistently observed during March and April, emphasizing the influence of catchment hydrology. Conversely, prominent seasonal lows in July and August, driven by reduced precipitation and heightened evapotranspiration, underscore the predictable nature of low-flow conditions during summer. The partial recovery in autumn reflects enhanced rainfall and storm-driven runoff, contributing to secondary peaks later in the year.

In addition to seasonal cycles, the decomposition analysis isolated long-term trends in water levels. These shifts correspond closely with the overall changes in mean, maximum, and minimum water levels discussed in Section 3.2. By disentangling seasonal influences from longer-term drivers, the underlying processes governing water level fluctuations have been more clearly delineated.

This integrated approach highlights the complex interplay between seasonal hydrological dynamics and long-term environmental trends, providing a comprehensive understanding of water level variability within the River Lielupe basin.

Yearly trends

Annual trend analysis revealed several significant changes (Figure 2). An upward trend was observed in the mean water levels ($\tau = 0.381$, $p < 0.001$). This suggests a consistent increase in baseline water availability over the studied period, which may indicate long-term hydrological or climatic changes impacting the region. The increasing mean levels could contribute to enhanced ecosystem stability and resource availability.

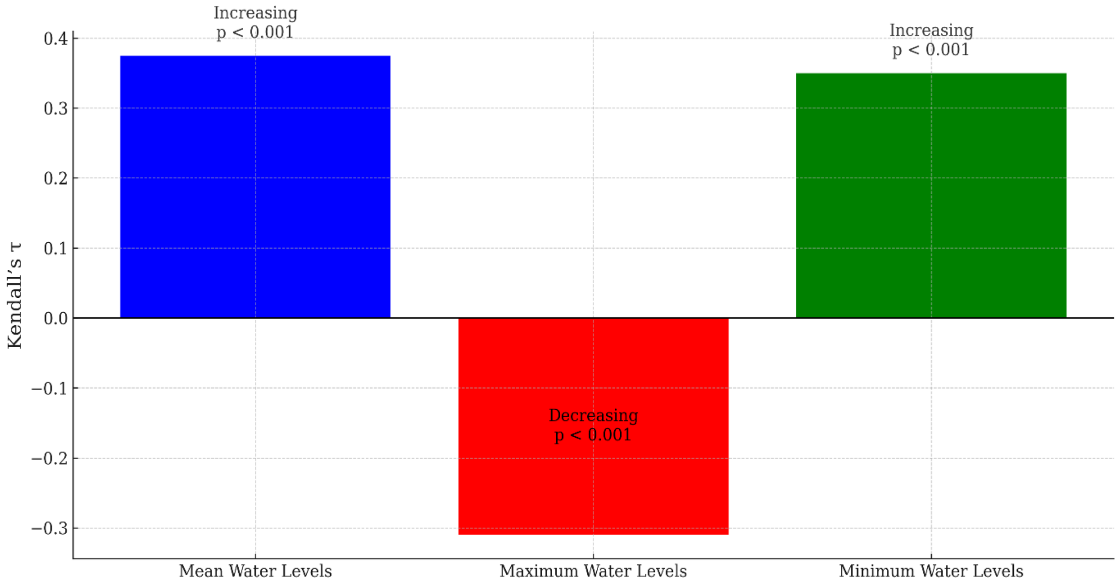
A declining trend in maximum water levels was identified (τ = -0.307, $p < 0.001$). This reduction in extreme flooding events suggests improved flood management practices, potential changes in precipitation patterns, or other environmental factors mitigating peak water flows. While the decline in maximum levels might reduce flood risks, it is essential to monitor these trends for their implications on floodplain dynamics and habitat maintenance.

A significant increase in minimum water levels (τ = 0.356, $p < 0.001$) was observed, indicating improved resilience of the river system during dry periods. Higher minimum levels are beneficial for maintaining ecological functions, supporting biodiversity, and ensuring water availability during droughts. This trend reflects positive changes in catchment area management, groundwater recharge, or seasonal flow regulation.

These findings underscore the importance of continuous monitoring and adaptive water management strategies to address both natural variability and anthropogenic influences on the River Lielupe's hydrological regime.

Figure 2

Long-term Trends in Water Levels for the River Lielupe at Jelgava



Factors influencing water level changes

The observed trends in the water levels of the River Lielupe are likely shaped by multiple climatic and anthropogenic factors (Krapesch et al., 2011; Miller et al., 2014). Regional climate change, characterised by modified precipitation patterns, rising temperatures, and altered snowmelt timing, is believed to exert significant influence on river discharge (Itoshiro et al., 2021; Guo et al., 2022). Hydrological responses are further modified by land use changes, urban expansion, intensified agriculture, and river regulation through dams and weirs, with impacts observed on both seasonal flow distribution and long-term water availability (Bertoldi et al., 2010; Saha et al., 2019).

Broader global changes, including sea-level rise and evolving atmospheric circulation, are also thought to interact with local watershed processes, potentially amplifying or dampening existing trends (Ge et al., 2018; Feng et al., 2020). The relative contributions of these various drivers must be understood to support the development of effective water resource management and climate adaptation strategies (Allen & Pavelsky, 2015; Zhang et al., 2016).

The impacts of climate alteration and human activities on the hydrological regime of the River Lielupe have been quantified to assess water demand, plan irrigation, and implement measures for flood control and drought mitigation (Li et al., 2012; Wei et al., 2016). Strategies for flood control, both structural and non-structural, alongside the dynamic operation of flood-limited water levels, have been explored to mitigate the effects of extreme weather events and to ensure sustainable water resource management (Usuda et al., 2010; Wu et al., 2018).

Critical insights for urban planning, agricultural management, flood risk reduction, and environmental conservation within the Lielupe basin are expected to be provided by this study. The findings are intended to contribute to the development of strategic, evidence-based policies and adaptation strategies to address the evolving water-related challenges faced by Jelgava City and the surrounding region.

Implication for future projections

The patterns observed in the water levels of the River Lielupe highlight several critical trends. A decline in maximum water levels has been identified, potentially reducing the severity of large-scale inundations. However, an upward trend in mean and minimum water levels suggests a more stable baseline water supply, which could support agricultural productivity and reduce drought vulnerability (Krapesch et al., 2011; Miller et al., 2014). Despite these benefits, localised flooding events driven by short-duration, high-intensity rainfall remain a significant concern (Itoshiro et al., 2021; Guo et al., 2022).

Seasonal variations have also been emphasised, with peaks in water levels occurring during spring due to snowmelt and secondary peaks in autumn attributed to enhanced precipitation. Meanwhile, summer months are marked by low-flow conditions caused by reduced rainfall and increased evapotranspiration. These patterns underscore the importance of managing seasonal water availability to mitigate risks and optimise resource use.

The implications of these hydrological changes extend beyond water supply and flood control. Urban infrastructure, including drainage systems and water treatment facilities, may come under increased pressure due to more frequent heavy rainfall events.

Agricultural practices could be both positively and negatively affected, with improved baseline water availability offset by challenges posed by unpredictable rainfall patterns and localised flooding.

Ecosystem health within the Lielupe basin is also likely to be impacted. Reduced maximum water levels could alter floodplain dynamics and wetland ecosystems, while higher minimum levels may enhance the resilience of aquatic habitats during dry periods. The interplay of these factors must be carefully managed to maintain ecological balance and biodiversity.

Regional climate change, when combined with local land use practices and river regulation, can intensify or reduce observed hydrological trends. Modified precipitation patterns, rising temperatures, and urban expansion have all been identified as key drivers of hydrological variability (Ge et al., 2018; Feng et al., 2020). These influences must be considered in both short-term planning and long-term adaptation strategies.

To address the challenges and opportunities posed by these trends, several actionable strategies are recommended:

1. To enhance flood management, structural and non-structural measures should be revisited to prioritise the mitigation of rapid-onset flood events, particularly those triggered by intense localised rainfall. Dynamic operation of flood-limited water levels can be optimised to account for evolving rainfall patterns, ensuring that localised flooding risks are minimised (Allen & Pavelsky, 2015; Zhang et al., 2016).
2. Urban infrastructure, including drainage and water supply systems, should be retrofitted or redesigned to accommodate increasing hydrological variability resulting from climate change and land use dynamics. Investments in resilient infrastructure, such as permeable surfaces and retention basins, can reduce the impact of flash floods on urban areas (Usuda et al., 2010; Wu et al., 2018).
3. Improved sustainable agricultural practices should make use of better water availability during dry periods to increase irrigation efficiency and crop yields. At the same time, it is important to prepare for the risks of irregular rainfall and localised flooding.
4. Integration of climate and hydrological model outputs can improve the accuracy of seasonal and annual flow forecasts, supporting better water resource planning and risk management. These forecasts can inform resource allocation, flood preparedness, and long-term water management policies (Forzieri et al., 2013; Borgomeo et al., 2015).
5. Long-term water policies and governance frameworks should aim to balance water use across sectors, promote efficient management practices, and strengthen the resilience of water systems to climate variability. Collaborative governance frameworks involving local authorities, stakeholders, and scientists are essential to implement these strategies effectively (Hansen, 2013; Zarafshani et al., 2016).

Conclusions

1. This study provides a detailed assessment of long-term water level fluctuations in the River Lielupe at Jelgava City, revealing increased mean and minimum levels alongside declining maxima. These findings underscore the complexity of hydrological responses to changing climate regimes, land use practices, and water management strategies. Although reduced flood extremes may alleviate certain historical challenges, shifting hydrological dynamics have the potential to alter floodplain processes, sediment transport, and wetland ecology.
2. The documented variability emphasizes the necessity of adaptive and forward-looking approaches in urban development, agricultural production, and ecosystem conservation. Infrastructure must be designed and maintained to withstand localized flooding, while farming practices should be flexible to capitalise on a more reliable water supply. Future work should integrate socio-economic considerations and advanced modelling techniques to develop a holistic understanding of the river's evolving behaviour.
3. In essence, the observed changes in the River Lielupe water levels reflect broader climatic and anthropogenic influences impacting river systems worldwide. Ongoing monitoring, coupled with proactive adaptation and policymaking, will be essential to maintain ecological integrity, ensure sustainable water resource use, and support socio-economic vitality under increasingly dynamic environmental conditions.

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