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Assessment of historical heavy precipitation in Poland based on documentary evidence

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Abstract

Anthropogenic climate change is intensifying the hydrological cycle and increasing extreme precipitation across much of Europe, yet understanding of pre-instrumental precipitation extremes in Central Europe remains limited by short instrumental records. This study presents the first comprehensive, documentary-evidence-based database of heavy and extreme precipitation events in Poland for the 12th–18th centuries. An assessment of a documentary-based database of heavy precipitation identified 477 such events. The extreme precipitation events were identified and classified into three types (long-lasting, heavy, or violent), based on reported impacts, duration, and affected regions. Results showed that the number of documented events increased over time, from a single event in the 12th century to 242 in the 18th century, with a peak of 182 events in the 1701–1750 sub-period. Silesia (37%) and the Baltic Coast and Pomerania (28%) were the most frequently affected regions, and summer accounted for the majority of all events. The duration of 273 events could be established, of which just over half lasted a single day. Notably, 316 impact assignments described damage never framed as a flood. These findings confirm that documentary sources capture fine-grained detail on the timing, duration, and consequences of past extreme-precipitation episodes, offering a valuable counterpart to multi-proxy reconstructions of longer-term hydroclimatic variability in Poland and Central Europe. This dataset offers a long-term baseline for evaluating present-day and projected changes in Central European precipitation extremes.

Keywords: Extreme precipitation; Historical climatology; Documentary evidence; Pre-instrumental climate; Central Europe; Poland

1. Introduction

Anthropogenic climate change has moved from a future projection to a rapid, present-day fundamental issue, reshaping the global hydrological cycle and amplifying the risk of extreme hydroclimate events (IPCC, 2021; Tripathy et al., 2023). Rising air temperatures enhance the atmosphere's capacity to hold and release moisture, a relationship long anticipated on thermodynamic grounds and now confirmed by both observational records and climate model simulations across most regions of the world (Fischer & Knutti, 2015; Trenberth et al., 2015; Myhre et al., 2019). As

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a direct consequence, the character of precipitation patterns is changing, where rainfall is becoming less evenly distributed in time, with longer dry spells interrupted by increasingly intense and, in many regions, more frequent extreme events (Westra et al., 2014; Donat et al., 2016; Papalexiou & Montanari, 2019). This intensification of the hydrological cycle is projected to continue and even accelerate over the 21st century, with important regional differences in the magnitude and seasonality of the response (Pfahl et al., 2017). Among the various extreme indices connected with climate change, extreme precipitation merits particular attention due to its direct and often abrupt consequences for human society and the natural environment. Extreme precipitation events can trigger flash floods, landslides, and severe soil erosion within hours, while prolonged spells of heavy or long-lasting rain are responsible for the majority of large, slow-developing river floods that cause the greatest economic losses (Alfieri et al., 2015; Tabari, 2020; Tabari et al., 2020). Europe has experienced several such catastrophic extreme-precipitation and flood events in recent years, including the July 2021 floods in Germany, Belgium, and the Netherlands, which were driven by an exceptionally intense and stationary rainfall system (Lehmkuhl et al., 2022; Mohr et al., 2022); the September 2023 Storm Daniel floods in Greece, where historic precipitation caused widespread inundation in Thessaly (Athanase et al., 2024); the September 2024 Storm Boris floods across Central and Eastern Europe, which produced record-breaking rainfall and severe flooding in Austria, Czechia, Slovakia, Poland, Romania, Hungary, and northern Italy (Athanase et al., 2024; Ferrari et al., 2025; Riboldi et al., 2026). In Poland, recent events further illustrate this vulnerability, including the August 2024 short-duration convective rainfall events in Warsaw and Zamość (Pietras & Pyrc, 2025) and the September 2024 flood in south-western Poland (Silesia) associated with Storm Boris, which again highlighted the high exposure of the Oder basin and Silesia region to extreme rainfall and flood hazards (Ghazi et al., 2025). At the continental scale, climate change is projected to both increase and decrease river flood and extreme precipitation hazards depending on the region, with Central and Eastern Europe, including Poland, generally falling among the areas of increasing risk (Dottori et al., 2023; Ghazi et al., 2023a; Fang et al., 2025). Estimates of the annual economic losses associated with flood-related phenomena in Europe already exceed 12 billion euros (Feyen et al., 2020), and in Poland alone, the catastrophic floods of 1997, 2001, and 2010 caused losses on the order of several billion US dollars (Kundzewicz et al., 2023).

Despite this growing concern, our understanding of how the frequency, intensity, and character of extreme precipitation have varied over the long term remains heavily constrained by the limited length of instrumental records. Reliable, continuous rain-gauge measurements in Central Europe rarely extend back earlier than the late 18th or 19th century, and in most of Poland, even shorter, fragmentary series are available only from a handful of locations (for details see Przybylak, 2010). This instrumental gap leaves a substantial portion of the most recent climatic period, including the Little Ice Age, essentially undocumented by direct measurements, even though this period is now recognized as particularly rich in hydroclimatic extremes across Europe (Glaser et al., 2010; Blöschl et al., 2020). In the absence of instrumental data, documentary evidence, that is, written notes about past weather preserved in chronicles, annals, diaries, administrative records, and similar sources, remains the most detailed and, in many cases, the only available source of information on the timing, duration, and severity of historical extreme precipitation events (Brázdil et al., 2005; Brázdil et al., 2006). Compared with other proxy data, such as tree rings or lake sediments, which typically resolve climate variability only at an annual or seasonal scale, documentary sources can preserve event-level

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detail, including the exact date, the character of the rainfall, and its immediate consequences, making them uniquely valuable for reconstructing short-lived extremes such as heavy or violent rain (Brázdil et al., 2006; Dobrovolný et al., 2015). It is also important to recognize that historical hydrology has, until now, focused mainly on reconstructing floods themselves rather than on the precipitation events that generated them. Our own previous work on the database of historical floods in Poland for the 11th–18th centuries showed that, although rain and its subtypes were the single most common documented cause of floods, they accounted for less than half of all classified cases, with snowmelt, ice jams, and other winter-related processes responsible for a substantial share of the remainder (Ghazi et al., 2023b, c; Ghazi et al., 2024; Ghazi et al., 2025). This means that a flood-occurrence database, even the most comprehensive, systematically under-represents the broader population of past intense rainfall events. Many heavy or violent rain episodes left no trace in the river flood record, yet they are still documented in the documentary record because of the damage they caused to crops, roads, mills, or buildings. Furthermore, not every flood resulted from a single, identifiable rainfall event. A dedicated database of rainfall events, distinct from but complementary to existing flood and drought databases, is therefore needed to capture this wider spectrum of historical hydroclimatic extremes and their varied consequences.

Over the past several years, a set of documentary-evidence databases addressing different components of historical hydroclimatic variability in Poland has been compiled to fill a long-standing knowledge gap in the pre-instrumental hydroclimatology of Central Europe. However, a systematic, event-level inventory of the heavy and extreme rainfall has been missing for Poland so far. Therefore, the present study addresses this gap by developing the first comprehensive, documentary-evidence-based database of heavy and extreme rainfall events in Poland covering the 12th to the 18th centuries, which is publicly available at https://doi.org/10.18150/T9KJGA. For each identified event, we classify the character of the rainfall itself (long-lasting, heavy, or violent rain) and its reported consequences (an unspecified flood, a small regional flood, a supra-regional or catastrophic flood, or other impacts such as crop or infrastructure damage), in addition to recording the date, duration, affected region, and source quality. By focusing on the rainfall event rather than solely on its most extreme hydrological outcome, this database provides a more complete and nuanced picture of historical precipitation extremes than has previously been available for Poland, complementing our existing flood and drought databases and offering a long-term baseline against which present-day and projected future changes in extreme precipitation can be assessed (Guerreiro et al., 2018; Kundzewicz et al., 2018).

2. Area, materials, and methods

2.1. Study area

This study covers the area of present-day Poland, a Central European country bordered by the Baltic Sea to the north and the Sudetes and Carpathian Mountains to the south (Fig. 1). As in our previous flood and drought reconstructions, the country was subdivided into six historical-geographical regions: Baltic Coast and Pomerania, Masuria-Podlasie, Greater Poland, Masovia, Silesia, and Lesser Poland (Ghazi, et al., 2023b; Ghazi et al., 2025). Because the political borders of Poland changed substantially over the study period, particularly with respect to Silesia and parts of Pomerania, the present-day administrative boundary was adopted for all spatial analyses, and historical sources originating outside the medieval and early modern Kingdom of Poland but relevant to this area were also consulted where necessary (Ghazi et al., 2023b). When a documentary source provided insufficient or only very general

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locational information, the corresponding event was assigned to a separate "Poland" category, consistent with the approach used in our earlier databases (Ghazi et al., 2025).

Fig. 1. Geographical location of Poland and its six main historical regions (modified from Ghazi et al., 2025).

The database of heavy and extreme precipitation (rainfall/snowfall) events was constructed by an interdisciplinary team of historians, climatologists, and hydrologists, following the same general workflow established in our earlier flood reconstructions for Poland (Ghazi et al., 2023b, c; Ghazi et al., 2024; Ghazi et al., 2025). Relevant weather notes were identified through a combination of newly conducted archival research and a systematic review of previously compiled source collections. The documentary evidence consulted included narrative sources such as municipal, monastic, and family chronicles and annals; private correspondence, diaries, and travel accounts; administrative records, including the minutes of city councils and provincial estates; and accounting and parish books recording expenditure on flood or storm damage. For each identified precipitation event, the database records the year and, where available, the month, season, and day of occurrence; the original textual description; the source and an assessment of its quality; the affected region and, where applicable, the river basin; and the classification of the precipitation type and its reported impact, described in detail below.

Following the procedure used in our previous studies, every source was assessed by the historians in the team using a three-degree quality scale: 1, weak, when the information derived from secondary literature rather than an original source; 2, moderate, when the description was recorded sometime after the event or differed in detail from a contemporaneous account; and 3, high, when the source was written close in time to the event and provided precise, internally consistent information (Ghazi et al., 2025). When more than one source described the same event, the most reliable available account was used for classification, and discrepancies between sources were resolved through discussion among the full team.

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2.2 Classification of precipitation type

Because documentary descriptions of precipitation events vary considerably in their level of detail, each event was classified according to the dominant character of the precipitation reported in the source, using a three-category scheme adapted from the rain-origin subtypes previously applied in our flood classification work (Lambor, 1954; Ghazi, et al., 2025); and refined here to describe the precipitation event itself rather than only its role as a flood trigger. The three categories, summarised in Table S1, distinguish precipitation events primarily on the basis of their duration and intensity. Where a source did not provide sufficient detail to assign a specific type, the event was retained in the database but coded as not classifiable (N/A) for this variable, rather than being assigned to any category by default.

In line with the precipitation-type classification, the reported consequences of each event were classified using a four-category impact scheme, summarized in Table S2. This scheme builds on, but is methodologically distinct from, the flood-intensity classifications of Brázdil et al. (2006) and Barriendos and Coeur (2004), which we applied in our earlier flood databases. Whereas those classifications were designed to grade the severity of an already-identified flood, the present scheme was developed to capture the full range of outcomes associated with a documented precipitation event, including cases in which no flood is mentioned at all. Category 1 covers events for which a flood is reported but with insufficient detail to assess its extent, broadly corresponding to a flood reported "without further information"; categories 2 and 3 distinguish small, regional flooding from more extensive, supra-regional or catastrophic flooding, in a manner consistent with the distinction between "smaller, regional" and "above-average or supra-regional" floods used in our previous work (Brázdil et al., 2006; Ghazi et al., 2025); and category 4 was introduced specifically for this database to record damage attributable to heavy or violent precipitation that was not described as a flood, most often the destruction of crops, meadows, orchards, or infrastructure. As with precipitation type, an event could be assigned more than one impact code where the source described multiple distinct consequences, and events lacking sufficient detail were coded as N/A.

All results are reported and summarized annually by event frequency, or by century, historical region, month, and season. Distinguishing events and seasonal occurrences were assigned to the season in which they began. In addition, monthly summaries include only records with a named month. The duration of events was calculated with identifiable start and end dates. Because precipitation types and their impacts can each be classified in multiple ways, event-type indexation is presented as assignments (or mentions) and may exceed the number of unique events.

Results

In the documented database, we recorded 477 heavy or extreme precipitation events (Fig. 2) during the period 1101–1800, with an increase noticeable by the end of the study period. In the 12th century, only one event was identified. There were only nine and ten heavy precipitation events in the 13th and 14th centuries, respectively. The number of recorded events increased steadily from the 15th century (35 events), rising through the 16th century (77 events) and the 17th century (103 events) to a maximum of 242 events in the 18th century, which alone accounts for just over half of the entire database. At a 50-year resolution, the 1701–1750 sub-period contains the largest number of recorded events (182).

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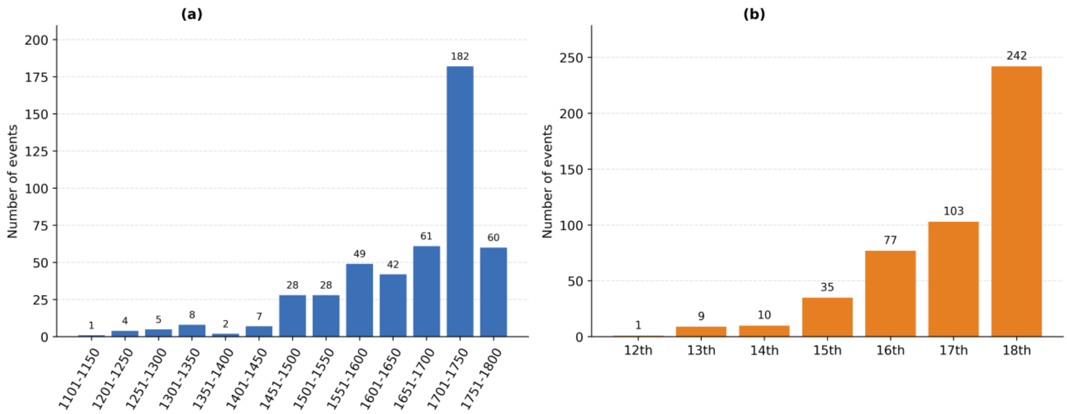

Fig. 2. Number of recorded heavy and extreme rainfall events in Poland in the 1101–1800 for 50-year periods (a) and centuries (b).

The distribution of heavy precipitation events varied across the historical regions (Fig. 3a). Silesia contained 176 events (36.9% of all records), followed by the Baltic Coast and Pomerania with 132 (27.7%) and Lesser Poland with 82 (17.2%). The remaining events were assigned to the "Poland" category (26; 5.5%), Masovia (23; 4.8%), Masuria-Podlasie (19; 4.0%), and Greater Poland (19; 4.0%). Silesia was the principal region from the 15th through the 17th centuries, with 21, 48, and 49 events, respectively. In the 18th century, the largest increase occurred along the Baltic Coast and in Pomerania, which accounted for 95 records, compared with 52 in Silesia and 43 in Lesser Poland (Fig. 3b).

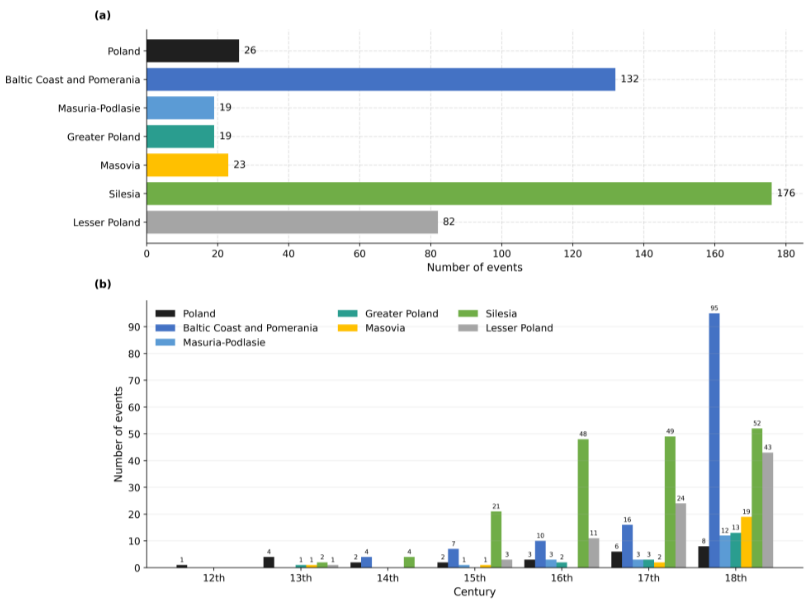

Fig. 3. Number of recorded heavy and extreme precipitation events in Poland according to regions: (a) totals for 1101-1800 and (b) totals for centuries.

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In the analysis of the database of historical extreme precipitation events, for 404 events, there was sufficient information to determine the month in which each occurred (Fig. 4). Nearly two-thirds occurred during June-August (266 events; 65.8%), with maximum in July (97) and August (94), followed by June (75) (Fig. 4a). May was a transitional month with 33 records, whereas each month from October to April contained fewer than 20. The occurrences of heavy precipitation events dominated in summer (287; 65.5%), while spring (61; 13.9%), autumn (46; 10.5%), and winter (44; 10.0%) were much less frequent (Fig. 4b). Summer was the leading season in every century with more than a few records, although the absolute numbers of winter, spring, and autumn events also increased in the 18th century (Fig. 4c).

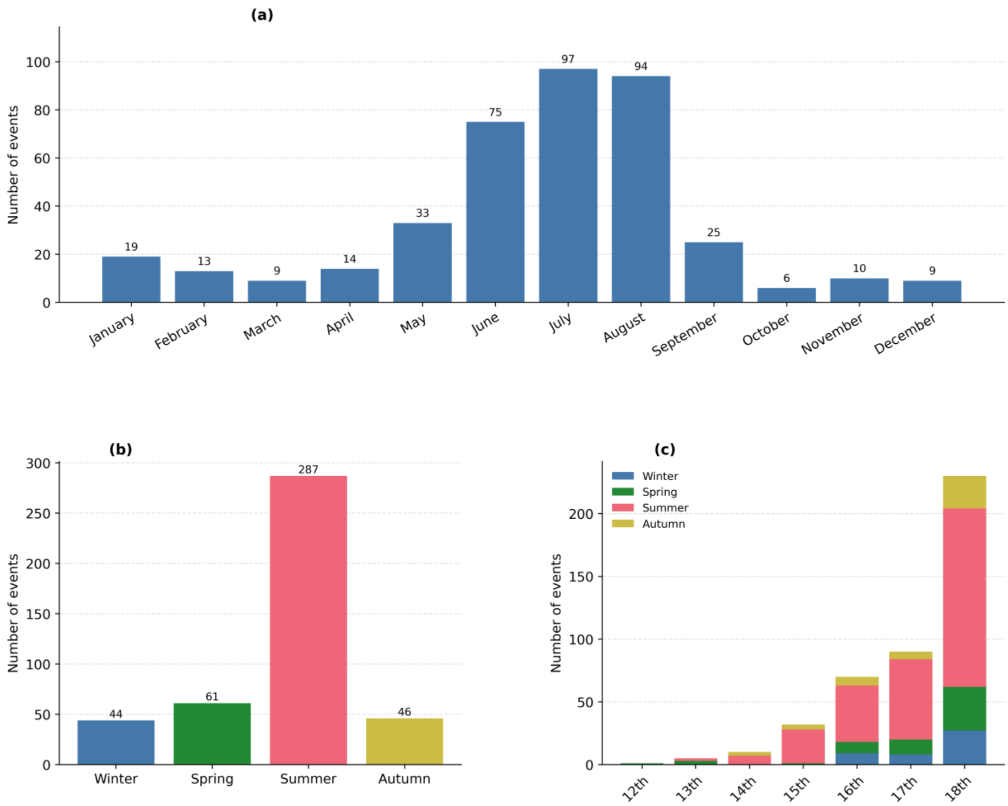

Fig. 4. Monthly (a) and seasonal (b and c) number of recorded events in Poland in the period 1101-1800. Key: a and b – totals for the entire period, c – totals for individual centuries

In assessing the duration of recorded events, we determined durations for 273 events with fully dated start and end times (57% of the database; Fig. S1a, Supplementary Material). Just over half of these (143 events, 52%) lasted a single day, consistent with the majority of short, violent precipitation in the record, while 40 events (15%) lasted 2–3 days, 33 (12%) lasted 4–7 days, 18 (7%) lasted 8–14 days, and 39 (14%) persisted for more than two weeks. The distribution of duration classes differs somewhat among regions (Fig. S1b), where single-day events are

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particularly prominent in Silesia and the Baltic Coast and Pomerania, whereas events lasting more than 14 days are concentrated in the Baltic Coast and Pomerania region, which alone accounts for 20 of the 39 such events.

Because precipitation type is a multi-label variable, the 477 events yielded 643 individual type assignments (Fig. 5a): long-lasting precipitation (≥2 days) was the most frequently assigned category (236 assignments), followed by heavy precipitation (219) and violent precipitation (188). Considering the specific combinations of types recorded for each event (Fig. S2, Supplementary Material), violent precipitation alone was the single most common designation (167 events), followed by the joint assignment of long-lasting and heavy precipitation (147 events), heavy rain alone (72), long-lasting precipitation alone (68), and the combination of long-lasting and violent precipitation (21 events), together these combinations account for 475 of the 477 events, with only two events lacking sufficient detail for classification.

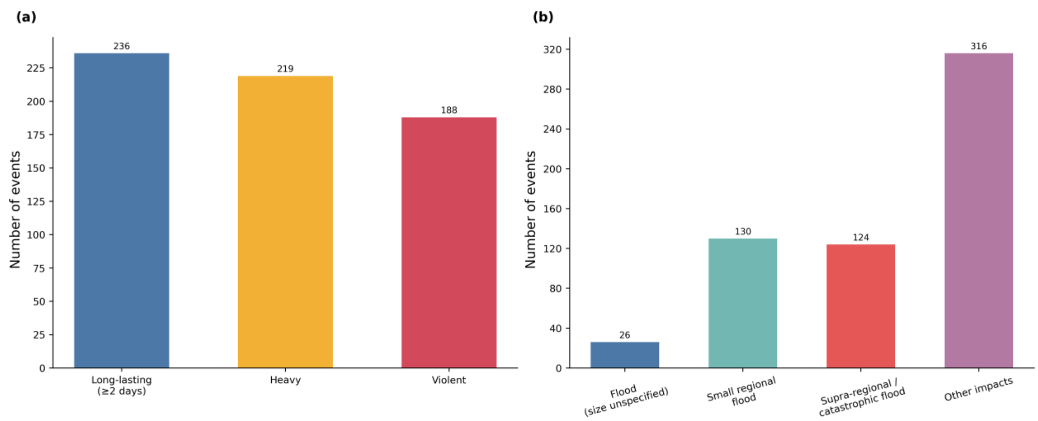

Fig. 5. Classification of recorded precipitation events in Poland in the period 1101-1800: (a) number of events by precipitation type; (b) number of events by impact category.

The relative contribution of each precipitation type to the regional totals is broadly comparable to each region's overall share of the database (Fig. 6), although violent precipitation is extremely concentrated in Silesia (45% of all violent-precipitation mentions, compared with 31–33% of long-lasting and heavy-precipitation mentions). The number of precipitation types of all three kinds rises sharply from the 16th century onward, with long-lasting precipitation accounting for the largest share of the 18th-century total (Fig. 6).

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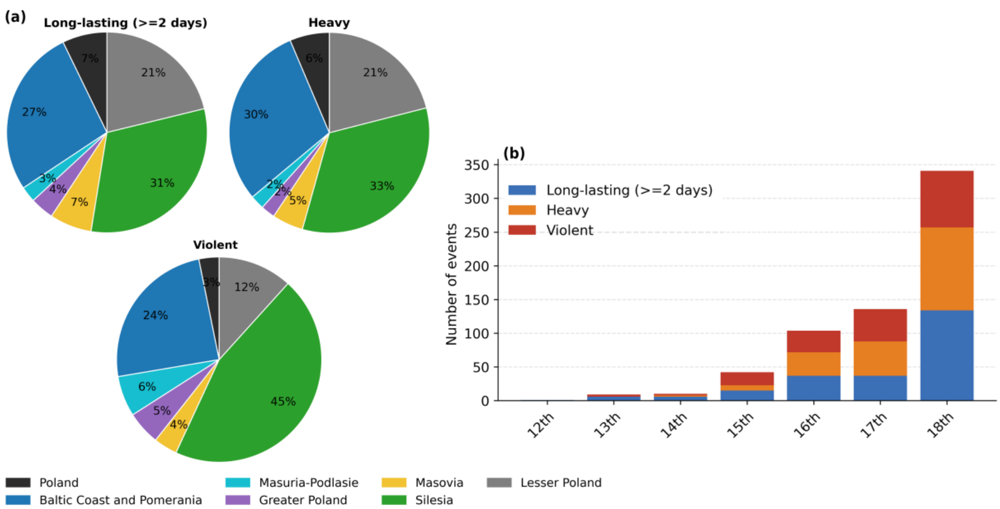

Fig. 6. Precipitation-type mentions for Poland by region (a, percentage values) and century (b) in the period 1101-1800.

The reported consequences of precipitation events were dominated by damage not associated with a described flood: “other impacts”, primarily damage to crops, meadows, orchards, roads, bridges, or mills, were recorded 316 times, exceeding the combined total of all three flood-related categories (280 mentions: 130 small/regional floods, 124 supra-regional or catastrophic floods, and 26 floods of unspecified extent). As with precipitation type, the regional distribution of impact mentions broadly mirrors each region's overall representation in the database, with Silesia accounting for more than half of all mentions of unspecified floods (58%) and supra-regional or catastrophic floods (56%), while the Baltic Coast and Pomerania region contributes to “other impacts” (23%) and small/regional floods (18%) (Fig. 7). The number of impact mentions of every category increase from the 15th century and later, with “other impacts” increasing especially sharply in the 18th century, when it accounts for more than half of all impact mentions recorded in that century (Fig. 7).

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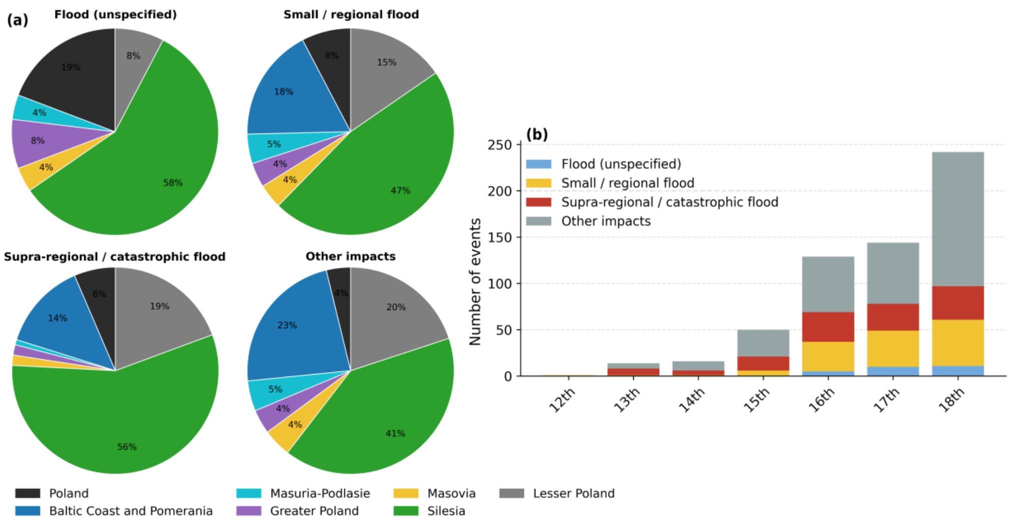

Fig. 7. Impact-category mentions for Poland by region (a, percentage values) and century b) in the period 1101-1800.

The distribution of events by location (Fig. S3) shows that Gdańsk alone accounts for 61 events, followed by Toruń (27), Kraków and Wrocław (24 each), Bolesławiec (20), and Warszawa (13), with the remaining top-20 locations contributing fewer than 15 events each. The spatial pattern (Fig. S4) shows a significant concentration of events along the Baltic coast, the Vistula and Oder river valleys, and within Silesia, consistent with the regional totals shown in Fig. 3 and reflecting the availability of historical sources and major archives preserved.

Discussion

Reconstructing the historical extreme precipitation (rainfall/snowfall) itself, rather than its downstream hydrological consequences, is a relatively new investigation in Central European historical climatology, even though notes on heavy, violent, or long-lasting precipitation are at least as common in pre-instrumental sources as explicit mentions of flooding (Brázdil et al., 2005; Brázdil et al., 2006). Most existing documentary reconstructions of Poland and its neighbours, including our earlier work, have approached the pre-instrumental period through the lens of the flood event, treating rainfall as only one of several possible triggers alongside snowmelt and ice jams (Ghazi et al., 2023b, c; Ghazi et al., 2024; Ghazi et al., 2025). The database presented here inverts that perspective, building around the precipitation event itself, regardless of whether it produced a recorded flood, and therefore offers a more direct, if still imperfect, window into the frequency and character of past heavy precipitation. As shown in the Results, 316 of the impact assignments in our database describe damage to crops, roads, or mills that the source never framed as a flood at all, while 280 assignments describe a flood of any size. A flood-centered database would, by construction, have missed the majority of these episodes.

As with any documentary reconstruction, the frequency pattern shown in Fig. 2 must be interpreted in light of source-related biases now well established in the wider historical-climatology literature (Brázdil et al., 2005; Burgdorf, 2022). The near-absence of events before the 15th century and the strong 18th-century maximum almost certainly combine a genuine increase in written weather observation with growing administrative, ecclesiastical, and

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personal record-keeping; Burgdorf's (2022) global inventory of quantitative documentary climate evidence similarly shows a marked worldwide increase in surviving weather sources from the 16th century onward, so the pattern identified here is far from unique to Poland. Regionally, the concentration of events in Silesia and the Baltic Coast and Pomerania (Fig. 3a) mirrors these two regions' dominance in our flood databases spanning the 11th to 20th centuries (Ghazi et al., 2023b; Ghazi et al., 2025). Furthermore, not every heavy precipitation event had an equal chance of being recorded. Brief, intense downpours usually entered chronicles only when they produced visible damage to a settlement, field, road, mill, or other named feature. Longer precipitation events were more likely to be mentioned when they disrupted harvests, transport, or river conditions. The number of records, therefore, depends not only on how often heavy precipitation occurred, but also on whether its effects were sufficiently noticeable and consequential to be documented. For this reason, the temporal distribution in Fig. 2 should be interpreted as a chronology of documented precipitation episodes rather than as a uniform meteorological frequency series (Kjeldsen et al., 2014).

One useful external check on the sparse medieval portion of the database is provided by the exceptionally wet conditions of 1314–1316. Based on the Old World Drought Atlas, Baek et al. (2020) ranked this interval as the fifth-wettest three-year sequence of European summers between 1300 and 2012, with a pronounced wet anomaly extending across Poland and much of the Baltic region. This proxy evidence agrees with historical descriptions of persistent precipitation, flooding, and agricultural disruption, including reports that the wet spring and summer of 1316 damaged hay production and sowing in Poland and Hungary. Documentary evidence from the neighbouring Carpathian Basin also indicates repeated abundant precipitation and flooding during 1315–1317 (Vadas, 2009). The contrast between this spatially extensive wet anomaly and the relatively small number of early 14th-century entries in our database underscores why individual medieval episodes should be evaluated using independent proxy and regional documentary evidence, rather than from event totals alone.

Placed alongside our team's earlier flood-focused databases for Poland, the present precipitation inventory is broadly consistent in its temporal and regional structure but adds an important corrective. Across the 11th–15th, 16th, and 17th–18th centuries, rain and its subtypes were identified as the triggering cause in only 38–53% of documented floods (Ghazi et al., 2023b; Ghazi et al., 2024), and in 44% of the full 1001–2000 flood record (Ghazi et al., 2025) meaning that snowmelt, ice-jams, and other winter-related processes accounted for roughly half of all flood causation, even though they lie entirely outside the scope of the present database. Here, of the 477 precipitation events identified, only 280 impact assignments describe an associated flood of any size, while 316 describe damage that was never described as a flood at all. Taken together, these complementary datasets confirm the argument advanced in the Introduction: a flood database alone systematically under-samples the population of damaging precipitation events, while a precipitation database alone would omit the substantial share of Polish floods generated by snowmelt and ice-jam processes rather than rain. The two approaches are best viewed as intersecting rather than nested sets of pre-instrumental hydroclimatic evidence.

The overall temporal profile identified here, a slow, uneven increase from the 12th to 14th centuries followed by a noticeable acceleration from the 15th century and later, matches the pan-European picture assembled by Starkel (2001) from independent flood chronicles, sedimentary records, and dendrochronological evidence spanning England, France, Spain, Switzerland, the Czech Lands, and the Vistula and Dnieper basins. Starkel (2001) identified a Europe-wide "flood belt" that extended across western and central Europe from around 1560, overlapping with the early onset of the Little Ice Age, and noted repeated clustering of heavy-rain and flood years near the turn of each subsequent century, approximately 1590–1610, 1705–1715, and 1800–1815. Our own 50-year sub-period record shows a broadly comparable, if more strongly source-driven, structure, with a first sustained rise in the second half of the 15th century and a pronounced peak in 1701–1750 that overlaps with the 1705–1715 clustering identified by Starkel (2001) and with the early 18th-century flood-rich phase documented independently in Sweden and southeastern Spain, discussed below. While the strong growth of source survival over time makes it impossible to fully isolate a climatic signal from a documentary one, the recurrence of an early-18th-century maximum across several independently compiled European datasets suggests a period of enhanced hydroclimatic activity in several European regions, superimposed on the longer-term documentary trend.

The pronounced summer concentration of heavy rainfall events is also consistent with previous seasonal reconstructions for Poland. For 1361–1500, Przybylak et al. (2023) found that very wet and extremely wet summers were especially frequent during the 15th century, with five such summers identified in the 1460s. The reconstruction for the 16th century similarly indicates that precipitation extremes occurred most frequently in summer. Very wet and extremely wet conditions together represented 26.8% of the indexed summers, and the highest decadal frequencies of wet summer extremes occurred in 1531–1540 and 1571–1580 (Przybylak et al., 2026). These reconstructions classify the overall moisture character of entire seasons, whereas the present database counts individual heavy-precipitation episodes. Exact correspondence between the two types of evidence is therefore not expected. Nevertheless, their agreement at the seasonal scale supports the interpretation that the summer dominance shown in our database reflects an important feature of Polish hydroclimate rather than solely the seasonal priorities of documentary observers.

Two independently constructed European databases offer particularly instructive parallels. In Sweden, Retsö (2015) identified 1591–1670 and the early 18th century as the two principal flood-rich sub-periods in a documentary record spanning 1400–1800, with especially dense clustering in the 1700s and 1720s; roughly a third of all Swedish events were classified as regional or supra-regional in scale, and half of these occurred in the earlier sub-period. The correspondence is notable despite the contrasting seasonal flood-generating mechanisms and raises the possibility of broader circulation influences, although it does not imply that the same spatially uniform precipitation anomaly affected both regions. A broadly similar picture emerges from southeastern Spain, where Machado et al. (2011) found that decadal-to-centennial wet phases, including the early 18th century, were closely tied to positive autumn rainfall anomalies, with an elevated flood frequency sustained through much of the 1600–1740 interval. By contrast, the quantitative precipitation reconstruction for the neighbouring Czech Lands by Dobrovolný et al. (2015) places the driest 30-year period of the entire 1501–2010 series, for winter, spring, summer, and annual totals alike, within the 18th century, apparently at odds with the high event counts recorded in Poland and elsewhere for the same century. This apparent inconsistency likely reflects the different quantities being measured: our database, like those of Retsö (2015) and Machado et al. (2011), counts the occurrence of discrete extreme events, whereas the Czech reconstruction estimates total seasonal precipitation amounts, and a season or century can readily combine a low overall total with an increased frequency of short, intense extremes embedded within otherwise drier conditions. Independent dendro-

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documentary evidence for Central European springtime hydroclimatic extremes supports this reading: Büntgen et al. (2011) found that the occurrence of extreme wet and dry springs was fairly uniformly distributed across the Medieval Climate Anomaly, the Little Ice Age, and the recent warm period, implying that extreme-event frequency need not track total precipitation reconstructions in a straightforward, linear way.

The correspondence among the Polish, Swedish, and Spanish records should nevertheless be interpreted cautiously. Seasonal precipitation reconstructions generally exhibit much weaker spatial coherence across Europe than temperature reconstructions, and relationships between precipitation series decrease rapidly with distance (Brázdil et al., 2022). The early-18th-century peaks in these documentary databases may therefore indicate a period of enhanced hydroclimatic variability across several parts of Europe, but they do not necessarily represent a single spatially uniform precipitation regime. This distinction is especially important because the principal flood-generating seasons and mechanisms differed among southeastern Sweden, Poland, and southeastern Spain.

An independent natural proxy comparison for northern Poland is provided by the oak-based reconstruction of June–July precipitation in Western Pomerania by Cedro et al. (2024). That reconstruction identifies relatively dry intervals in 1703–1706 and 1739–1748, within the same half-century in which our documentary database records the greatest number of individual precipitation events. This apparent difference is not necessarily contradictory. Several brief but damaging downpours may occur during a summer in which accumulated precipitation remains below average, whereas tree-ring growth integrates moisture conditions over a substantially longer period than an individual rainfall event. The reconstruction also identifies wetter phases in 1694–1698, 1776–1780, and 1791–1794, indicating that agreement between seasonal precipitation totals and documentary event counts varies through time rather than remaining uniform throughout the 18th century.

At Gdańsk, the precipitation chronology derived from Gottfried Reyger's observations provides additional temporal context for the northern Polish record. Filipiak et al. (2019) identified generally humid conditions during the first decades of 1721–1786, including a particularly wet phase in the 1730s, followed by drier conditions later in the record. This supports enhanced wetness during part of the 1701–1750 documentary maximum, while also showing that the first half of the 18th century was not uniformly wet. Taken together, the tree-ring and documentary reconstructions suggest that the high event count reflects a combination of genuinely wet intervals and concentrations of short-lived precipitation extremes that are not necessarily expressed in seasonal precipitation totals.

The concentration of recorded events, and particularly of violent, thunderstorm-associated rainfall, in Silesia (Figs. 3a, 6) is consistent with the physical mechanism identified by Mudelsee et al. (2004) for the Elbe and Oder catchments. Using flood chronologies extending back to AD 1269 for the Oder, Mudelsee et al. (2004) attributed the recurrent heavy summer floods of these basins in part to the so-called "Vb" cyclone track, in which low-pressure systems moving northeastward from the Adriatic draw moist air against the Sudetes, the Ore Mountains, and the Beskids, producing intense orographic rainfall in precisely the upland fringe of our Silesia region. This offers a plausible physical, rather than purely documentary, explanation for why violent rain accounts for 45% of all violent-precipitation mentions in Silesia alone (Fig. 6), a substantially higher share than the region's overall 37% contribution to the database (Fig. 3a), and it links our historical record directly to the mechanism invoked for several of the most

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damaging modern Central European floods, including those of 1997, 2021, and Storm Boris in 2024, discussed in the Introduction.

The comparatively modest number of events recorded for the 17th century (103 events, Fig. 2b) relative to the 18th century for heavy precipitation is connected to the Thirty Years' War (1618–1648), which directly affected Silesia, our most productive region, for three decades. Brázdil et al. (2023) documented numerous floods and intense precipitation spells across central Europe during the conflict, including in Silesia itself, alongside population losses that locally exceeded 70% and a substantial decline in building activity in the worst-affected territories. Although that study did not directly assess documentary continuity, such a scale of demographic and administrative disruption makes it plausible that chronicle-keeping and archival preservation in Silesia were also affected during and shortly after the war, which may help explain why the rise in recorded events between the 16th and 17th centuries in our own database (77 to 103 events, Fig. 2b) is comparatively modest relative to the increase into the 18th century, by which time the network of chronicles, parish books, and, from the 1700s, early newspapers had recovered and expanded.

Beyond its value as a historical archive, the database developed here provides a long-term baseline against which modern and projected changes in Central European precipitation extremes can be assessed. Multi-model analyses spanning the last millennium through to the end of the 21st century indicate no systematic change in extreme precipitation between the pre-industrial past and the mid-20th-century historical period, but project large increases in the magnitude of extreme precipitation across most of Europe under both moderate and high-emission scenarios, with the largest relative increases expected for short-duration, high-return-period events (Huo et al., 2021). Instrumental records already point to a tendency toward greater extreme-precipitation intensity across much of Europe (Kundzewicz et al., 2006), and the increasing frequency of catastrophic rainfall-driven flooding described in the Introduction, from the 2021 central European floods to the 2024 Storm Boris event that struck Silesia directly, suggests that this projected intensification is already underway. Observed against our documentary record, in which the greatest historically recorded concentration of heavy-precipitation events also falls in Silesia and coincides with the same Vb cyclone (Messmer et al., 2015) pathway invoked for several of these recent disasters, the present database indicates that this region's vulnerability to violent, orographically enhanced rainfall is not a new phenomenon but a centuries-old feature of its climate, one that anthropogenic warming is now poised to intensify rather than to create. The predominance of "other impacts", damage to crops, orchards, roads, and mills, over flood impacts throughout our record (Fig. 5b) further suggests that the societal costs of heavy precipitation in Poland have historically extended well beyond river flooding itself, an observation of direct relevance to present-day adaptation planning.

Conclusions

This study developed the first comprehensive, documentary-evidence-based database of heavy and extreme precipitation events in Poland spanning the 12th to 18th centuries, identifying 477 events classified by precipitation character, reported impact, duration, and region. By focusing on the precipitation event itself rather than solely on its flood outcome, the database captures a substantially wider population of damaging precipitation than existing flood-centered records: 316 impact assignments described crop, road, or infrastructure damage that was never framed as a flood, exceeding the 280 assignments describing a flood of any size.

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The temporal distribution of recorded events increased steadily from the 12th to the 18th century, most strongly from the 15th century onward, culminating in a maximum of 182 events in the 1701–1750 sub-period. While this pattern is consistent with the well-documented growth of source availability over time, its correspondence with independently compiled flood- and rainfall-rich phases identified in Sweden, Spain, and other parts of Europe suggests that the documentary maximum may also reflect a period of enhanced hydroclimatic activity across several regions of Europe during the early 18th century. Regionally, Silesia and the Baltic Coast and Pomerania together accounted for almost two-thirds of all recorded events, with Silesia showing a particularly strong association with violent, thunderstorm-related rainfall. Generally, heavy precipitation in Poland was considered a summer phenomenon, with nearly half of all classified cases occurring as violent rain alone rather than in combination with long-lasting or heavy precipitation.

Overall, these findings demonstrate that flood-occurrence databases alone systematically underrepresent the historical occurrence of damaging precipitation events in Poland, and that the two types of records should be treated as complementary rather than similar sources of pre-instrumental hydroclimatic evidence. The database presented here, therefore, fills an important gap in the historical climatology of Central Europe and provides a robust, long-term baseline against which present-day and future changes in precipitation extremes can be evaluated. Given the demonstrated concentration of historical precipitation risk in Silesia and its documented mechanistic link to modern flood-generating weather patterns, including Storm Boris in 2024, this record is directly relevant to regional climate risk assessment and adaptation planning.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Author contributions

Babak Ghazi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Rajmund Przybylak:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Piotr Oliński:** Validation, Resources, Investigation, Data curation.

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Availability of data and materials

The database of historical extreme precipitation for Poland during the 12th–18th centuries is available at (https://doi.org/10.18150/T9KJGA). Other data used in this research are available from the corresponding author upon reasonable request.

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