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The 2021 extreme rainfall in Gävle, Sweden: impacts on municipal welfare services and actions towards more resilient premises and operations

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ABSTRACT

Climate-related risks, vulnerabilities, and impacts are increasing in cities, illustrated by precipitation-driven pluvial floods. Post-event analyses can aid in reducing urban flood risks, but knowledge gaps exist regarding how welfare services and premises are impacted and can be adapted. This study analyses an extreme precipitation-driven event generating extensive flooding in Gävle, Sweden, in 2021. The objective is to increase knowledge about how municipal welfare services are vulnerable to pluvial floods, and of appropriate actions towards improving the response capacity and building more resilient welfare premises and operations. The study shows that the Swedish weather warning system generally worked well, but the analysed property companies lacked strategies and equipment to evade flooding in their properties. Flood damages in 60 analysed buildings were generated by different causes, demonstrating the importance of contemplating the vulnerability of welfare buildings when conducting flood risk assessments. Although the flood event did not cause deaths or serious personal injuries, the study identified impacts on welfare service operations in both the short and long terms. The event increased learning on climate adaptation but did not trigger adaptive action. Identified keys for adaptation include prioritizing premises to protect, knowledge of flood protection equipment, insurance company requirements, and updated emergency plans.

Key words: climate change adaptation, extreme events, impacts, pluvial flooding, Sweden, welfare services

HIGHLIGHTS

- Results show that the Swedish weather warning system generally worked well.
- Short- and long-term impacts on welfare buildings and services are reported.
- The 60 damaged buildings analysed were found flooded due to different causes.
- The amount of damage was driven by the vulnerability of buildings rather than exposure.
- The pluvial flood increased learning on adaptation but did not trigger adaptive action.

INTRODUCTION

Climate-related risks, vulnerabilities, and impacts are increasing in cities, housing considerable economic activity, vulnerable groups, and critical activities (Dodman *et al.* 2022). In Swedish cities, this is illustrated by recent precipitation-driven floods that have caused severe damage (Sörensen & Mobini 2017; Knös *et al.* 2022). Currently, on average around 45 heavy precipitation events that cause societal damage occur annually in Sweden (Nyberg *et al.* 2019), and such events are expected to become more intense and occur more frequently (SMHI 2019).

Post-analyses of urban flood events can give real descriptions of the impacts of flooding, and thus present an opportunity for learning and developing applicable actions to mitigate future impacts (Laudan *et al.* 2017; Rosenzweig *et al.* 2018; Schanze 2018). Consequently, such analyses have been conducted both in Sweden (Grahn & Nyberg 2017; Mobini *et al.* 2021; Knös *et al.* 2022) and abroad (Spekkers *et al.* 2015; Van Ooetegem *et al.* 2015; Rosenzweig *et al.* 2018; Koç *et al.* 2021) often focusing on economic, health or infrastructure impacts. For example, an evaluation of pluvial flood events in six US cities found that impacts on roads, underpasses, cars, and housing were common, not only in low-lying areas, while personal injuries and fatalities were rare (Rosenzweig *et al.* 2018). Furthermore, an analysis of pluvial flood impacts on homeowners in Rotterdam, the Netherlands, found that most insurance claims were caused by sewer backups, to a lesser degree by runoff entering building entrances, and occasionally from latent leaks which only could be observed during rainfall (Spekkers *et al.* 2015). Moreover, correlations between water depth and damage costs for buildings are widely researched, assuming water on the surface as the leading cause of flood damage (Van Ooetegem *et al.* 2015; Wing *et al.* 2020).

While such post-event analyses have indeed improved our understanding of urban pluvial flood impacts, scholars suggest that these studies often overlook the causes of flood damage, how the use rather than the type of buildings affect the extent and type of impacts, and indirect impacts such as disruptions in services (Rosenzweig *et al.* 2018). Particularly, impacts on public welfare services are rarely considered (Allaire 2018), resulting in repeated calls for studying how welfare services and premises are impacted to inform the development of adaptation strategies and measures (Thieken *et al.* 2016; Curtis *et al.* 2017; Allaire 2018). Not least, increased knowledge about the causes of pluvial flood damage and how various critical services and premises are vulnerable have been warranted (Curtis *et al.* 2017; Schanze 2018; Opach *et al.* 2020; Koks *et al.* 2022). Such knowledge gaps mean that most decisions on flood risk mitigation are taken without a full overview of the vulnerabilities, and 'a more comprehensive understanding of losses would provide essential evidence as communities around the world adapt to extreme events' (Allaire 2018: 24).

There is, however, some research on flood impacts on public welfare services to build on. A study addressing the July 2021 pluvial floods in Germany, Belgium and the Netherlands demonstrated drastic impacts on critical infrastructure, healthcare and education, including 68 affected hospitals in the state of North Rhine-Westphalia, taking up to 1.5 years to rebuild. Furthermore, more than 8,000 students in the region of Rhineland-Palatinate were affected when 17 schools were damaged (Koks *et al.* 2022). Studies after Hurricane Katrina showed that many schools were either closed or had premises suspended years after the fluvial floods, and found healthcare impacts, including drastically reduced psychiatric capacity, due to affected premises and health infrastructure (Gray 2008). A German post-flood event study demonstrated that many schools, preschools, and health facilities were impacted (Thieken *et al.* 2016), and an analysis of media articles in Sweden found affected schools, preschools and elderly homes following pluvial flood events as well as health impacts (Nyberg *et al.* 2019). A post-event study of floods combined with subsequent power outages in New York showed impacts on care facilities and medical equipment that generated drastic increases in illness (Deng *et al.* 2022). Furthermore, the few studies that have analysed flood damage in premises for welfare services show that the placement, use and storage of medical equipment (Chambers *et al.* 2020; Deng *et al.* 2022), the use of flood-prone premises and the robustness of power supply (Curtis *et al.* 2017), and access to alternative premises (Chambers *et al.* 2020) influence flood impacts on healthcare services.

The initial literature on flood impacts on welfare services stipulates that an increased understanding of vulnerabilities is key to identifying risk-reducing actions (Koks *et al.* 2022). This involves improving both the *response capacity* (Chambers *et al.* 2020), and the *resilience* of buildings, premises and support infrastructures (Curtis *et al.* 2017) and welfare service operations (Singh-Peterson *et al.* 2015). The response capacity has been found negatively affected by lacking knowledge of the course of a pluvial flood event, related risks and action alternatives among property owners (Hjerpe *et al.* 2020) and healthcare operations (Chambers *et al.* 2020).

Following the outlined research needs, this study aims to increase knowledge about the vulnerability of municipal welfare services to pluvial floods, and of appropriate action towards building more resilient welfare premises and operations, by analysing a, by Swedish standards, extreme precipitation-driven event leading to extensive floods in Gävle, Sweden, in 2021. Although investigations of the economic impacts of this event have been conducted, no detailed analysis of impacts on welfare services and premises has been presented. Zooming in on 60 damaged welfare buildings owned and managed by a municipally owned property company, Gavlefastigheter, from early warning to the company's follow-up work and perceived adaptation action needed, the paper addresses three research questions:

1. How did the property company act before, during and after the pluvial flood event, and what actions can be taken to improve their response capacity?
2. How did the water enter the analysed welfare premises, what was damaged, and what actions can be taken to increase the resilience of the welfare buildings?
3. How did the pluvial flood event impact municipal welfare services, and what actions can be taken to increase the resilience of the welfare service operations?

STUDY AREA AND ANALYSED FLOOD EVENT

Located in East Sweden, the municipality of Gävle (60°40′29″N 17°8′40″E) sits on the mouth of the river Gavleån with an outlet in the Gävle bay, the Baltic Sea. In December 2020, the population in Gävle municipality was 103,500 people, where around 79,000 lived in the urban area (Statistiska centralbyrån 2023). Like many other urban areas in Sweden and abroad, the city consists of a large proportion of impervious surface, and the oldest parts have a dated and partly combined storm and wastewater system.

Swedish municipalities are not only responsible for physical planning and municipal administration but also for providing welfare services, ranging from preschools to eldercare, which a large part of the population depends on. In Sweden, 84% of children aged 1–5 years attend preschools and 9 years of primary education is mandatory. In Gävle, 1,056 people older than 65 years lived in elderly homes and 870 people in other care homes and assisted living at the time of the study.

Gavlefastigheter is a municipally owned property company, that owns and maintains 358 properties including schools, preschools, care and nursing homes, activity centres, cultural buildings, offices and sports facilities. During the 2021 pluvial flood event, 60 (17%) of these were damaged, including 21 schools, 5 preschools, 9 activity centres, 12 sports facilities and 13 other buildings such as municipal offices, theatres, museums and event facilities.

On Sunday, August 15, 2021, the Swedish Meteorological and Hydrological Institute (SMHI) issued a class 1 warning, implying some risks for the public and disruptions to some social functions, due to anticipated heavy rain in Gävleborg county. On Tuesday, August 17, the warning was upgraded to a class 2 warning, implying danger to the public, the risk for major material damage and major disruptions in important social functions, due to very large amounts of rain in the magnitude of 70–100 mm (Länsstyrelsen Gävleborg 2022). The warning was never updated to a class 3 warning, meaning great danger to the public and very large disruptions to important social functions, but triggered several coordination meetings within Gävle municipality, resulting in employees being sent out to clean storm drain grates at selected locations, and information about the weather warning was sent out to property owners including Gavlefastigheter (Gävle Municipality 2022).

During the night between August 17 and 18, 2021, extreme precipitation hit Gävle, breaking national records for 2- to 12-h rainfall events (SMHI 2021), with estimated historical return periods of up to 3,900 years (Länsstyrelsen Gävleborg 2022). Over 24 h, the SMHI automatic measuring station Gävle A recorded 161.6 mm of precipitation with 121 mm occurring during the three most intense hours from 21:45 to 00:45 (Jeppson Stahl 2022; Länsstyrelsen Gävleborg 2022). Not only was the intensity of the rain extreme, it was also preceded by a prolonged period of rain, saturating the ground and reducing its infiltration capacity (Jeppson Stahl 2022). The rapid progress meant that already in the morning of August 18, most of the water had receded in urban Gävle, except in underpasses and low-lying areas. However, the heavy rains also caused high water flows in small and medium-sized watercourses, resulting in fluvial floods within urban Gävle as well as adjacent residential and industrial areas on August 18–19 (Länsstyrelsen Gävleborg 2022). Since the heavy rain occurred the night before schools were to open after the summer holidays, the municipality decided to postpone the school start, communicated via media the early morning of August 18 (Gävle Municipality 2022).

Initial analyses of this pluvial flood event uncovered, for Sweden, substantial damage on insured property, resulting in 6,830 insurance claims, including 5% of all single-family houses in the county of Gävleborg, exceeding EUR 160 million in insured damage costs (Finansinspektionen 2023). Furthermore, a number of bridges collapsed in Gävleborg County (SMHI 2021), several roads in Gävle were undermined, collapsed or had to be dug up to remove water masses, and many low-lying areas and underpasses were inundated, compromising the accessibility for the rescue and home care services (Gävle Municipality 2022). However, only minor personal injuries and social impacts have been reported (Länsstyrelsen Gävleborg 2022).

METHODS AND EMPIRICAL DATA

Data were collected in four ways, following a methodology to assess climate-related risks in property portfolios (Opach *et al.* 2020). As the *first* data source, three stakeholder workshops were conducted with employees from Gavlefastigheter and a municipal official (Table 1). Workshops are described as a suitable research method for leading discussions on problems and problem-solving in a collaborative setting (Ørngreen & Levinsen 2017). The method was thus deemed apt to gain insight into the responses by the property company, the damaged buildings and actions perceived as effective in reducing flood risks in the property portfolio. The first workshop, WS1, focused on how the flood event was handled by the property company. Moreover, the 60 damaged buildings were scrutinised. It was decided to follow-up on the extent and origin of the damages

Table 1 | Workshop themes, participants, and duration

Date	Theme (s)	*N*	Participant's role in organisation	Length app.
28 February 2022	Discuss the course of the flood event, company responses and damaged buildings	3	CEO, property manager, area manager	1h
25 April 2022	Discuss impacts and flood causes in damaged buildings. Selection of buildings to inspect	7	Managers for properties, development, operation and maintenance; area managers, municipal planner	1 h 30m
18 August 2022	Analyse inspection material. Discuss adaptation needs and measures to mitigate flood risks	8	CEO, managers for properties, development, operation and maintenance; area manager, municipal planner; warden	1 h 45m

using an open-ended survey, the *second* data source, to gauge: where water entered the flood-damaged buildings, the location and extent of water in the building, how the building was impacted by the flood, and if and how the welfare service operation was impacted. To categorise where water entered the damaged buildings, a distinction was made in the survey between: (1) *surface openings*: water entered the building through openings such as entrances, garage doors, windows, external access to basement or exterior basement stairs (Godfrey *et al.* 2015; Hjerpe *et al.* 2020; Sandink & Binns 2021), (2) *sewer backup*: water flowed up through floor drains or toilets (Spekkers *et al.* 2015; van Ootegem *et al.* 2015; Rözer *et al.* 2016), (3) *other openings*: water entered the building from latent openings such as ventilation shafts, sump pits, groundwater leaks or other ways (Godfrey *et al.* 2015; Spekkers *et al.* 2015; Sandink & Binns 2021), and (4) *multiple causes* of flooding, i.e. from combinations of the other three ways. Nine out of ten property managers responded to the survey, resulting in responses for 53 of the 60 damaged buildings.

At the second workshop, WS2 results from the survey were discussed and overlayed on a flood risk map. In 20 buildings, the causes of flood damage were either deemed unclear or information was missing, and for these *in situ* inspections were carried out, as the *third* data source, following a protocol (Hjerpe *et al.* 2020) to validate and complement survey results. In most cases, the inspections were conducted together with a property manager. The results were documented in a Word file together with photographs of damages and likely causes of impacts, i.e. where water entered the building.

At the third workshop, WS3, the inspections and survey results were discussed, focusing on common flood causes in the buildings, material damage, and actions to reduce flood risks.

As a *fourth* data source, complementary information about possible flood damage in care homes and assisted living was obtained through two semi-structured interviews with one official at the caring department and one official at Gavlegårdarna, the property owner of residential buildings and some municipality-run care homes and assisted living.

The empirical material was analysed thematically following the three research questions.

RESULTS AND DISCUSSION

The results are presented per research question.

Property company responses to the flood event and actions to improve the response capacity

At WS1, Gavlefastigheter's early action after having received the weather warning to the follow-up work after the pluvial flood event was discussed.

Responses before the flood

The respondents described that the company had a good grasp of the weather forecast and warning, via both its own weather application and the municipal coordination meetings. Based on this, operating technicians and tenants were informed of the expected pluvial event. The respondents described that some district managers informed operational staff about buildings that could be particularly vulnerable, but no list of prioritised buildings to protect was available.

Responses during the flood

As the rainfall intensified late in the evening of August 17, on-call staff were sent out to monitor how the event was unfolding and deal with the rainwater, driving between various buildings. As large amounts of water began to flood the buildings, mass text messages about the status of buildings were sent from on-call staff, who were also described as beginning to 'fight the water with shovels and brooms' (WS1). This feedback led to an internal crisis team being set-up during the night, consisting of managers, representatives of operation areas and Human Resources in case the pluvial flood led to fatalities or personal injuries. When the crisis team realised the extent of the water volume at about 01:30, contacts were made to locate pumps. Pumping of individual buildings began at 04:30, somewhat delayed by difficulties in accessing buildings due to inundated roads and underpasses. The respondents noted shortages of both staff and pumps. At this stage, tenants and other staff were instructed to stay at home and avoid the roads. Early in the morning, the company received many error reports from tenants.

Responses after the flood

The WS1 respondents described that immediately after the pluvial flood event, the company sought to obtain a clear picture of the state of damage in all their 358 buildings, aiming to make them usable for tenants as soon as possible. The management decided at this stage to prioritise healthcare facilities, schools, and preschools when allocating resources. In most schools and preschools, thus, operations were resumed already two days after the event, even if parts of the premises, often basements, were unusable. Even in cultural buildings, and most municipal offices, operations were resumed relatively soon, while sports facilities, some cultural buildings and buildings for day activities for the disabled remained closed for up to a year. Early efforts to make premises usable meant pumping water from basements and elevator shafts, repairing electricity main switches and roping off dangerous areas.

Subsequently, post-event responses were targeted at, firstly, producing documentation to comply with insurance rules to ensure damage costs were covered by the insurance. Respondents found this very time-consuming, demanding them to prove to the insurance company that it was the heavy rains and not faulty construction in the buildings that caused damage and to find the right way to report damage in accordance with how insured objects were grouped. Secondly, coordinating the restoration of the 60 damaged buildings to their original condition was challenging. Finding craftsmen for all restoration tasks was described as difficult due to the large number of damages in the county. According to the respondents, the insurance companies had demands on maximum renovation budget but did not bring up the issue of preventing future damage during restoration.

Actions to improve the company response capacity

At WS1 and WS2, respondents discussed positive aspects of their management of the pluvial flood event, and actions to improve the company's response capacity based on their experiences. The respondents concluded that the warning chain, including coordination meetings with other municipal departments and utilities, worked well overall. Furthermore, loyal and energetic staff, good contacts with tenants and municipal officials, continuous information from operating technicians about the state of damage throughout the event, and the composition of competencies in the internal crisis team, were also viewed as contributing positively to their response capacity during the event. However, they also noted that internal routines and equipment were lacking, constraining their capacity to respond. Four actions to improve the company's response capacity stood out as particularly important: (1) Prioritisation of the most important buildings to protect during a pluvial flood, described securing staff on site, ready to respond at the prioritised objects. Availability of equipment described as needed for on-site staff included high-capacity pumps, barriers, and sandbags. As argued, staff also need to know how to operate and use this equipment, emphasising scenario training for extreme rain. Updated information about the most critical welfare service operations, the location of vulnerable persons, and buildings in which expensive or critical material is being stored were seen as key to developing the priority list. (2) To train crisis groups for different types of extreme events, comprising different competencies that should be activated once a weather warning is received was viewed as key for enabling rapid and adequate responses at the immediate stage. (3) Develop and share checklists and acquire material needed to identify and respond to detected damages, such as sinkholes and fallen trees. (4) Establish principles for restoration after damage, including installing backflow-blockers, choosing waterproofed doors, and avoiding water-sensitive construction material, described as important to have decided beforehand, since restoration needs to happen quickly to avoid long-term consequences for welfare services in a situation where the staff are overburdened. Related to this, ensuring documentation of damaged buildings was viewed as key to facilitate learning from the event and avoid building in the same level of risk during restoration.

Discussion

What stood out as particularly positive is that the Swedish flood warning system, with weather warnings from the SMHI and internal coordination at Gävle municipality, seems to have worked well, providing the analysed property company with an opportunity to prepare. This demonstrates the benefit of a well-functioning warning system, enabling the property company to quickly mobilise staff, provide a live overview of the buildings' inundation status, and set-up a crisis team to lead early responses. Although the municipality and the property company had no previous experience with extreme precipitation-generated floods, other weather events, such as an extreme snowfall in 1998, appear important, showing that previous events can facilitate quicker responses. However, the company does not seem to have had a sufficiently clear emergency strategy or equipment to counteract flood damage, as also found in previous studies (Chambers *et al.* 2020; Hjerpe *et al.* 2020). Here, a prioritisation of which buildings to protect appears key since the pluvial flood made it difficult to get around to all buildings, and a property company cannot reasonably be expected to have enough personnel or equipment to protect all buildings at risk. However, further learning appears needed to identify effective measures to avoid flooding in prioritised buildings. For example, respondents mentioned actions, such as filling and stacking sandbags, which appear too slow to deal with a rapid course of events such as a pluvial flood. This shows a need to disseminate knowledge about effective measures to protect buildings from pluvial flooding to property owners, often being distinct from fluvial flooding that Swedish actors generally are more used to dealing with due to recurring spring floods.

What is really problematic is that no preventive measures have been implemented during the restoration of the damaged buildings, indicating a lost opportunity to adapt when large amounts of money are spent on restoration. Here, the logic of quickly restoring buildings seems to have blocked an analysis of the causes of damages and preventive measures. Also, the insurance company did not require any risk-minimizing measures, which indeed is remarkable and thus does not incentivise risk reduction (c.f. Rosenzweig *et al.* 2018). Information on how flood risks can be mitigated during restoration and requirements for such measures from insurance companies appears central to avoiding returning to the same level of risk after renovation.

Impacts on welfare premises and actions to increase the resilience of welfare buildings

The survey, WS2 and the *in situ* inspections were used to gauge the cause of flooding in the damaged buildings, and the type and extent of damage in the buildings and in the yards.

Causes of flooding in buildings

The survey and the inspections established where the water flooded into the buildings in 53 of the 60 damaged buildings. In the seven remaining buildings, no clear cause could be detected, since the waterlogged area had been very limited and was already restored at the time of the inspections. In line with pluvial flood studies of residential buildings, we found that the water entered these buildings in several ways (Table 2).

The results show that the most common way water entered the building was through *surface openings*, corresponding to 65% of the 53 buildings. Although this is not unexpected, an overlay of the damaged buildings with the low point mapping in Gävle (Figure 1) shows that most of the surface-flooded buildings are not located in or near a low point. Rather these buildings have very low entrances, often 0 cm from the ground, and exterior basement stairs and windows located at or below

Table 2 | Share of flooded welfare buildings after type of building, and ways in which water entered the building

	1. Surface openings[a]	2. Sewer backup[a]	3. Other openings[a]	4. Multiple causes	*N*
Schools	65%	35%	35%	35%	20
Preschools	40%	80%	20%	20%	5
Activity centres	83%	17%	33%	33%	6
Sport facilities	64%	55%	9%	27%	11
Other buildings	45%	0%	73%	18%	11
All buildings	65%	35%	35%	35%	53

[a] The figures in groups 1–3 include all buildings that were damaged in this way. Since water was reported to enter buildings through one or more mechanisms the total percentages in each row sum up to more than 100%.

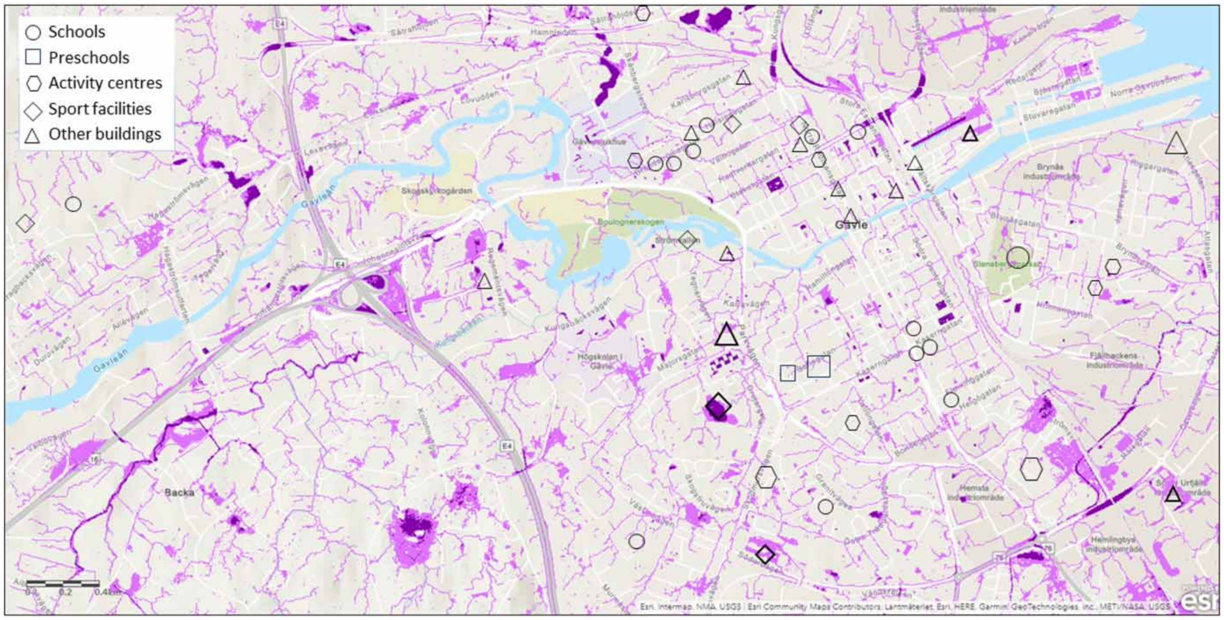

Figure 1 | Overlay of damaged buildings with a low point mapping of Gävle, adapted from Tengdelius Brunell & Sjökvist (2016), representing modelled flood areas during a rainfall event with a historical return period of 100 years. The deep purple layer represents flood areas with water levels exceeding 1 m. The light purple layer represents flood areas with water levels exceeding 0.2 m. Buildings with substantial damages are represented by larger symbols in the figure, and damaged buildings located in a low point are represented by bold contour lines.

ground level. Moreover, the results suggest that flood water entered welfare buildings in different ways with 35% of buildings experiencing water ingress through at least one of the following; *sewer backup*, *other openings* and *multiple causes*. Examples of identified ways in which water entered the *other openings* category were leaky basement walls and floors, sump pits, hatches to culverts, roofs, internal roof drainage systems and ventilation shafts.

The *in situ* inspections provided additional details about the above patterns, and revealed some important lessons:

(i) Although surface flooding was most frequent, indicated by 65% of the damaged welfare buildings, two-thirds of the buildings that were flooded only through *surface openings* reported no or small damage whereas two-thirds of buildings where the surface was one of the multiple reasons reported major damages or damages to several rooms. The inspections indicate that entrance doors, in particular, have been proofed enough to allow only small volumes of water to seep in, often limiting the inundated area to just inside the door. Exceptions include entrances with impervious reverse slopes, or where water has been standing in exterior basement stairs, generating a longer exposure time.

(ii) In buildings flooded by very large volumes of water, in some cases up to 2 m of water depth, this was attributed to the presence of a sump pit. Sump pits were usually found in older buildings where groundwater is continuously pumped away through a hole in the ground via the stormwater system, often in combination with leaky basement walls. Large volumes of water were found to be pushed up via sump pits and the pumps overheated and broke down once the stormwater system was full.

(iii) *Sewer backup*-floods, indicated in 35% of the buildings, demonstrate how difficult it is to assess the degree of flood risk. Contrary to what was expected, few sewer backup-flooded buildings were located in areas with combined stormwater and wastewater systems, and just over half of them had basements. A telling example is a building on the top of the slalom slope just outside the urban area, the highest-situated building in the city, receiving substantial amounts of water via internal drainage wells.

Damages in buildings and yards

Generally in all assessed welfare buildings, damages most frequently occurred in basements, and the following vulnerability parameters were found to greatly influence the extent of these damages: (1) usage of basement premises, (2) storage of material in basements, and (3) the height of technical installations in relation to ground level or basement floor. Regarding usage, basement premises are often used as classrooms in schools, play areas in preschools, and rehabilitative activities such as art rooms in day-care activities. This implies that basement premises in welfare buildings in many cases have similar floor and wall material and equipment as above-ground premises, making restoration costly. This also generated greater impacts on the welfare operations in basement premises, as will be described in the following. Material and furniture stored in basements were also frequently damaged. In individual cases more critical materials were stored in basements such as the city archive. Regarding technical installations, we found that elevator shafts were often damaged but described as relatively easy to remedy, power switches were damaged and thus power was cut off in a few buildings. Notably, the inspections found that in buildings equipped with backup power, found in some schools and care facilities, these were located at floor level in basements.

In relation to the magnitude of damages in the assessed buildings, Table 3 reports the share of substantially damaged buildings. It is worth noting that all building types are represented within each of these categories and that only nine of the 60 damaged buildings were located at a low point (Figure 1). This indicates that the design of the buildings, and likely the micro-topology of yards not captured in the low point mapping, maybe more important drivers for substantial damage than the welfare activity in them and their overall topographic location. Moreover, the study found that damages in school buildings were the most costly, nearly SEK 700,000 per school, and that a higher share of activity centres was damaged, with a higher average damage cost (SEK 550,000) compared to the overall average. Fewer preschools were damaged, and the average damage cost in preschools (SEK 213,000) was lower than the average damage cost in all buildings.

The eight buildings with substantial damages have the following characteristics: five of them were flooded through multiple openings, three of them through drainage sump pits or underground openings; six of them had basements with rooms used for activities, i.e. with more costly walls and floor material and equipment; and three of them were located in a low point.

To get an indication of whether welfare buildings were more or less impacted than other building types, a comparison was made with the municipal housing company, Gavlegårdarna, in Gävle, which mainly owns residential buildings. According to their annual report (Gavlegårdarna 2022), 175 of their buildings were damaged during the pluvial flood event. According to the interviewee from Gavlegårdarna, a slightly lower proportion of their buildings were damaged compared to Gavlefastigheter, while damage cost per building was higher. For Gavlegårdarna, the total amount of compensation claimed from their insurance company amounts to SEK 150 million, i.e. roughly SEK 850,000 per damaged building, thus almost double in residential buildings compared to welfare buildings. According to the interviewee from Gavlegårdarna, this may be because homes are more expensive to restore, due to, for example, a high degree of wooden flooring.

On the yards of welfare buildings, the pluvial flood event generated sinkholes, in some cases up to three metres deep, along facades, in sandboxes and on impervious surfaces in mainly school and preschool yards. Most sinkholes were described as having been discovered shortly after the event, but some later on where impervious surfaces had upheld the ground. Locations of sinkholes were described as very hard to predict. Furthermore, a few trees in school and preschool yards were also described as being so affected by the water-saturated ground that they were about to fall and had to be cut down. This was described as a wake-up call as the property company lacked both the equipment and skills to handle this.

Table 3 | Number and share of damaged and substantially damaged buildings, and total and average damage cost after type of building

	Number of buildings	Number and share of damaged buildings	Number and share of substantially damaged buildings	Total damage cost (SEK 1,000)	Damage cost per building (SEK 1,000)
Schools	79	21 (27%)	2 (2.5%)	14,503	691
Preschools	93	5 (5.4%)	2 (2.1%)	1,066	213
Activity centres	19	9 (47%)	1 (11%)	4,403	550
Sports facilities	40	12 (30%)	1 (2.5%)	808	67
Other buildings	127	13 (10%)	1 (0.8%)	6,158	474
Total	358	60 (17%)	8 (2.2%)	26,939	449

Actions to increase the resilience of welfare buildings

Four categories of adaptation actions to increase the resilience of welfare buildings were highlighted to decrease flood risks in the company's property portfolio, and some actions also mitigate other climate-related risks and enable co-benefits. To some extent, these actions overlap with actions seen as important to address in a more thoughtful restoration work:

First, reducing latent defects in the buildings, including addressing groundwater pumping by installing watertight hatches for sump pits, lining interior pipes for roof drainage, elevating low-located air ventilation and ensuring that holes in pipe penetrations in basement walls and roofs are sealed. This was viewed as low-cost actions, easy for caretakers to perform when knowing what to look for, and able to reduce some damage if a similar pluvial event should occur in the future.

Second, reducing the risk of major flood damage in basements is viewed as difficult or too costly to completely eliminate in all buildings. Proposed actions included protection of power switches, elevator machinery and archives using waterproof doors, water-resistant construction material and furniture and ensuring that reserve power units are not placed on the floor. This, too, were described as relatively low-cost and easy actions, particularly well-suited to highly exposed city districts.

Third, reducing the exposure of some critical welfare buildings by, for instance, installing backflow-blockers on main pipes for storm and wastewater, constructing low points in the yards, and ensuring that the ground slopes away from entrance and garage doors and exterior basement stairs. The inspections found reverse slopes towards entrances in many welfare buildings, described as being there due to high demands on accessibility. Creating low points at some distance from the building was seen as a way to remove reverse sloping and still meet accessibility demands. However, these actions were described as more costly and only possible to carry out in conjunction with major construction work.

Fourth, increasing the amount of greenery and enhancing the infiltration capacity of yards. Currently, many schoolyards consist of 'asphalt seas' that the company was not proud of but reduced maintenance costs and facilitated emergency vehicles. Even if these actions were viewed as more costly, time-consuming and requiring collaboration with the welfare operations, they were viewed as the most important for the company to put in place. Here multi-functionality was brought up, as these actions can simultaneously meet other important needs such as reducing the risk of high temperatures, increasing attractiveness, and enabling outdoor education.

Discussion

Results from the analysis of flood causes in the damaged buildings largely follow patterns in previous studies (e.g. Sandink & Binns 2021). Most buildings were flooded via surface openings (Van Ooetegem *et al.* 2015) and similar numbers were flooded via back pressure in storm and wastewater systems (Spekkers *et al.* 2015), multiple causes (Grahn & Nyberg 2017), and latent leaks (Spekkers *et al.* 2015). In line with Grahn & Nyberg (2017), the study suggests that the vulnerability of the building rather than on surface exposure explains whether flooding occurred. Moreover, the great diversity between different flood causes can be attributed to the fact that many welfare buildings are large and complex, illustrating the difficulty of assessing flood risks stemming from extreme rainfall events in welfare buildings.

The study identified sump pits as a flood cause in a few buildings (Sandink & Binns 2021) but also found that buildings flooded through sump pits were receiving the largest volumes of water and were substantially damaged, which was not previously mentioned. Furthermore, the study suggests that flooding via entrance doors may be less problematic than often assumed (e.g. Spekkers *et al.* 2015). In the analysed buildings, entrance doors appeared to only let in small water volumes. This may be because entrance doors on welfare buildings often are extra robust for other reasons, but this needs further investigation.

Related to actions to increase the resilience of welfare buildings, the study suggests a range of technical measures that the property company has knowledge of and can implement by themselves, and that actions to make buildings less vulnerable by, for instance, sealing leaks, protecting vulnerable technical installations, and installing backflow-blockers, neither need to be expensive nor difficult to implement. Measures on yards that could reduce exposure, including creating local low points, ensuring that land slopes away from buildings and increasing the infiltration of surfaces, were also seen as feasible. Respondents underscore the importance of ensuring that these measures are implemented in future renovation projects. A checklist that specifies how such easily usable measures can be included in renovation projects thus appears central to property companies' climate adaptation work.

Impacts on welfare services and actions to increase the resilience of welfare service operations

Overall, the immediate impact on the welfare services was described as surprisingly small, in view of the significant extent of the pluvial flood. The major reason was attributed to the fortunate timing of the event, occurring around midnight when few people were staying in the buildings and basements, and one day before the schools were to open after summer break. The respondents were worried about the personal injuries and fatalities that they feared could have occurred if the rain had come during daytime when children would have been present in basement classrooms and playrooms, and wheelchair users in activity rooms, where power switches and basement premises were flooded. However, seven categories of impacts in the medium- and long-term could be identified:

First, in at least six flooded schools, classrooms for special education, crafts, music, and physical education where it was difficult to find replacement premises were unusable for periods ranging from a few months up to over a year. Second, rehabilitative activities for people with non-normal abilities were suspended for several months, impacting their physical and mental well-being. Third, staff and goods, including food, could not be transported to individual schools, preschools, and caring facilities for a few days due to inundated or collapsed roads, leading to temporal closure. Fourth, elevators were out of order for a few days in nursing homes, making it very difficult for staff to work and for patients to move. Fifth, the usage of preschool and schoolyards was restricted due to sinkholes, in some occasions up to a year after the flooding, also causing fear that more sinkholes could appear and that someone could be injured. Sixth, staff in schools, preschools and care homes that were flooded continuously were concerned about strange odours, or if they felt unwell, were worried that it could be a consequence of the flood. This, in turn, was described by the property company as something they needed to respond to, generating costly and time-consuming investigations. Seventh, the caring department respondent described that while the flood did not generate any fatalities or serious accidents among the elderly, it caused reoccurring anxiety among staff during rain and it created disputes at workplaces since staff and dressing rooms were unusable, damaged equipment was not replaced, and the routine during flooding was seen as unclear.

Actions to increase the resilience of welfare service operations

During WS1, WS3 and both interviews, the respondents discussed actions to make welfare service operations more resilient to a pluvial flood event. Four categories of actions were frequently discussed: (1) Develop a plan for joint use of undamaged premises, including how to co-use classrooms across schools and use art classrooms in schools for rehabilitative activities for people with non-normal abilities. (2) Reduce the usage of basement premises for critical welfare operations since they are generally not built for critical operations, and it would be best to avoid using them for such purposes. (3) Prioritisation of which patients are most important to care for, including people with disabilities for whom rehabilitative interventions are most important, and those home care users most in need of care. Such priorities would reduce the stress and anxiety among staff, and minimise the suffering of the welfare service users. (4) Developing a routine, specifying tasks that staff should deprioritise to reduce staff stress and anxiety. These partially overlapping actions are linked to existing, but more general, crisis plans in both the care and education departments, that, according to respondents, should be updated with extreme weather events in focus.

DISCUSSION

The above results indicate that municipal welfare services and people's health were more impacted by the pluvial flood event in Gävle than reported by the County Administrative Board (Länsstyrelsen 2022) in their preliminary assessment. The study thus strengthens conclusions from previous studies highlighting that the impacts of urban flooding on welfare services and people's health are often underreported (Thieken *et al.* 2016). Although the studied pluvial flood event did not generate deaths or serious personal injuries, there were both short-term and long-term strains on particular municipal education and care activities, as found in previous studies in healthcare (Curtis *et al.* 2017; Chambers *et al.* 2020; Deng *et al.* 2022). Not least, the study shows the impact on staff well-being in schools, preschools and caring, and the impacts on disabled people who lost out on rehabilitative activities. The study further highlights a need to update emergency plans for education and care with pluvial flood events in focus, and internal routines and priorities for staff. Finally, the study highlights vulnerabilities in welfare services caused by the usage of basement premises, similar to what has been found for residential buildings (Spekkers *et al.* 2015; Sandink & Binns 2021). Basements seem to have become more frequently used over time, as buildings are being equipped with new technical installations and cities become more compact. As the risk of these premises being damaged during a pluvial flood is high, a broader debate should be held about how basements should be used and by whom.

CONCLUSIONS

This study is based on a, by Swedish standards, extreme precipitation-driven event leading to extensive floods in Gävle, Sweden, in August 2021. The study set out to increase knowledge about how municipal welfare services were affected and are vulnerable to urban pluvial floods, and of appropriate actions towards improving the response capacity and building more resilient welfare premises and operations.

The study shows that the Swedish weather warning system worked well overall, providing the property company with an opportunity to prepare. The company was able to put together an internal crisis team and alert on-call staff but lacked a clear emergency strategy and equipment to avoid or reduce flood damages in their buildings. To improve the company's response capacity, a prioritisation of buildings to protect, and ensuring the availability of knowledge about how to operate equipment to prevent precipitation-driven flood damages appear central.

Furthermore, the study established shares of causes to why the buildings were flooded, with surface as the most frequent but least damaging cause, and similar shares of buildings being flooded from sewer backup, other and multiple causes. Consequently, the study found a range of causes as to why the 60 analysed buildings were flooded, likely due to the fact that welfare buildings are generally large, complex and more vulnerable than other building types. This underscores the difficulty of performing accurate flood risk assessments for welfare buildings, especially if assessments rely heavily on the water on the surface as the primary cause of pluvial floods. In the Gävle event, the risk of damage appeared driven more by the vulnerability of the buildings rather than their flood exposure, and most significant damages were not caused by water entering via surface openings but via sump pits or other so-called latent leaks, suggesting that they are important to consider in flood risk assessments.

Moreover, this study established a range of short- and long-term impacts on welfare service operations that have not been found in previous assessments of this pluvial flood event (Länsstyrelsen Gävleborg 2022; Finansinspektionen 2023). These do not only include direct impacts such as material damage, but also longer-term impacts on operations due to unusable classrooms, damaged premises for rehabilitation activities for the disabled and sinkholes in preschool yards. This study thus strengthens previous conclusions, suggesting that societies around the world need to increase focus on the resilience of critical welfare services in their adaptation work (Thieken *et al.* 2016; Allaire 2018; Koks *et al.* 2022). This study identified long-term effects including stress and anxiety which have been observed in other countries and made visible, for example, the need for actions to deal with post-traumatic stress.

Related to climate adaptation, the study shows that no risk-minimizing measures were implemented during the restoration of the 60 damaged buildings and that the insurance company neither brought up nor required any such measures. Yet, respondents have identified many cheap and simple actions that can be implemented in the future to make the property portfolio more resilient. Moreover, multifunctional adaptation actions such as increased greenery in school yards were emphasised, since such actions arguably address other pressing risks such as urban heat. The study also found important actions to make welfare service operations more resilient including updating crisis plans, staff allocations and routines. The post-analysis of the pluvial flood event appears to have facilitated the property company and welfare service operations to identify such adaptation actions able to mitigate pluvial flood risks. However, as shown, such adaptation actions are not implemented automatically, as there are many factors maintaining a status quo. How incentives and knowledge that steer towards climate adaptation can be created warrants further research.

AUTHOR CONTRIBUTIONS

E.G. and M.H. conceived and designed the study; E.G. and M.H conducted the workshops; E.G. conducted the survey; E.G. and M.H. performed the inspections; E.G. conducted the interviews; E.G., M.H., and S.S. analysed the data; E.G. M.H., and S.S. wrote the draft paper. All authors have read and agreed to the published version of the manuscript.

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DATA AVAILABILITY STATEMENT

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

CONFLICT OF INTEREST

The authors declare there is no conflict.

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