Vulnerability of water infrastructure in urban communities

A comparison of cities within Europe

Bachelor's thesis in International Logistics

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Cover: Clear water running out of a faucet into a sink. Photo is staged outside.
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SUMMARY

This report is a comparison of three European cities; Berlin, Gothenburg, and London. Water supply infrastructure is explored and analyzed to find possible vulnerabilities. Similarities in problems, approach and handling are investigated as well. The common denominator for these cities is their demographic growth as well as their geographical location in the northern hemisphere. Further, the common vulnerabilities and solutions are explained and compared.

Key words: Water infrastructure, Water supply systems, Urban water planning, Urban flooding, Precipitation

Abstract

Water distribution is a vital part in an urban society. The water distribution infrastructure contributes to multiple necessary functions, the most vital being potable water distribution to the inhabitants. Analyzing the vulnerabilities to this system can be an important part of it is function. In this thesis a further comparison of this subject will be made through three European cities; Berlin, Gothenburg, and London. Previous research is presented to give an understanding of the current systems in the respective cities, research is used to look further into the possible vulnerabilities for these cities. Later a comparison of the three cities' vulnerabilities and future possibilities is made. To gather material and research a qualitative document analysis has been condoned to answer the research questions. Through the qualitative document analysis literature was gathered and an expert interview was performed. The main result from this study; the impact of precipitation on the water supply systems and urbanization expansion problematics is discussed.

Innehållsförteckning

1. Introduction

Drinking water is one of the basic needs for every living thing. In cities today there is a common obstacle to being able to provide potable water to a growing population. In the urban societies in the world there are over two billion citizens in need of clean water, this is a constantly growing number (Wilson Center, n.d). Water supply and its infrastructure is an essential part of modern society and a key to the expanding of cities. Growing populations in European cities put a strain on infrastructure and create vulnerabilities and threats.

This study is a comparison between Berlin, Gothenburg, and London, three cities in Europe with a similar population growth percentage. To be able to understand how the cities handle their vulnerabilities the problematic relationship between growing populations and existing water infrastructure is explored. In order to analyze this relationship, the report explores the possible vulnerabilities and threats towards the water infrastructure. The possible expansion of the infrastructure is analyzed as well. By analyzing these relationships within the cities, the report presents possible threats to the infrastructure and how these might hinder the cities from further expansion. Through this a better understanding of the water infrastructure, vulnerabilities and expansion of urban areas is analyzed and discussed.

A vulnerability is something that can easily be hurt or influenced by external factors. In this report *vulnerabilities* are explored from a point of view towards water infrastructure in the cities and an analysis of external factors, that can affect the water infrastructure to discern the systems. The vulnerabilities can be connected to global weather changes such as floods and droughts, as well as weak infrastructure and the infrastructure's ability to adapt to the growing population. Urban floods pose one of the largest vulnerabilities towards cities. As cities grow the risk of urban floods only increases. However, the risk can be minimized, and the solutions explored.

1.1 Aim of the study

This report aims to give an understanding of three cities in Europe and their vulnerabilities regarding the water infrastructure through comparison. The goal is to be able to identify and present possible solutions based on each city's prerequisite through a qualitative document analysis. This to answer the research questions of a deeper understanding how each city individually works to prevent and handle vulnerabilities. As well as finding similarities within vulnerability connected to water infrastructure system. The comparison aims to analyze different solutions to similar problems, this provides a broader understanding of how water infrastructures are vulnerable to external factors.

1.2 Research questions

- What are the biggest vulnerabilities each city has towards their water infrastructure?
- What has been done already to ensure that the city can expand according to the demand of the population growth?

2. Background from prior research

To better understand the rest of the report the following segment will provide a background. The paragraphs are based on empirical facts that can be found and aim to give the reader a broader understanding when moving through the report.

2.1 Understanding water supply systems

A water supply system can be built up in different ways. The water is first retrieved from a source, in an urban society this source is normally surface water from watercourse or groundwater. The water is transported through pipes to a treatment plant or a water tower, from here the water is transported out for use (World Health Organization [WHO], 2019). There are different ways to distribute the water from a treatment center. Which system a city uses depends on the layout and infrastructure of the city. Some systems are: *Ring system*, when using this the pipes form a circle around the point of distribution, this is a good system for a city with good infrastructure. *Radial system*, with a radial system the city is divided into zones connected to different points of distributions. *Dead-end systems* are good to use in cities that do not have good infrastructure or clear roads. The dead-end systems work by having a main line running throughout a city and having pipes branch off from the main line. A *Gridiron system* does also have a main line with pipes branching out, but in contrast to the dead-end system in a Gridiron system the branched-out pipes all connect back (Blair Supply Corporation, 2019). Each system has its own sensitivities. When designing a water system, the choice of system will be a vital part, the choice of systems should be based on layout of the city. The access to water and the current infrastructure. Depending on the system a city uses, it will lead to different challenges for expansion.

2.2 Correlation between urban expansion and precipitation

It is nearly impossible to not consider urbanization and growing populations when touching upon the subject of vulnerabilities, possible flooding, and the consequences of heavy precipitation. As the above-mentioned cities are located in the northern hemisphere both snow and rain create precipitation and must be considered a possible threat. Along with the steady growth of urban populations, it puts a strain on the runoff possibilities for precipitation in the cities. Bengtsson and Westerström (2009) conclude that the “conditions within an urban area are heterogeneous” (p. 264). Therefore, rain and snow have different runoff possibilities within the urban areas. The possibility also depends on the season and whether the snow has melted or not. Urban floods mainly occur by cities having large impenetrable surfaces that cause rapid runoff during heavy rainfall (Jha et. al., 2012). When focusing on the risks of urban flooding there are two major sources to this phenomenon - rapid urbanization and climate change. According to Cities and Flooding the two most pressing possibilities are “the rapid development of flood-prone areas as urbanization proceeds, and the changes in weather patterns in association with climate change” (Jha et. al., 2012, p. 26). As both of these are important to mention, this report aims to focus on the risks connected to population growth and flooding in the urban areas. “Poorly planned and managed urbanization [also] contributes to the growing flood hazard” (Jha et. al., 2012, p. 21).

Urban conditions have different kinds of surfaces, such as grass, compact soil, and grassy parks as well as gravel and asphalt. These different conditions offer different possibilities for precipitation to infiltrate or run off. Due to the denseness of asphalt, rain and snowmelt have a hard time being absorbed back into the ground. However, gravel or an urban park offers much better absorption back into the ground. The denser materials are being used in urban communities, the larger the runoff is. This concludes to larger probability of runoff into manholes, and therefore larger risk of urban flooding as the manholes might not be able to comprehend the amount of runoff from the dense areas. However, it must be considered that in urban communities there are also some areas that are kept snow-free. To the furthest extent roads and walkways are kept snow-free to the comfort of pedestrians on and off the road. Roofs are usually snow-free as well, however that depends on the slope of the roof. The flat, or mild sloping roofs, might contribute to a higher runoff into manholes when snow melts (Bengtsson & Westerström, 2009). On the flipside, steep roofs contribute to a higher runoff when heavy rain occurs. This means that some areas, artificially, experience heavy precipitation. Areas where snow is plowed to and stored through the winter to keep roads snow-free will also experience all that snow melting when spring comes. If there are poor runoff possibilities where the snow had been stored the risk of urban flooding increases.

Furthermore, in a report from SVU (Svenskt Vatten Utveckling [Swedish Water Development]) it is stated that the possibilities to anticipate heavy downpour is varying and very much dependent on the weather. For the forecasts to be of any usefulness it must be very accurate in the time- and space frame. Beyond the need for preciseness, it is very hard to create accurate models as the weather before is often unpredictable (SVU, 2017). According to SMHI (Swedish Meteorological and Hydrological Institute) research shows a correlation between extreme weather and climate change. The probability for extreme precipitation has only increased and will continue to increase. SMHI defines “extreme precipitation” as at least 40 millimeters of precipitation during a 24-hour period. Research predicts that extreme precipitation during a day (24-hour period) will only increase in the future (SMHI, 2023).

2.2.1 Urban expansion problematics

When expanding a water infrastructure system, the city has to analyze the cost of the expansion. However, in many cases a responsible water provider has a responsibility to be able to provide drinkable water in all areas of a city, and this includes newly built neighborhoods. The providing company needs to take the whole supply chain into perspective. From seeing if the water resources are enough to provide, how the possibility to expand or use the current water infrastructure can be used and utilized (Chang, et, al. 2012).

Bergkamp et. al (2015) mentions that when building an infrastructure system most cities have a subsystems approach, this means that they focus on finishing the access to water first, and secondary is finishing points such as sanitation and sustainability. This makes a city livable quicker but will affect the overall quality of life within the city as other perspectives are not taken into consideration as they expand the city. When building in an urban city today Bergkamp et. al (2015) means that we have started to think in a more sustainable way, this to prevent effects that came with climate change. With new natural disasters such as flooding and heavy amounts of rain cities need to be able to utilize the extra water in certain situations. By including the principle of the “5 Rs” *Reduce*, *Reuse*, *Recycle*, *Recover*, and *Replenish* in urban water planning, it can become more sustainable for an urban setting (Bergkamp et. al. 2015). Furthermore, the report mentions that urban water planning has gone from a multidisciplinary sequential to transdisciplinary holistic perspective on water planning. By applying a transdisciplinary holistic perspective, the system can be analyzed as a whole. The transdisciplinary holistic system also emphasizes the interaction between different systems that can affect individual systems. In water planning a transdisciplinary holistic system takes other societal systems in perspective but is also subject to climate change impact on the systems (Bergkamp et. al. 2015).

2.2.2 Vulnerabilities in flooding

As stated above, rapid urbanization is the biggest contributor to the increased risk of urban flooding. As this is a human made problem there is also a solution humans can implement. By having an integrated flood risk management, the risk of urban flooding can be decreased. Flood management consists of two parts - structural and non-structural measures. The goal for structural measures is to reduce the flood risk by “controlling the flow of water both outside and within the urban settlements” (Jha et. al., 2012, p. 32) and can be made through urban design and management. Some structural measures that can be taken includes more green urban areas, improving drainage, and better maintenance of infrastructure. These are examples of measures that can decrease the risk of flooding (Jha et. al., 2012).

There is a wide range of structural measures that can be taken. It can consist of everything from engineered structures to more natural alternatives such as wetlands and natural buffers. When used appropriately they are highly effective. Sometimes, structural measures reduce flood risk in one area by moving it to another area. However, there is a risk that the structural measures are not enough against natural events. If there also is the risk of natural events posing too big of a strain on the structural measures this could conclude in a very large risk of urban flooding. All this together can add up to even more strain on the natural conditions and still present a flood risk, and in the worst case it can even worsen the natural state and therefore pose an even bigger threat of urban flooding. Non-structural systems are the most important measures to have to be able to safeguard the population from floods by means of better planning and management of urbanization. Such as flood warning systems and evacuation planning. The biggest flaw in society is humans and it tends to be forgotten that disaster can strike again. This lack of memory can result in old and weakened systems and resources, and overall preparedness (Jha, K. A. et. al., 2012).

3. Method

This study is based on a qualitative document analysis (QDA) that follows the premises of Conducting a Qualitative Document Analysis by Morgan (2022) and Application of Rigour and Credibility in Qualitative Document Analysis: Lessons Learnt from a Case Study by Wood et. al. (2020). Wood et. al. (2020) introduces four overlapping interwoven steps; First pass document analysis, this step is to find literature related to the purpose of the report. The second step is to conduct interviews and to analyze the result of all the gathered material. The material gathered from the interview(s) will be used to compare the information presented in the literature and give further information than the literature can. The last step is thematic document analysis and literature, this step is to analyze the credibility of the facts through categorization. To summarize, QDA is a method to help gather and compare data and information with similar information to have a reliable outcome. After reviewing more documents and data is collected and compared, to secure more reliable sources. This was to systematically identify patterns and possible bias in the information. By implementing this strategy, the analyze could move forward with only the most relevant information and conclusions that could be made.

To gather literature for this thesis different search motors have been used, mainly ResearchGate, Scopus and Google Scholar. Different search words were being used to find relevant information, following were used to find articles; “water resources”, “water risk”, “water”, “risk”, “water infrastructure”, “Water infrastructure” AND “resilience”, “urban”, “precipitation”, and “urban” AND “Precipitation”. After gathering the articles were sorted out the articles that could be relevant for the thesis. However, in this thesis the main sources have been government sources, they have been used to gather information about the comparison of the cities and their infrastructure. These sources are considered to be primary sources as they are based on firsthand information. Other primary sources have been used when analyzing the water supply infrastructure and distribution. Secondary sources that are based on information from primary sources. The secondary sources for this thesis are articles, books and reports connected to the research questions. The information from this literature has mainly been used to provide a broader understanding of the vulnerabilities and general information of water supply systems.

An interview was conducted for this thesis to provide information regarding the Swedish water infrastructure. As information regarding the Swedish water infrastructure is classified the interview acted as an alternative to written information from a primary source. To see if the information from the interview was legitimate it was compared with information regarding water infrastructure gathered from Berlin and London.

An important source for this thesis has been the non-profit organization International Water Association [IWA]. The organization is a global non-profit organization built up by water professionals, the goal is to be able to bind together knowledge from different countries to find solutions to water related challenges. They conduct studies, collect and compile data on different water related issues. IWA is a partner to the United Nations [UN] and assists in water related questions (UN water, n.d.). For this thesis a big part of the fundamental information regarding the comparison cities' water infrastructure has come from collected information from IWA.

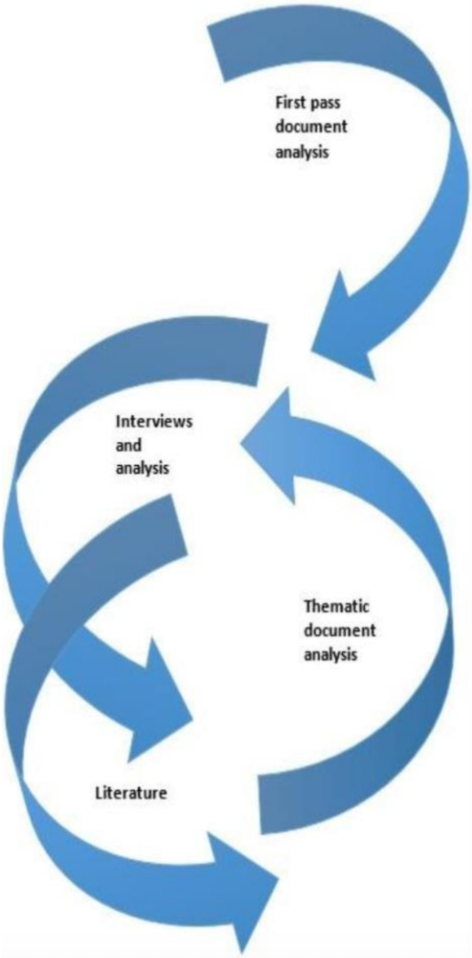

Figure 1: Graphic illustration of the QDA process (Wood, et. al., 2020)

Upon gathering material for the method, the paper written by Morgan (2022) presents a figure from Kridel (2015) that explains a method of selection of sources. A large quantity of literature and government documents were collected for this thesis. To decide if the sources were going to be used in this thesis the method from Morgan (2022) was followed to establish its relevance. The primary sources used in this thesis were not as thoroughly analyzed, as they provided firsthand information. For the thesis this method has been applied, it presents four factors to include when deciding on a source. The four factors are, *Authenticity;* this factor is to analyze how genuine a document is if it is biased or not. *Credibility:* credibility is a factor where it is analyzed how well the document is written and if the source is free from errors. *Representativeness:* for this factor it is analyzed how well the source document contains idiosyncratic content instead of information from relevant sources. The last factor *Meaning;* this analyzes what the purpose of the sources could be. These four factors contribute to the relevance of a source to this rapport. By looking for these factors sources with a lower credibility can be eliminated and highlight usable sources. For this study it has been an essential part as there is a large number of studies and literature on the thesis subject. Being able to compare sources has been a way to eliminate sources with lower credibility.

To analyze the sources the four steps from Kridel (2015) were applied to further deepen the analysis. The four steps of the figure from Kridel (2015) are document analysis, this step consists of collecting and gathering the relevant material for the premise of the report. In this step ways to prioritize the material based on the recurrence of relevant phrases for the thesis are analyzed. For this step a larger search on water infrastructure and vulnerabilities was conducted, without the limitations of our comparison cities. This gave background information to the subject and set delimitations. The second step is interview(s) and analysis, the interview was conducted to give a broader understanding of the subject. To strengthen the facts from the interview the literature was reanalyzed to ensure the support behind the statements. Thirdly a thematic document analysis was conducted, with a thematic analysis the discovered facts are analyzed to establish the trustworthiness of the relevant facts. The facts are categorized based on their credibility, relevance, and perspective on the research questions. This step was to create credibility of the thesis and its literature. Last was the literature step, to strengthen the facts presented in both the interview and literature used to answer the research questions. All gathered and categorized material was revisited to reinforce the credibility of the thesis. This has made the literature that is been used more credible for its purpose.

4. The comparison

In this paragraph a deeper introduction to the cities Belin, London and Gothenburg is given. This is to later compare these cities' similarities and differences. These cities follow directives regarding water supply from the European commissions and rules for potable water supply. One regulation all these cities work with is the Drinking water directive (DWD) from the European Union (EU). After the United Kingdom's exit from the EU, they based their own legislations on the DWD to keep up to the standard (Drinking Water Inspectorate, n.d.). The European commission (2023) mentions that DWD is the European union's main law regarding all drinking water, this law is implemented to protect human health through a high-quality standard for drinking water.

4.1 Berlin

Berlin is a city rich in water and people. With a population of 3,87 million registered citizens, it is Germany's largest city (The Official Website of Berlin, 2023). During the year of 2022 the city experienced a 2.1% growth in demographic (Berlin Business Location Centre, 2023). Due to all the rivers and canals that run through the city and the closely located lakes, Berlin is rich in water. Lakes and rivers make out 6% of the city's surface area. This facilitates somewhat natural conditions for collection and disposal of wastewater (Berlin Business Location Centre, n.d). Unfortunately, Berlin is very rich in water because it is built on a swamp. Berlin is an expanding city, new constructions are a fact. As the city is built on a swamp there is a constant need to move groundwater from construction sites in order to ensure a dry stable base when building. This makes it impossible to dig down groundwater pipes and the solution was to simply put them above the ground instead to be able to carry and release groundwater into surrounding rivers (Pollems, n.d).

Berliner Wasserbetriebe (BWB) is the water distributor responsible for the city and distributes water to an area of approximately 900 km^2. The water supply consists of 100% groundwater that is collected from the river Havel that is artificially recharged with recycled water from the city's treatment plants (Berlin Business Location Centre, n.d). The BWB also handles the treatment of drinking water, wastewater, and recycling of water as they are responsible for recycling phosphorus in the sludge cycle. The BWB and Berlin Senate have a common goal of implementing self-sufficient wastewater treatment plants and pursuing a management strategy that allows the city to rely on its own water resources (IWA, n.d.A). Furthermore, the city aims to reach the goals of the European Water Framework Directive (EU-WFD).

In the city center there is a combined system that carries both rainwater and wastewater in the same pipes and is directly pumped to the treatment plant. This combined system is used within the urban railway of the city (Berliner Wasserbetriebe, 2023). As all water gets treated in the combined system there is an inability to handle extreme downpours. To prevent flooding, additional overflow drains have been put in place that directly distribute water into the rivers and canal outside of the city center. The rainwater and wastewater flow in separate pipes. Wastewater is transported to the treatment plant and the rainwater is distributed back into the rivers and lakes. A possible problem with the collected rainwater being distributed back into the rivers and lakes is that possible pollutants could be washed into the rivers (Berlin Environmental Atlas, 2022).

4.2 Gothenburg

Gothenburg has a population of 604.616, from 2022 to 2023 there has been a demographic increase of 1.6%. In all of Sweden there are different municipalities, so in Gothenburg it is the municipality's responsibility to be able to provide drinking water (Göteborgs stad, n.d.A). The municipalities need to follow the Act on public water services, which regulates the standard the water needs to keep. This regulation meets the regulations set by the EU. The potable water in Gothenburg is collected from Göta älv, and later transported to one of the two waterworks, Alelyckan and Lackarebäck. As of now the municipality is investigating building a new waterwork with the neighboring municipality, this to be able to match the demand of the growing city (Göteborgs stad, n.d.B). In the water works the water is treated to reach the drinking water standard. The process starts off by using sedimentation to remove bacteria and larger particles from the water. The water is later filtered through active charcoal to remove the smaller particles and remove any smell or taste. Depending on the water works the water is later treated with UV light or ultrafilters to reduce microorganisms. The water pH-level is also adjusted, but this is mainly done to protect the pipes from deteriorating.

What specific water distribution system that is being used in Gothenburg is for security reasons confidential in Sweden. But the information that is enclosed is that there are 13 water towers around the city that act as reservoirs for high pressure times or in crisis situations. There are 68 drinking water stations that pump water in the towers during the night, this to even out the production and consumption (Göteborgs, stad, n.d.B). Further information is that the pipes in Gothenburg's system, most of the infrastructure were built in the 1950s and 1960s, and older pipes can also allow polluted water to seep in the potable water (Göteborgs posten, 2020).

One of the bigger challenges for the city according to IWA (n.d.B) is that the city is growing, and providing water has become harder. Gothenburg is a city on fen land and clay, this means that the foundation of the city is threatened by large amounts of rain and rising sea levels. Due to this having the pipes underground is no longer a viable option. Stormwater is kept at a surface level to reduce flooding. The IWA (n.d.C) mentions that one of the biggest dangers with flooding could be that the water becomes polluted and landslides.

4.3 London

The greater London area holds a population of 10 million citizens in need of potable water, from the year 2022 to 2023 there has been a population growth of 1.04% (World Population Review, 2024). In a day around 7 billion liters of water is transported in London's water systems. The private company Thames water is responsible for the water distribution and infrastructure in London. Thames Water provides potable water for the London area and the Thames valley (Thames water, n.d.). Most of the water that is used as potable water comes from the Thames and Lee River, the remainder comes from London's groundwater (The London Assembly, n.d.B). Thames water is responsible for collecting the water and transporting it to their treatment plants and is later distributed out.

To distribute the water in London, Thames Water uses a system called Ring main, this is a ring system that is built up with pipes that lie 10-60 meters underground. The Ring main has 20 shafts that extend from the Ring main that pumps up water into their zones. This system has been in place since the 1980's and still holds the same principles as it did when it was first introduced (Hydraulic analysis group, n.d.). There is an ongoing project to develop the Ring main, partly to easier distinguish if there are any leaks or problems in the pipes, but also to be able to expand the Ring main as the city is growing (New civil engineer, 2019). To supply the entirety of London Thames water also uses the older existing infrastructure, Hydraulic analysis group (n.d.) mentions that they use pipes that date back to 1838. The water system used in London is a ring system that is divided into zones.

To make the water reach all the criteria for potable water, Thames Water uses a system that has been used in London since the late 18th century. They use two different sand filtration systems to filter out bacteria and particles. This has proven to be an effective way to clean out the water and make it meet the regulations (Institution of Civil Engineers [ICE], n.d.). First the water passes through a rapid gravity filter, this is a tank filled with coarse sand which filters out larger bacteria and particles. The water is later filtered in a tank with slow sand filters with finer sand to get rid of small particles (Thames Water, n.d.). At the end of the process chlorine (less than milligrams per liter) is added to the water to get rid of the last particles and bacteria.

4.4 Prospects and possibilities

As previously mentioned, these cities all have in common that they are urban areas that are expanding and have a growing demographic. The following chapter provides information on what is done today by each city and what their biggest vulnerabilities are.

4.4.1 Berlin

As Berlin is an expanding city some of their biggest challenges are their demographic, general resilience to intense events of rain and the resilience of critical infrastructure (in intense rain events). To tackle these challenges the city has the goal of self-sufficiency and to come closer to this goal they have adapted the principle of a *sponge city*, meaning that the city is designed to collect rainwater. This is to minimize flooding and utilize the rainwater in a more efficient way. The Berlin senate is developing the *sponge city*-approach together with the "rainwater agency" - Regenwasseragentur (IWA, n.d.A).

The concept of a *sponge city* is that the city will absorb water, like a sponge, and then distribute the water back into the city. The method's goal is to adapt "urban environment design to absorb large amounts of precipitation and/or runoff to prevent flooding" (Ungvarsky, 2023). The concept was developed in China in 2014 due to the increasing population in urban areas and climate changes made urban flooding a big problem. When urbanization leads to green areas being replaced by pavement and concrete the precipitation only has manholes to runoff into. By introducing greenery in urban areas, somewhat "natural", runoff possibilities are created and help absorb the precipitation. Greenery can also be placed on roofs to absorb and hopefully slow the flow of rainwater (Ungvarsky, 2023). With the *sponge city*-method whole *green roofs* can be introduced. According to the Research Institute of Sweden *green roofs* aim to delay the "effect of rain on the stormy water system". Other than slowing down the effects of rain they can also help with lowering temperature and provide greenery for insects and critters (RISE, n.d). A consideration of hard materials can also be made. By choosing materials that allow water to pass through its surface more easily, more runoff possibilities are created without having to add more greenery to the area (Ungvarsky, 2023). All of this is done to minimize the impact from extreme precipitation and must be done alongside city developers.

4.4.2 Gothenburg

Due to the security classification of water infrastructure in Sweden it is not possible to retrieve any specific information regarding a specific city. But due to Gothenburg's location, close to the open sea and with inland waterways an assumption can be made that water flooding can be a problem in the future.

By conducting an interview with an expert, from a larger city in Sweden, within the field on what the biggest and critical vulnerability could be and what measures are taken to reduce the risks. Overall Sweden has a good infrastructure system, the vulnerability to the system that this expert could see is the increase of precipitation can affect the water facilities through flooding. However, this will not affect the drinking water supply system itself. The biggest vulnerability for the infrastructure is the change of temperature in the raw water and drought that leads to drier soil having a bigger impact on the infrastructure as that could lead to the pipes in the distribution system bursting.

The infrastructure is also affected by urban development. The challenge with expansion is to see how existing infrastructure can be sufficient and keep up with the development, this is an important aspect that to have in consideration when working with urban planning. In general Sweden is a country with good connections to raw water, but to be able to increase capacity there are measures taken to be able to ensure new water resources. With the increased capacity there is work being done to reduce the consumption of potable water from a sustainability perspective.

4.4.3 London

The biggest vulnerability that has been identified for London is the possibility for Thames water to be able to provide potable water to the growing population. Thames water (2024) mentions that the largest water company in London has invested 400 million pounds to expand and upgrade the water infrastructure. In conjunction with the upgrade of the systems Thames Water is set to upgrade two of their water treatment works. By upgrading the waterworks, they want to be able to handle the water supply for the growing population, but the upgraded water treatment works will also help ensure the water supply during summers that has become drier and hotter.

An advantage for London when expanding the water infrastructure is that the ring main was built with expansion in mind. After its compilation ideas for developments has been a discussed topic, as expansion would be a to ensure water supply (Bensted, 1996).

As previously shown, precipitation and flooding can become big vulnerabilities for a city's water infrastructure. In London a project named Drain London, the project's main mission is to fund and develop sustainable drainage projects in London (London Assembly, n.d.B). London also has a sustainable drainage action plan, the goal with the action plan is to reduce the environmental effects of flooding, but the action plan goal is also to provide solutions to how they can save and use the water that comes with flooding (London Assembly, n.d.B).

4.5 Precipitation average

City	Yearly average precipitation (mm)	Monthly average precipitation (mm)
Gothenburg	919,2	76,53
Berlin	690,2	57,53
London	686,0	57,18

Table 1: Displays the yearly average precipitation in millimeters for each city. Average mean based on precipitation data gathered from 1981-2010 (ERA5 explorer, 2019).

Presented above is a table of the monthly and yearly precipitation for each city. As previously stated in the comparison cities are built on fen land, the definition of fen landmass is that it is a low-lying land area with a stable bottom that is waterlogged. With a higher precipitation average the possibility of urban flooding increases as the precipitation cannot be absorbed by the ground in the same ratio as it would in an area that is not waterlogged. When comparing the yearly precipitation of the comparison cities to the yearly precipitation of representative countries some assumptions of precipitation can be made. In Germany the yearly average is 624 mm, in Sweden the yearly precipitation is 700 mm and, in the United Kingdom the yearly precipitation is 1220 mm (World Bank Group, 2024). This information shows that proportionally Berlin and London have a lower average than the countries. Gothenburg on the contrary has a higher average.

4.6 Conclusion of the comparison

After analyzing the comparison cities' water supply systems vulnerabilities, the common denominator for all the cities is that an increase of precipitation will and can be a larger vulnerability for the infrastructure. The data displayed the same effects of an increase in precipitation. The precipitation will impact the infrastructure with an increased risk of flooding which can affect the infrastructure. The way an increase in precipitation becomes a problem is if it does not have a way to runoff as that leads to flooding. A common denominator for the cities is that they have identified this problem and have different methods when trying to find a sustainable solution. Berlin is working with the sponge city model; the model is a sustainable method when trying to work with precipitation in a fen city to reduce the impact on the current systems. London's initiative with Drain London has the same goal as the sponge city but is adjusted to fit the infrastructure in London. Both these initiatives are presented as a sustainable way to keep precipitation from becoming an urban flooding problem. The goal for both cities is that this will work as a way to utilize the possible newly added water through precipitation. Information regarding how Gothenburg works with precipitation and flooding is not information that can be found, however from the information presented it shows that Gothenburg also has identified this problem. A solution for Gothenburg could be to also implement the sponge method as it is suitable for cities for fens cities, this would also be sustainable reuse of the water. The cities' ways to find new water resources are something that they work on as they are growing, which leads to an increase in demand. Being able to reuse the precipitation as drinking water would be a sustainable way to ensure the supply.

5. Discussion

Urbanization is a common denominator for the comparison cities, as they will need to adapt to new challenges as the population grows. The two biggest vulnerabilities connected to urbanization that can be found are the ability to meet the demand of potable water and for the water supply infrastructure to be able to meet the growing capacity. In the comparison it can be seen that the cities mostly trust in the infrastructure that already exists and expands with the previously set conditions. This can become a problem in cities like Gothenburg and London where parts of the infrastructure can be older, which leads to the systems not being as well documented as the newer infrastructure. Trying to expand a system that is not well documented can result in infrastructural problems. Berlin and London have documented newer systems, the pink pipes and the ring main, these newly developed systems are documented and are built for expansion. With a new system the possibilities of development are better as the systems are built up to be able to expand with current and new technology. One of the biggest advantages of having a new system is the possibility to detect leaks more easily as it is better documented. Since information about Gothenburg is classified the expansion plans are not a part of this thesis. What we can conclude is that Gothenburg is satisfied with the system in place today, however the system used today is older.

With the rapidly growing cities supply is also a vulnerability, when analyzing these cities, the biggest problems for the cities will not be to find water sources. As all three cities are in the northern hemisphere, the accessibility to water is not the biggest vulnerability. However, utilization and possible storage of water sources can become an infrastructural problem as water works and water plants have a production limitation. Gothenburg has presented that they are working to add another water work to their system to be able to meet the growing demand.

One coherent aspect that the comparison cities are working with is to have a more sustainable urban water planning. The “5 Rs” mentioned in Background from prior research, Reduce, Reuse, Recycle, Recover and Replenish, are five principles to work through to have a more sustainable urban planning. None of the cities have mentioned that they specifically are working with these specific principles. However, by researching these cities' principles and future plans for the urban planning and infrastructure, it can be concluded that they work with these principles. The cities are mainly working with these points through the sponge city model and the Drain London project. If the cities were to look closer into these five principles it would lead to sustainable urban planning. When analyzing the three cities the aspect of sustainability seems to be a vital part when discussing future planning.

To summarize, Berlin, Gothenburg, and London all have identified their vulnerabilities. Throughout this thesis it can be concluded that the vulnerabilities are similar to one another. It can be noticed that the cities are opting for more sustainable urban planning to reduce the impact.

6. Conclusion

The cities all have several similarities, in everything from possible threats to their demographic growth to their geological location. As this study began factual similarities could easily be spotted, and sense then more similarities have been sought out. They face the same threat from the climate and have formulated their own solution. However, these solutions are more alike than first glance might give away. This segment of the report will summarize the insights that have been gained, both similarities and differences.

The most mentioned threat for the three cities' water infrastructure are urban growth and precipitation. Separately these threats could possibly be easier to handle, however together these create a vulnerability in the water infrastructure. Each city has a way of handling vulnerability. Berlin and London pretty much have the same approach, just different wording to the solution. The similarities between the Drain London initiative and Berlin's sponge citymethod are several. The city of London aims to reduce environmental effects of flooding and save and use the water from floods. The Berlin Senate aims to find a sustainable way to collect and reuse water from heavy rainfall and precipitation. As well as becoming a selfsufficient city in their water supply system. The similarities are striking. Both cities aim to handle the heavy precipitation and flooding by having infrastructure that can collect or absorb the water to store and use. Although it is not obviously stated anywhere, it can be assumed, based on the methods described from Berlin and London, that both structural and nonstructural measures are part of their plan to handle the vulnerabilities and threats. As mentioned in, Background from prior research, both structural and non-structural measures are necessary for a city to be able to create a functioning defense against the threat of urban flooding.

Based on the literature research and the expert interview, an assumption about Gothenburg can be made that the municipality of Gothenburg most likely has a plan similar to the plan for the water infrastructure of London and Berlin. This assumption is furthermore based on the fact that Berlin and London have approximately the same plan for handling their vulnerabilities as all three of these cities experience roughly the same amount of precipitation (see table 1.) and urban growth.

The aim was to research the biggest vulnerabilities each city's water infrastructure face and to analyze if the infrastructure can match the demographic growth. To conclude, all three cities face the same problems of urban flooding and heavy precipitation. As they all face the same vulnerabilities the goal for all is to reduce the impact of these challenges with different means of accomplishment. For a less problematic future the cities must expand their possibilities of adapting their water infrastructure in accordance with their urban growth. The biggest problem is the lack of adaptable infrastructure that matches the pace of the demographic growth.

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