NEW DATA SOURCES FOR CLOUDBURST RISK ASSESSMENT AND MANAGEMENT

NYA DATAKÄLLOR FÖR BEDÖMNING OCH HANTERING AV SKYFALLSRISKER

Lars Nyberg[1,2], Shifteh Mobini[3,4], Konstantinos Karagiorgos[1,2], Jonas Olsson[3,5], Rolf Larsson[3], Louise Petersson[5], Remco van de Beek[5], Kristin Gustafsson[1], Tonje Grahn[1]

[1] Karlstad University, Risk and Environmental Studies, 651 88 Karlstad
[2] Centre for Natural Hazards and Disaster Science (CNDS)
[3] Lund University, Water Resources Engineering, Box 118, 221 00 Lund
[4] Trelleborg Municipality, Rådhuset, 231 83 Trelleborg
[5] Swedish Meteorological and Hydrological Institute (SMHI), Hydrology Research, 601 76 Norrköping

Abstract
Urban flooding causes large societal damages and increased climate adaptation measures is needed. The rapid and local character of extreme rain events make them difficult to observe and predict, and to issue warnings for. There is also a lack of data on urban flood damages, mainly because of scarce and non-systematic data collection and management. In this paper, we present the approaches behind the new research project SPARC. The overarching aim of the project is to improve urban rain safety by establishing a participatory system for crowdsourcing of data, to support urban flood risk modelling and adaptation of cities to intense rainfall. The project will also investigate flood damage mechanisms on the built environment as well as evaluate and communicate small-scale adaptation measures. Municipal water and wastewater utility organizations and insurance industry representatives will be included in a trans-disciplinary process, also including crowdsourcing in a citizen science approach.

Sammanfattning
Urbana översvämningar orsakar stora samhällsskador och skyfallens snabba och lokala karaktär gör dem svåra att observera, förutsäga och varna för. Det finns också brist på data om översvämningsskador, främst på grund av knapp och icke-systematisk datainsamling och -hantering. I denna artikel presenterar vi ett nytt forskningsprojekt: SPARC. Det övergripande syftet med projektet är att förbättra säkerheten i städer i samband med skyfall genom ett deltagardrivet arbete för insamling av data som stöd för analyser och modellering av urbana översvämningsrisker, och för att i förlängningen anpassa den byggda miljön till intensiv nederbörd. Projektet kommer också att undersöka mekanismerna bakom översvämningsskador samt utvärdera och kommunicera småskaliga anpassningsåtgärder. Kommunala VA-organisationer och företrädare för försäkringsbranschen kommer att ingå i en tvärvetenskaplig process, som även inkluderar insamling av data från medborgare, och riskkommunikation med fastighetsägare.

Keywords: intense rain, cloudburst, flood, damage, risk management, data, crowdsourcing, participation

Introduction

Flood events due to local intense rainfall are frequently causing damage and disturbance in Swedish cities. A cloudburst flood occurs every second day in summertime somewhere in Sweden (Nyberg et al., 2019). Each event typically has limited consequences at local level, but the high frequency generates a large accumulated societal effect. We also, however, experience large-scale catastrophic events, such as in Germany and Belgium in summer 2021 (see e.g. Bosseler et al., 2021), with more than 200 lost lives. One reason for the potentially large consequences of cloudbursts is the uncertainties of when and where they will occur, which makes prevention and preparedness difficult. The knowledge of the natural and societal processes related to cloudburst flood events is still limited, and new data sources are needed to improve the resolution of spatial and temporal observations in order to fully capture the variability of intense rain and, in turn, assess and understand its societal consequences.

This article presents the concepts behind SPARC (see Table 1), a new Swedish research project funded by Formas during 2022–2025. Based on the need for more data with high temporal and spatial resolution, the project will investigate possibilities to involve crowdsourcing methodologies to increase the available amount of data on intense rainfall, flood damage and potential adaptation measures at local level, as a contribution to improved cloudburst flood risk assessment and management in urban environments.

Cloudbursts risks and its assessments

Cities are affected from cloudburst events that cause damage to buildings and critical infrastructures (Figure 1). The future projections for Sweden indicate that we will face more extreme summer rainfalls (Olsson et al., 2017). The 2011 Copenhagen cloudburst caused more than 8 billion SEK in insurance claims (Meyer et al., 2013). On 31 August 2014, Malmö was hit by a torrential rainfall that already has become historic in terms of measured rainfall in Malmö (data records from 1880). This event resulted in more than 2,000 insurance claims (Hernebring et al., 2015; Sörensen and Mobini, 2017) and an approximate total damage of more than 600 million SEK. An event in Gävleborg and Dalarna in Sweden on 17–18 August, 2021, had its rain maximum around the city of Gävle which resulted in new Swedish rain records from 2 h rain (102 mm), up to 12 h rain (148 mm)

Table 1. *SPARC: Stakeholder participation for climate adaptation – data crowdsourcing for improved urban flood risk management (www.kau.se/csr/sparc). The project is organised in four interconnected work packages:*

WP 1: Innovative data collection and high-resolution urban flood modelling	WP 2: Systematic management of urban flood damage data	WP 3: Risk communication and integration of urban rain adaptation measures
Focus: Collect rain data and water depth data from extreme events using crowdsourcing. Assess the added-value of enhanced data-resolution for hydraulic modelling. *Stakeholder participation:* Engage citizens in rain data collection and observations of flood depth and extent.	*Focus:*Systematically collect and analyse damage data. Develop methods for data collection and secure management. *Stakeholder participation:* Involve municipal water utilities, and insurance companies in systematic collection, management and use of damage data.	*Focus:* Integrate and communicate the use of small-scale adaptation measures (SSA) in urban flood risk management. *Stakeholder participation:* Establish focus groups of house owners and municipal planning officers for risk communication around small-scale adaptation measures.
WP 4: Project management and communication		

Figure 1. *Example of a flooded Swedish urban environment. Photo: Mikael Svensson.*

(SMHI, 2021). A first assessment of the damage is that the event generated more than 7,000 insurance claims, corresponding to more than 1 billion SEK (SVT, 2022).

The global warming is expected to lead to more intense cloudbursts, as a warmer atmosphere can contain more water vapour and as convection will be triggered more often. Current estimates for Sweden (Svenskt Vatten, 2011; SMHI, 2022a) suggest that the 10-year rainfall will become 20-40% larger by the end of the century, depending on how the emissions of greenhouse gases develop. This estimated increase turned out to be rather independent of duration and valid also for other return periods (Olsson et al., 2017).

Design of societal structures that are sensitive to cloudbursts is based on Intensity-Duration-Frequency (IDF) and Depth-Duration-Frequency (DDF) statistics, generally based on a generalized mathematical expression fitted to empirical observations. In Sweden, current guidelines use a national relationship, i.e. without regional differences (Dahlström, 2010). More recently, regional statistics as well as location-dependent relationships have been developed (Olsson et al., 2019) and it is likely that these will replace the national relationship (SMHI, 2022a).

There is a lack of knowledge and data on damage and disturbances caused by cloudbursts. An increasing scientific literature in the Nordic countries on cloudburst flood risk (see e.g. Skovgard Olsen et al., 2015; Torgersen et al., 2015; Grahn, 2017; Blumenthal, 2018; Mobini, 2021) has substantially increased the level of knowledge, but there is still much to learn about damage and costs at societal and property levels. Better knowledge about the damage is also a way to improve the understanding of the mechanisms that connect intense rainfall, flooded objects, and the consequent damage.

Cloudburst risk assessments are less used than risk assessments for other types of floods. One example of this is the implementation of the EU Flood directive in Sweden, where cloudburst risk information is included as a recommended but not an obligatory complement to the assessments of river, lake and coastal floods (MSB, 2018). Another example is the recent assessment of the ten worst risk-exposed areas in Sweden, which includes risks from river, lake, and coastal floods, together with landslides and erosion, but not floods from cloudbursts (SGI and MSB, 2021). This is likely because this type of assessments is less developed than for rivers, lakes and coasts, but also because of various methodological difficulties. With the limited knowledge of today, cloudburst risk assessment and management have to be carried out for all areas where there are potentially negative consequences, which mainly correspond to all urban areas. The knowledge of the hazard component, e.g. which areas will be inundated, has increased due to the use of various types of topographic and hydraulic models. The complicated link to the vulnerability component, i.e. where the water causes damage and disturbances and how effective adaptation measures can be implemented, is less known. A better understanding of spatial and temporal variability of individual cloudbursts, their negative consequences, and potential adaptation measures would decrease these uncertainties and make preventive action more precise.

To complement the traditional data sources on cloudburst risks, we can see great potential in crowdsourcing techniques. Such techniques, linked with public engagement activities via so called citizen science, are frequently used across science to supplement traditional means of data collections. As such, people are nowadays also data producers. In the SPARC project, we will investigate the potential for crowdsourcing in three areas:

- Rainfall observation: The cores of high-intensity rain events are often not captured in national, or even municipal, gauge networks because of its local character and information from private weather stations as well as from social media could substantially increase the density of spatial information of rain events.
- Damage assessment: Damage data are heavily scattered between different actors and the EU directive GDPR makes it difficult to share sensitive data at property level. Voluntary sharing of damage data by public and private actors, including a secure treatment of sensitive data, would increase the data amount and enable flood analyses at property level as well as aggregated assessments at local, regional and national levels.
- Local countermeasures: Adaptation measures at property/block level are needed to infiltrate and store stormwater to reduce damage from intense rainfall. The effects of such measures and the citizens' willingness to protect themselves and their neighbourhoods will be investigated with help of focus group discussions and network activities.

The three areas are described further in the three following sections.

Data sources for intense, local and short-duration rain events

Urban flooding, which occurs when the stormwater drainage systems are totally or locally overloaded due to heavy rainfall, is very strongly related to the characteristics of the individual rain event. Quite often, such events are associated with large variations of rain intensity in both time and space. This means that a design storm with simplified distribution in both time and space can seriously misrepresent the rain in a real case. Consequently, in such a case, any attempt at calibrating or validating a flood model will be in a poor starting position without high-resolution measurements of the rain.

Apart from hydrological/hydraulic modelling one can approach the design and analysis of urban stormwater systems using the concept of critical rain intensity. Also, for this method, it is crucial to have a quite precise representation of the rain distribution in time and space. Finally, in a more general sense, improved rain data with more details about spatial and temporal variations in rain intensity would serve as essential input to urban planning with consideration to climate adaptation as well as improve our understanding of the small-scale rainfall process.

For observations of rainfall with a short time step, there are mainly two types of devices used: weighing gauges and tipping buckets. The weighing gauge, as the name suggests, continuously weighs a container that is automatically emptied when full. A regular time step is used between the weighings and this time step can be very short, down to single seconds. A tipping-bucket gauge contains two small buckets, with a volume of typically 0.1 or 0.2 mm, that tip over when filled up, allowing the other bucket to start getting filled up. Typically, the tipping times are recorded, thus the output is a series of time stamps representing "bucket tips". Gauge observations provide the best estimates of "ground truth" with respect to rainfall, but they are associated with errors, e.g. due to wind-induced losses (undercatch).

Another important technique for observing rainfall is weather radar, which may be used at temporal resolutions down to single minutes. In terms of spatial resolution (and coverage), different types exist, the main ones being C-band radar (resolution ~1-2 km) and X-band radar (~500 m). Radar has the advantage of full spatial coverage, in contrast to the point observations of gauges, but the estimated rainfall intensity is uncertain and it is affected by a range of error sources. Therefore, gauge adjustment is generally required (e.g. Berg et al., 2015). A final technique worth mentioning is rainfall estimation by using signal attenuation in commercial microwave link networks, which can provide observations with a time step down to 10 seconds (e.g. van de Beek et al., 2021).

In Sweden, since 1995–1996, SMHI operates a network of ca. 130 automatic weather stations that measures rain with a 15-min time step currently (the time step is being reduced). Additionally, a network of 12 C-band radars is used to provide observations at 2×2 km² resolution. The C-band data are gauge adjusted into the HIPRAD product (Berg et al., 2015). Furthermore, many cities and municipalities operate their own gauge networks, and even X-band radars (VA Syd in Dalby, NSVA in Helsingborg) and currently a project focuses on transferring these observations into a joint database at SMHI (SMHI, 2022b).

Meteorological information can now be obtained from many non-traditional sources such as citizen scientists, amateur weather stations and sensors, smart devices and social media (Muller, 2015). De Vos et al. (2017) examined the potential of crowdsourced datasets and the quality of the measurements of rainfall for Amsterdam. Another example is from Chapman et al. (2017) who explored the use of air temperature data from private weather stations to monitor London urban heat. Positive experiences from using citizen observations of air temperature to improve forecasting were recently reported from Norway (Nipen et al., 2020). Such studies highlight the potential of crowdsourcing of amateur measurements, but there remains a scientific challenge in scaling up the measurements and achieving a fusion possible to expand and complement existing data sets. In Sweden, initial tests have been carried out of the performance of the Netatmo rain gauge, which is one of the brands commonly used as private weather stations (Figure 2).

SMHI has launched a web site in Sweden connected to the international Weather Observation Website (WOW) initiative (www.smhi.se/vader/observationer/mina-observationer-wow). Here, any citizen may connect their device and upload weather observations in real time. Currently, more than 300 private weather stations are connected in Sweden.

The SPARC project will engage citizens in rain data collection and observations of flood depth and extent, to assess the added value of the data for generating integrated rainfall products and to increase the understanding of flood drivers. The project will use principles of sensor fusion to enhance resolution and accuracy of existing official rain data from SMHI and Swedish municipalities. The project will also validate the significance of high-resolution input data on the performance of two widely used hydraulic models: LISFLOOD FP and HEC-RAS.

We need coordination of damage data

Following a cloudburst event, basements of buildings are usually the first to suffer flood damage due to sewer connections, as the urban drainage system quickly fills (Mobini et al., 2020). Flood water rises in low terrains, causing damage to var-

Figure 2. *Test of performance of a Netatmo rain gauge, carried out by SMHI. Photo: Mikael Stenström, SMHI.*

ious objects such as cars – more than 1500 cars were damaged during the storm event August 31, 2014 in Malmö (Sveriges Radio, 2014). Insurance data is an important source as the insurance sector have direct contact with the property owners and perform the initial assessment of the damage cost (Wing et al., 2020). Flood damage data, however, is dispersed across the insurance companies, each company collects data in their own way, and there is no systematic collection at regional or national level. In Sweden, insurance damage data are privately owned (Grahn and Olsson, 2019) and not easily accessible, in comparison to other European countries where damage data are shared with academia (e.g. in Germany: Kellermann et al., 2020).

In Sweden, a special legal practice allows insurance companies to claim their payouts to affected property owners from municipal water and wastewater utilities following a flood event (Regresskrav). This means that after a flood event, the data collected by these municipal organisations become a source of claims of all insurance companies. As a result, the role of municipal water and wastewater utilities in Sweden is critical for both collecting and disseminating data. The damage cost, however, does not represent the total cost. The cost of flood damage to buildings can be divided into three categories: cleaning costs, building material damage, and content damage (Mobini et al., 2021). Having access to each component of the total cost is critical for assessing the parameters that influence the cost. The ideal scenario for Sweden would be to have a systematic national flood damage database with data directly from insurance companies. Meanwhile there could be a national collection of flood damage data from municipal water and wastewater utilities to establish a collection of standardized flood damage data nationally.

We find a very good example of sharing insurance data in Norway, where the branch organisation for the insurance sector Finance Norway, together with the governmental authority Direktoratet for samfunnssikkerhet og beredskap (DSB), have created a database – Kunnskapsbanken (https://kunnskapsbanken.dsb.no) – containing information and data to support prevention and preparedness at local and regional levels. One part of the database contains data on previous disaster events, including consequences and costs, and via a log-in, municipalities and other actors can get access to data. A similar initiative has not yet been taken in Sweden.

The SPARC project will increase the knowledge of flood damages on built environment, and develop a method for systematic and secure damage data collection in collaboration with municipalities and the insurance sector.

Interesting development of adaptation measures

While urbanisation historically has proceeded by areal growth starting from old city centers a.k.a. urban sprawl, the new paradigm is based on densification (Rosenberger et al., 2021). In Europe and North America, this is a big shift in strategies and practices of urban planners, and the result is that many spaces between existing buildings are developed for housing or commercial use. In turn, this shift has potentially substantial effects on urban hydrological processes. The most important effect of densification is that surfaces are changing from being capable of infiltrating rainwater to being close to impervious.

As a result of urban densification, and associated increased impervious areas, the response from water engineers is to focus on various specific measures to mitigate these problems. The principles used are to infiltrate, store and discharge water in safe ways. The actions taken involve a mix of what is often denoted as blue-green solutions. Typical examples are rain gardens, green roofs, ponds, permeable asphalt, swales etc. While the technical design of many of these structures are well established, various obstacles hamper their implementation. Problems arise, for example, due to issues regarding maintenance and financing. One complicating factor is that measures taken in one location (typically upstream) is beneficial at another location (typically downstream). This latter issue can be resolved by using financial incentives like reduced water fees for those property owners who implement flow-reducing measures.

Another problem for promoting blue-green measures is that they are still often considered as new and unproven. In order to improve this situation, it is necessary to keep on evaluating the performance of such measures from various points of view, like hydrological, ecological, and economic. Furthermore, such information needs to be collected and made easily available to anyone interested, e.g. on the Climatescan platform (www.climatescan.nl).

In recent years, incentives have been offered to property owners in various municipalities throughout Sweden for disconnecting gutters from the city's drainage system. For example, in Malmö, 2500 SEK have been offered for each gutter disconnected from the building (VASYD, 2022), which has contributed to a reduction in stormwater flow in the city's drainage system. There are numerous other ways for property owners to manage stormwater on their own land. As part of the project "Plats för vatten" (Room for Water) in Malmö, house owners receive suggestions from the municipal water and wastewater utility VASYD.

Another approach to reduce stormwater flow that has been used in several other countries (for example Austria, Australia, Canada, France, Germany, and Poland) is to base the monthly fee on the amount of stormwater (Tasca et al., 2018; Dierkes et al., 2015). In Sweden, different municipalities have different strategies for the stormwater fee. However, before proceeding with a suggestion to place the responsibility for stormwater reduction on the house owners, it is necessary to establish a common understanding of who is responsible for urban flooding due to cloudbursts, and whether the allocation of responsibility on the owner is correct according to current Swedish legal practice.

The SPARC project will assess and communicate the use of small-scale flood adaptation measures as a way for homeowners and property owners to be part of a space-for-water approach to reduce flood risk for themselves and their communities. The project will establish focus groups of house owners and municipal planning/building officers for effective assessment and communication.

Conclusions

It is clear that Sweden as well as many other countries will suffer from increased cloudburst flood risk, both because of the global warming and the urban development. To prevent further damage, the knowledge about key factors behind these risks needs to increase. The positive side of the problem is that there is large potential for using data from new sources to get a better understanding of the spatial and temporal variability of rainfall, as well as of flood damage and potential countermeasures. This data already exists to a large extent, but needs to be collected, coordinated, analysed, and translated into practice. Existing data sources, mainly managed by public actors, need to be combined with crowdsourcing where citizens are involved and share their data in different ways. Management of cloudburst risk is a typical area where participatory approaches for data sharing can be fruitful, and where new data sources can contribute substantially to increased urban safety.

References

Berg, P., Norin, L., Olsson, J. (2015) Creation of a high resolution precipitation data set by merging gridded gauge data and radar observations for Sweden. J. Hydrol., 541A: 6-13.

Blumenthal, B. (2018) Nederbördsintensitet och andra faktorer som påverkar skyfallsskador. Licentiate Dissertation, Dept of Risk and Environmental Studies, Karlstad University, Sweden.

Bosseler, B., Salomon, M., Schlüter, M., Rubinato, M. (2021) Living with Urban Flooding: A Continuous Learning Process for Local Municipalities and Lessons Learnt from the 2021 Events in Germany. Water, 13:2769.

Chapman, L., Bell, C., Bell, S. (2017) C an the crowdsourcing data paradigm take atmospheric science to a new level? A case study of the urban heat island of London quantified using Netatmo weather stations. International Journal of Climatology, 37:3597-3605.

Dahlström, B. (2010) Regnintensitet – en molnfysikalisk betraktelse. Svensk Vatten Utveckling, Report 2010-05.

De Vos, L., Leijnse, H., Overeem, A., Uijlenhoet, R. (2017) The potential of urban rainfall monitoring with crowdsourced automatic weather stations in Amsterdam. Hydrology and Earth System Sciences, 21:765-777.

Dierkes, C., Lucke, T., Helmreich, B. (2015) General technical approvals for decentralised sustainable urban drainage systems (SUDS)-the current situation in Germany. Sustain., 7:3031–3051.

Grahn, T. (2017) Risk assessment of natural hazards – Data availability and applicability for loss quantification. PhD dissertation, Dept of Risk and Environmental Studies, Karlstad University, Sweden.

Grahn, T., Olsson, J. (2019) Insured flood damage in Sweden, 1987-2013. J. Flood Risk Manag., 12: e12465.

Hernebring, C., Milotti, S., Kronborg, S.S., Wolf, T., Mårtensson, E. (2015) Skyfallet i sydvästra Skåne 2014-08-31: Fokuserat mot konsekvenser och relation till regnstatistik i Malmö. VATTEN – J. Water Manag. Res., 71:85–99.

Kellermann, P., Schröter, K., Thieken, A.H., Haubrock, S.N., Kreibich, H. (2020) The object-specific flood damage database HOWAS 21. Nat. Hazards Earth Syst. Sci., 20:2503–2519.

Meyer, V., Becker, N., Markantonis, V., Schwarze, R., Van Den Bergh, J.C.J.M., Bouwer, L.M., Bubeck, P., Ciavola, P., Genovese, E., Green, C., et al. (2013) Assessing the costs of natural hazards-state of the art and knowledge gaps. Nat. Hazards Earth Syst. Sci., 13:1351–1373.

Mobini, S. (2021) Just or Unjust: Assessment of rainfall-related flood damage in a Swedish context. PhD dissertation, Water Resources Engineering, Lund University, Sweden.

Mobini, S., Becker, P., Larsson, R., Berndtsson, R. (2020) Systemic Inequity in Urban Flood Exposure and Damage Compensation. Water, 12:3152.

Mobini, S., Nilsson, E., Persson, A., Becker, P., Larsson, R. (2021) Analysis of pluvial flood damage costs in residential buildings – A case study in Malmö. Int. J. Disaster Risk Reduct., 62:102407.

MSB (2018) Översyn av områden med betydande översvämningsrisk. Swedish Civil Contingency Agency, report MSB1152.

Muller, C.L., Chapman, L., Johnston, S., Kidd, C. , Illingworth, S., Foody, G., Overeem, A., Leigh, R.R. (2015) Crowdsourcing for climate and atmospheric sciences: C urrent status and future potential. International Journal of Climatology, 35:3185-3203.

Nipen, T.N., Seierstad, I.A., Lussana, C., Kristiansen, J., Hov, Ø. (2020) Adopting citizen observations in operational weather prediction. Bulletin of the American Meteorological Society, 101:E43-E57.

Nyberg, L., Hakkarainen, H., Blumenthal, B., Moberg, J.-O. (2019) Consequences of summer cloudbursts in Sweden 2009–2018. Centre for Climate and Safety, Karlstad University, report 2019:2.

Olsson, J., Berg, P., Eronn, A., Simonsson, L., Södling, J., Wern, L., Yang, W. (2017) Extreme rainfall in present and future climate, SMHI Climatology No 47, SMHI, 601 76 Norrköping, Sweden, 82 pp (in Swedish).

Olsson, J., Södling, J., Berg, P., Wern, L., Eronn, A. (2019) Short-duration rainfall extremes in Sweden: a regional analysis, Hydrol. Res., 50:945–960.

Rosenberger, L., Leandro, J., Pauleit, S., Erlwein, S. (2021) Sustainable stormwater management under the impact of climate change and urban densification. Journal of Hydrology, 596: 126137.

SGI and MSB (2021) Riskområden för ras, skred, erosion och översvämning, Redovisning av regeringsuppdrag enligt regeringsbeslut M2019/0124/Kl. Swedish Geotechnical Institute (SGI) and Swedish Civil Contingencies Agency (MSB).

Skovgard Olsen, A., Zhou, Q., Linde, J.J., Arnbjerg-Nielsen, K. (2015) Comparing methods of calculating expected annual damage in urban pluvial flood risk assessments. Water, 7:255-270.

SMHI (2021) Svenska nederbördsrekord. https://www.smhi.se/kunskapsbanken/meteorologi/ svenska-nederbordsrekord-1.6660. (accessed 11 Jan, 2022)

SMHI (2022a) Statistik för extrem korttidsnederbörd. https://www.smhi.se/kunskapsbanken/ meteorologi/statistik-for-extrem-korttidsnederbord-1.159736. (accessed 17 March, 2022)

SMHI (2022b) Nationell insamling av nederbördsobservationer. https://www.smhi.se/polopoly_fs/ 1.159895!/Faktablad%20Nationell%20insamling%20av%20nederb%C3%B6rdsobservationer%20-%20200403.pdf. (accessed 17 March, 2022

Svenskt Vatten (2011). Nederbördsdata vid dimensionering och analys av avloppsvatten. Publikation P104. Svenskt Vatten AB, Stockholm.

Sverige Radio (2014) Lång väntan innan skadade fordon ersätts. https://sverigesradio.se/artikel/5962538. (accessed 14 March, 2022)

SVT (2022) Kostnaden för översvämningen i Gävle – över en miljard kronor. https://www.svt.se/nyheter/lokalt/gavleborg/kostnaden-for-oversvamningen-i-gavle-over-en-miljard-kronor. (accessed 8 May, 2022)

Sörensen, J., Mobini, S. (2017) Pluvial, Urban Flood Mechanisms and Characteristics – Assessment Based on Insurance Claims. Journal of Hydrology, 555: 51–67.

Tasca, F.A., Assunção, L.B., Finotti, A.R. (2018) International experiences in stormwater fee. Water Sci. Technol., 2017:287–299.

Torgersen, G., Bjerkholt, J.T., Kvaal, K., Lindholm, O. (2015) Correlation between extreme rainfall and insurance claims due to urban flooding – Case study fredrikstad, Norway. Journal of Urban and Environmental Engineering, 9:127-138.

van de Beek, R., Olsson, J., Andersson, J. (2020) Optimal grid resolution for precipitation maps from commercial microwave link networks, Adv. Sci. Res., 17:79-85.

VASYD (2022) Plats för vattnet Available online: https://platsforvattnet.vasyd.se/. (accessed 13 Feb, 2022)

Wing, O.E.J., Pinter, N., Bates, P.D., Kousky, C. (2020) New insights into US flood vulnerability revealed from flood insurance big data. Nat. Commun., 11:1444.