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The two sides to climate change adaptation

ASSESSING THE POTENTIAL AND RISKS OF CLIMATE CHANGE ADAPTATION IN SAN FRANCISCO, CALIFORNIA

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Abstract

This research studied the two sides to climate change adaptation through nature-based solutions. It aims to find ways where nature-based solutions will reduce spatial injustice in the city of San Francisco, chosen due to its geographical location, climate and high inequality. Findings are derived through a literature review, content analysis, Exploratory Spatial Data Analysis using GIS and a Spearman´s rho correlation analysis using SPSS. It shows that adaptation is needed but not necessarily successful. On the one side, cities become more and more pressured by the negative effects of climate change, increasing the need for adaptation. These negative effects are unevenly distributed across society impacting the poorest groups the most. Nature-based solutions have proven to be able to increase urban liveability as they are able to cool down local temperatures, recover the quality of urban nature and regulate stormwater runoff. On the other side, nature-based solutions have shown to be able to increase spatial injustice due to the effects of green gentrification as well, where investments in nature lead to higher housing prices displacing its most vulnerable residents. Findings show that in San Francisco, denser populated neighbourhoods experience more risk to climate change effects due to their higher percentage of impervious surfaces. Moreover, it suggests that the risk of displacement is lower when nature-based solutions are implemented through bottom-up processes.

Keywords: nature-based solutions, climate change adaptation, spatial justice, maladaptation, San Francisco.

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1. Introduction

San Francisco is well-known around the world for its natural beauty, arty neighbourhoods, and impressive architecture. However, the Californian city is also known for its inequality problem. San Francisco not only houses the richest tech billionaires but has one of the highest numbers of chronically homeless individuals that need continuous care in the United States as well (Neate, 2020; Henry et al., 2021). Additionally, the city has one of the highest median home values in the country, with a value of around 1.18 million US dollars. This is almost four and a half times more expensive than the national median home value of $269.000 (Bay Area Council Economic Institute, 2021). Likewise, the National Rent Report by Zumper, North America's biggest privately owned rental platform, shows a median rent price of $2,800 for a one-bedroom accommodation in San Francisco, only showing higher prices in New York (Zumper, 2021). Since the 1990s, the city thrived economically due to a major influx of high income, educated people, working in the tech industry. Consequently, this enhanced the ongoing process of gentrification, making San Francisco America's most gentrified city by 2000 (Mitchel, 2001). In 2018, about 18.5% of the neighbourhoods of San Francisco experienced ongoing and advanced gentrification, the highest percentage of the whole Bay Area (Chapple et al., 2021).

Next to this problem regarding inequality, the city also faces risks concerning climate change. Located on the Californian coast, the city is expected to face problems regarding sea level rise, air quality and water availability (Kirkland et al., 2019). Without proper adaptation, sea-level rise could lead to regular flooding, whereas heat and droughts can lead to nearby wildfires resulting in poor air quality and the melting of snow that feed the Californian rivers are a crucial water source during late summer (Ibid.). The city of San Francisco recognises the aforementioned challenges of climate change. It specifies that since 1990, while the population still grew, the city has reduced its emissions by 44 per cent. However, on their official website, the San Francisco Department of Environment state the following: *"While the City is proud of the progress it has made, climate change still threatens San Francisco communities and puts the most vulnerable at risk."* (SFEnvironment, 2020).

Therefore, it is important to take spatial justice into account when looking at the city of San Francisco and its attempts to combat climate change. The term 'spatial justice' focuses on the geographical aspects of (in)justice, starting with a fair and equitable distribution of opportunities and resources across space (Soja, 2009). Spatial justice does not replace a different form of justice but adds to it as a way of looking from a certain spatial perspective to justice (Ibid.).

This research will build on the argument that nature-based solutions are able to cool down the city and provide an opportunity for urban areas to cope with the consequences of climate change (Czubaszek & Wysocka-Czubaszek, 2016; Depietri & McPhearson, 2017). The goal here is to find out the impact that the increasing heat has in San Francisco on problems regarding its spatial justice problems and to what extent such nature-based solutions can help in combating such phenomena. Moreover, it presumes that the most vulnerable communities are not only in San Francisco at the highest risk. The Intergovernmental Panel on Climate

Change (2015) states that climate-related hazards mostly affect people living in poverty, whether this happens directly through impacts on livelihoods or indirectly when food prices rise. Likewise, Wondmagegn et al. (2019), who researched health care costs and extreme heat in the USA, Australia and Europe, found that the highest heat attributable healthcare costs were associated with females, the elderly and low-income groups, both confirming the statement by the San Francisco Department of the Environment. Findings can be helpful for local governments to provide an insight into the careful act of implementing nature in the city. In addition, finding ways in which the city can implement nature-based solutions to create a better living environment for all urban residents can be helpful for multiple cities around the world.

The high levels of inequality in the city of San Francisco, increasing pressures of climate change, and the potential of nature-based solutions to build resilience for climate change explain the role that these solutions can have in combating a bigger problem. However, the risk that these solutions can lead to an increasingly unjust situation portrays the vulnerability to maladaptation. Therefore, this research aims to answer the following central question:

> *"How can nature-based solutions contribute to building resilience for climate change while reducing spatial injustice rather than increasing spatial injustice in San Francisco, California?"*

In order to answer this question, current debates on spatial justice will be discussed during the literature review, whereas an Exploratory Spatial Data Analysis through GIS, later on, will show how this relates to the spatial context of San Francisco. This current situation regarding spatial justice will function as a basis for the research as it provides an overview of the spatial context, possibly being influenced by climate change and nature-based solutions. The research looks into what nature can do in combating the problems that it faces regarding climate change. In order to answer the main research question, multiple sub-questions were formulated. The research will look into climate change in San Francisco and the potential of nature-based solutions in reducing climate change risks with the help of the following sub-questions:

> *"What is the potential of nature-based solutions in reducing climate change risks?"*

> *"What types of climate change risks does the city of San Francisco face?"*

After discussing the potential of such solutions, Exploratory Spatial Data Analysis through GIS together with a Spearman's rho correlation analysis through SPSS will be used to look into the city its demographics, risks and potentials regarding climate change, and the possible correlations between them. Therefore, the third and fourth sub-questions are:

> *"Which areas in San Francisco have the highest risk regarding climate change impacts?"*

“How do these areas correlate with its urban nature and demographics?”

Since this research aims at finding ways in which nature-based solutions can help build resilience for climate change while reducing spatial injustice rather than increasing it, the risks of adapting these solutions need to be discussed as well. For that reason, the final sub-question is as follows:

“What are the risks of maladaptation concerning spatial justice?”

In the next chapter, I will present a literature review on theories regarding spatial justice, nature-based solutions, and maladaptation. In doing so, I answer the first and last sub-question as well as present a conceptual model of the relationship between these theories. Consequently, I focus on the data collection and data analysis process in the methodology section. Then, I present the results supported through maps and a Spearman’s rho correlation analysis which will be given meaning in the subsequent discussion. In doing so, I aim to answer the other sub-questions that are focused on the spatial context of San Francisco. Finally, the conclusion will present my main findings and, in doing so, answer the main research question as well as showing recommendations for further research on the topic.

2. Theoretical framework

Generally, cities can be seen as highly pressured by climate change due to them having to serve the most people with limited resources, impacting a lot of people when a natural disaster occurs (Rosenzweig, 2011). In order for cities to tackle the threats that climate change gives them, leading the way in adaptation strategies is required (Rosenzweig et al., 2018). Extreme heat is generally recognised as a major threat to public health, showing greater healthcare expenditures when temperatures rise (Houghton et al., 2017; Wondmagegn et al., 2019). Conversely, in OECD countries, only a little percentage of health spending is spent on preventive activities (Gmeinder et al., 2017).

According to Depietri & McPhearson (2017), cities are dependent on their ecosystems in order to build resilience for climate change. Such urban green spaces have proven to be able to have a positive impact on both an inhabitant's mental and physical health as they are able to lower peoples' stress levels, function as a social hub in a neighbourhood, and act as a motivator for physical activities (Hartig et al., 2014; Sugiyama et al., 2018). Moreover, urban green spaces can be helpful in reducing the effect of the urban heat island, an increase in air temperatures in urban areas due to the high thermal conductivity of buildings and other man-made structures as well as heat from traffic and building ventilation (Czubaszek & Wysocka-Czubaszek, 2016). A collective name for the approaches in which nature forms a central role in tackling various issues is 'nature-based solutions' (Cohen-Schacham et al., 2016). The European Commission defines this as: *"Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions"* (2021). However, the possible risks of nature-based solutions will be discussed as well, as it can be argued that such adaptations can have counterproductive effects regarding spatial justice (Shokry et al., 2020).

In the following chapter, I present a discussion on relevant literature regarding spatial justice, nature-based solutions and maladaptation. I will first define spatial and urban justice as it provides the backbone for this research, followed by the potential of nature-based solutions, and ways to implement them. After that, I specify the risks of maladaptation as I look into the risks of counterproductive results. Consequently, I present findings in relevant literature on ways in which these maladaptive outcomes can be presented. Finally, this overview will help to visualise the relationship of these main theories in a conceptual model and with that provide an understanding of how these concepts and theories have to do with each other.

2.1 Defining spatial and urban justice

Around 1990, an epistemic turn in literature and discourse among scholars across different disciplines occurred and is called the spatial turn, where the concept of space is increasingly taken into consideration in research (Soja et al., 2011). This change is about the social and cultural meaning that a geographical space can have, where a spatial understanding can change based on social processes that occurred. Since this spatial turn, it has become more important to approach research from its relevant spatial context, whenever possible

(Kistemann & Schweikart, 2017). Looking at justice took a turn towards spatial justice, making the spatial context an important starting point. Soja, an influential scholar regarding spatial justice, uses the spatial dimension when describing justice to see how the spatial context might allow new ways of looking at important theories and ideas (Soja et al., 2011). According to Soja (2009), spatial justice can be defined as the intentional focus on the geographical aspects of justice, starting at the fair and equitable distribution of opportunities and resources across space. Spatial justice does not replace a different form of justice but complements it as a way of looking from a significant geographical scope to justice. Today spatial thinking revolves around three main assumptions. First, is the idea that everyone is a spatial, social and temporal being. Second, there can be assumed that spatiality is socially produced and is, thus, able to be socially changed. The final assumption is on the relation between the social and space. Not only is the social able to form the space, but the space can also shape the social (Ibid.).

A spatial scope of justice that one can take is that of the urban, where scholars suggest that urban justice is a field of social justice on its own (van Leeuwen, 2020). In the 1960s, debates regarding urban justice started, often when plans for urban redevelopment or new infrastructure projects were presented destroying housing in low-income neighbourhoods (Fainstein, 2014). Recently, more of the discussion regarding urban justice is about uneven development, gentrification and social protection (Ibid.). This focus of social justice theories, according to van Leeuwen (2020), should not only be on the international or national level but on the city level as well. Due to processes of globalisation and urbanisation, the societal unit of the city is one that is closest to peoples living world, making it a relevant part of evaluation for social justice (Ibid.). Chatterton (2010) interprets urban justice as seeing the urban as an ultimate common good. Here, the principles and social relations that underpin the urban common, show the greatest ways in creating greater justice within the urban context. In defining urban justice theories, van Leeuwen (2020) determines three criteria. First, an urban justice theory should be relational in its character. Cities are defined by their characteristics of having a large population size in an often relatively small geographical area. This living together with other people can lead to a sense of community but does lead to multiple networks within the city. These networks, however, can differ in intensity, where some are not embedded within a social network whereas others can feel very connected to a certain place and its residents. Second, an urban justice theory requires spatiality. He here argues that most urban injustices are produced and preserved through space rather than just embedded in space. At last, urban diversity should be recognised as social diverseness is the main component of a city. Due to this wide range of people living together, clusters of subcultures are able to form and a relatively small number of people are able to express their thoughts leading to high cultural complexity (Ibid.).

According to Soja (2009), it is impossible to have a geography that is perfectly socio-spatial equal and has flawless distributional justice. Even though he recognises the impossibility of a perfectly just society, he does state that it is the central goal in all societies to increase justice to sustain human decency. How to reach justice, however, is a topic on which scholars hold a different opinion. Moreover, which perspective one takes can define the way in which one looks at (in)justice, therefore, the following sections will focus on perspectives and ways of reaching greater justice. Later, this will be linked to the city of San Francisco when trying to find out how these debates on spatial justice relate to the spatial context.

2.2 Nature-based solutions

Previous studies have shown that nature in the city is able to provide multiple positive effects for the urban resident (Ambrey, 2016; Jennings et al., 2016). Urban green spaces are, for example, able to have a positive effect on one's health in multiple ways. So can urban blue and green spaces act as a therapeutic landscape and have a positive effect on mental health (Volker & Kistemann, 2013). Bigger green spaces, such as parks, help in encouraging physical activity (Jennings et al., 2016). Moreover, Thompson et al. (2011) found that performing such physical activity outside has a better effect on an individual's mental health than doing it indoors. Additionally, cities are dependent on their nature and ecosystems to build resilience for climate change (Depietri & McPhearson, 2017). Therefore, this part will look into the potential of nature-based solutions.

As stated at the beginning of this chapter, nature-based solutions can be defined as solutions that are inspired and supported by nature, which provide environmental, social and economic benefits and help build resilience for climate change (European Commission, 2021). Nature-based solutions are generally seen as a collective name as it includes well-known approaches like ecosystem-based risk reduction, landscape restoration, and green and blue infrastructure (Cohen-Schacham et al., 2016). These solutions can, thus, be seen as a plethora of sustainable measures and are often able to complement or replace conventional techniques (Lupp & Zingraff-Hamed, 2021). Adaptation to climate change or expected climate change to reduce a society its vulnerability exists out of multiple measures being taken (Emilsson & Ode Sang, 2017). Therefore, nature-based solutions can be seen as a valuable asset in climate change adaptation (Ibid.).

In order to cope with the effects of climate change and biodiversity loss, new approaches like nature-based solutions are needed to increase resilience and recover the quality of urban nature. This is seen as a turn in designing for risk reduction towards nature as it is seen as an affordable way to deal with the city's challenges (Lupp & Zingraff-Hamed, 2021). In the same manner, nature-based solutions in different shapes and sizes have proven to be helpful for multiple societal challenges such as human health, disaster risk reduction, and climate change (Cohen-Schacham et al., 2016). Next to that, nature-based solutions are able to cool the city down as they can reduce the urban heat island effect (Czubaszek & Wysocka-Czubaszek, 2016). Where the high thermal conductivity of man-made structures such as large buildings and paved roads lead to extremely high temperatures during the day, nature is able to cause more moderate temperatures (Ibid.).

In their work on disaster risk reduction, Depietri & McPhearson (2017) talk about three different adaptation options: grey, green, and hybrid. Here, grey infrastructure consists of hard, engineered structures such as canals, or pipes of a drainage system. A common critique on grey infrastructure, however, is that it only tackles the problem but often disregards the origin of the risk, only increasing the vulnerability in the long run. Green and blue infrastructure, on the other hand, consists of ecosystems such as green buffers, urban trees and rivers. Proposing the problem that this might not be enough to face the climate risks of the future. The hybrid, however, is a blend of both worlds, mixing the biophysical with the engineered world. As visualised in Figure 2.1 (Depietri & McPhearson, 2017), this would include green solutions embedded in the urban environment such as rain gardens, green roofs and bioswales to transport stormwater. According to their research, such a hybrid approach

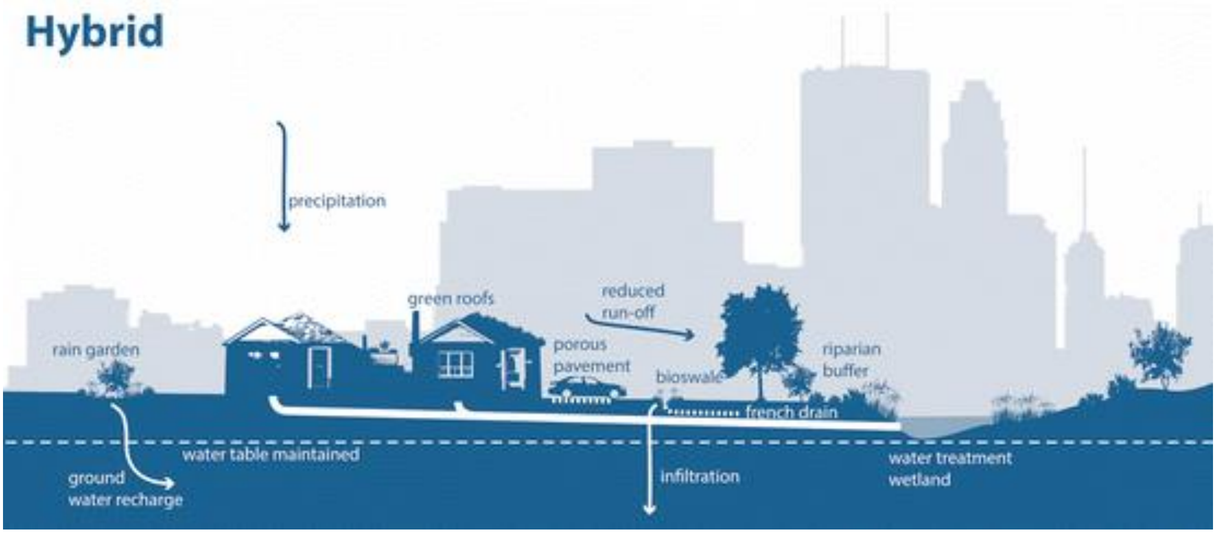

Figure 2.1: Hybrid approach (Depietri & McPhearson, 2017)

is the most effective way in implementing nature-based solutions, giving the most economic and climate certainty (Ibid.). Likewise, Cohen-Shacham et al. (2016) state that such ecosystem-based adaptations can increase the effectiveness and complement grey infrastructure like dykes in an economically practical way. Moreover, the ecosystems that are provided by nature-based solutions can have the same function as grey infrastructures such as the collection, storage, or transportation of water (Dalton & Murti, 2013). Multiple governments have recognised nature's ability to reduce disasters and used nature-based solutions to reduce disaster risk. So did the United States invest 500 million US dollars for the restoration of the coastal national parks and salt marshes after research showed that this reduced the damage (Cohen-Shacam et al., 2016). Likewise, Japan expanded its coastal forests after these proved to reduce the impacts of the tsunami that hit in 2011 (Renaud & Murti, 2013). Mueller & Bresch (2014) confirm the aforementioned argument that nature-based investment can be very cost-efficient. In Barbados, which is often hit by tornadoes, each investment of a single dollar into its marine national park can avoid 20 million US dollars in damages annually (Ibid.). Therefore, these examples show the effectiveness of hybrid approaches where nature-based solutions are incorporated into the engineered world and confirm the argument made by Depietri & McPhearson (2017), that such an approach gives a lot of economic and climate certainty.

Nature-based solutions are able to play a part in combating climate change on a global scale as well. In order to prevent the world from warming up by 2 degrees Celsius, efforts across all sectors and levels are obviously needed, but nature-based solutions can form a large part in that. Planning for green into the built environment can help in preventing the loss of ecosystems, and can absorb and close off CO2 emissions as well, and with that, have a positive effect on the air quality of the city (Cohen-Schacam et al., 2016, Toxopeus et al., 2020).

On the neighbourhood level and city level, nature can act as preventive medicine. It can form a hub for social contacts and can be able to promote physical activity (Jennings et al., 2016). Moreover, trees and other greenery are able to cool a place down through evapotranspiration next to providing shade, making urban nature truly important for municipalities that struggle with heat-related illnesses and mortality (Middel et al., 2021).

When said hazards of climate change occur, cities will be the main areas of vulnerability due to their population density. Moreover, since cities are often placed along the coast or a river, negative impacts are most likely to happen in cities, where coastal communities are feeling the impacts already (Depietri & McPhearson, 2017; Spalding et al., 2014). With San Francisco being one of these cities located in a coastal area and a city that is struggling with heat, drought and rising temperatures, urban nature ought to be of importance with a lot of potential for nature-based solutions.

All in all, this section aimed to define nature-based solutions and provide their potential in reducing climate change risk. There can be said that on the city level, integrating nature-based solutions within the built environment can have multiple positive effects. First, it has the potential to recover the quality of urban nature and combat processes of biodiversity loss (Lupp & Zingraff-Hamed, 2021). Second, it has been shown to be able to reduce extreme heat in the city as it reduces the urban heat island effect (Czubaszek & Wysocka-Czubaszek, 2016). Finally, nature-based solutions are able to regulate stormwater runoff as well as they can function in collecting, storing, and transporting water (Dalton & Murti, 2013).

2.3 Maladaptation

The outcome of an adaptation strategy can be unwanted although it was implemented with the right intentions. In situations like this, when adaptation goes wrong, there is spoken about maladaptation (Schipper, 2020). In cases like this, the adaptation that was implemented as a solution can even worsen the previous situation. When these processes of maladaptation happen, not only time and money are wasted but the most vulnerable communities become more vulnerable (Ibid.).

The effects of climate change impact people all over the world, however, these effects are distributed unevenly. The poorest groups of society, which are often responsible for a relatively little percentage of CO2 emissions, are among the most affected (Shi et al., 2016). Moreover, the most vulnerable citizens are often unprotected by efforts made by the government in combatting climate change (Shokry et al., 2021). In addition, these vulnerable groups, often existing of people with a low-income or ethnic minorities, are worried about the consequences of (green) gentrification when investments in their neighbourhood are being made (Ibid.). Gentrification can be defined as the process that occurs when investments are being made into lower-income neighbourhoods along with an influx of middle- and high-come residents. This can help to rejuvenate neighbourhoods through business developments, investments and more taxable income, while gentrification is widely known for its negative effects (Mujahid et al., 2019). The term green gentrification is used when processes of gentrification occur due to the implementation of green infrastructure (Gould & Lewis, 2012).

As stated before, nature, in different shapes and sizes, can be helpful when it comes to building resilience for the risks of climate change, making planning for nature-based solutions of growing importance. However, when planning for green spaces, societal factors are often forgotten (Sosa Silva et al., 2018). Due to the often disregarded societal factors, the effects can be counterproductive. As it is aimed to reduce the risks of climate change, processes of green gentrification can actually intensify the risks of displacement of vulnerable communities: a green resilience paradox (Shokry et al., 2021). In this paradox, the need for nature-based solutions, especially for the most vulnerable communities, stands on one side, while the risk of displacing them through processes of gentrification stands on the other. Moreover, as these authors mention in their research (Ibid), in the city of Philadelphia most green interventions were placed in the wealthier central gentrified neighbourhoods and those close to them, enhancing the processes of gentrification. Here, Shokry et al. (2021) state that such adaptations are often embedded in uneven social dynamics, making the investments only benefit new and wealthier residents, rather than the long-time and vulnerable. Gould & Lewis (2012) explain that urban nature is able to rise the neighbourhoods' property value through processes of green gentrification. Therefore, new inhabitants with more income are attracted to the neighbourhood while the poorest are forced out of the neighbourhood. Additionally, one could argue that gentrification can also lead to new neighbourhood investments such as nature, but also new stores or better amenities (CJJC, 2014). However, the communities that need this most cannot always experience it due to displacement (Ibid.).

With this, the benefits that the nature-based solution brings are not experienced by those that lived close but distributed to those that can afford it. For that reason, there can be assumed that, in some cases, improvements in urban nature can increase the inequality between social classes and decrease environmental justice (Ibid.). Shokry et al. (2020) came to a similar conclusion when researching climate gentrification in Philadelphia where they discovered that green resilient infrastructure created new urban conditions for the privileged, while the social risk increased for the underprivileged. Garcia-Lamarca (2017) sums it up and describes such greening attempts as "environmentally sustainable but tend to be socially unsustainable". In such cases the focus is on the environmental factors while disregarding the societal factors, therefore, its effect can reduce one problem and simultaneously increase a different problem as well.

To sum up, nature-based solutions that are aimed to build resilience for climate change are most needed by vulnerable communities, often consisting of low-income and minority groups (Shokry et al., 2021). Here, the main risk of maladaptation concerning spatial justice are that the positive effects of nature-based solutions are not always experienced by vulnerable communities. Due to processes of green gentrification, these communities are most vulnerable to displacement, as the positives of nature-based solutions are only experienced by those who can afford them (Gould & Lewis, 2012).

2.4 Balancing act

In her work on maladaptation regarding climate change, Schipper (2020) visualised the possible outcomes of adaptive strategies. As shown in Figure 2.2, adaptation and coping strategies are needed as they can lead to favourable outcomes. It presents the idea that adaptation strategies go through different stages and can eventually succeed through learning and feedback. Coping strategies are often relatively short-term implications that can allow people to not become more vulnerable while not making them adapt to a new situation. Strategies that start out as adaptive or coping can, however, also become maladaptive. Moreover, not responding to climate change at all can be considered maladaptive as well as it will eventually lead to increased vulnerability (Ibid.).

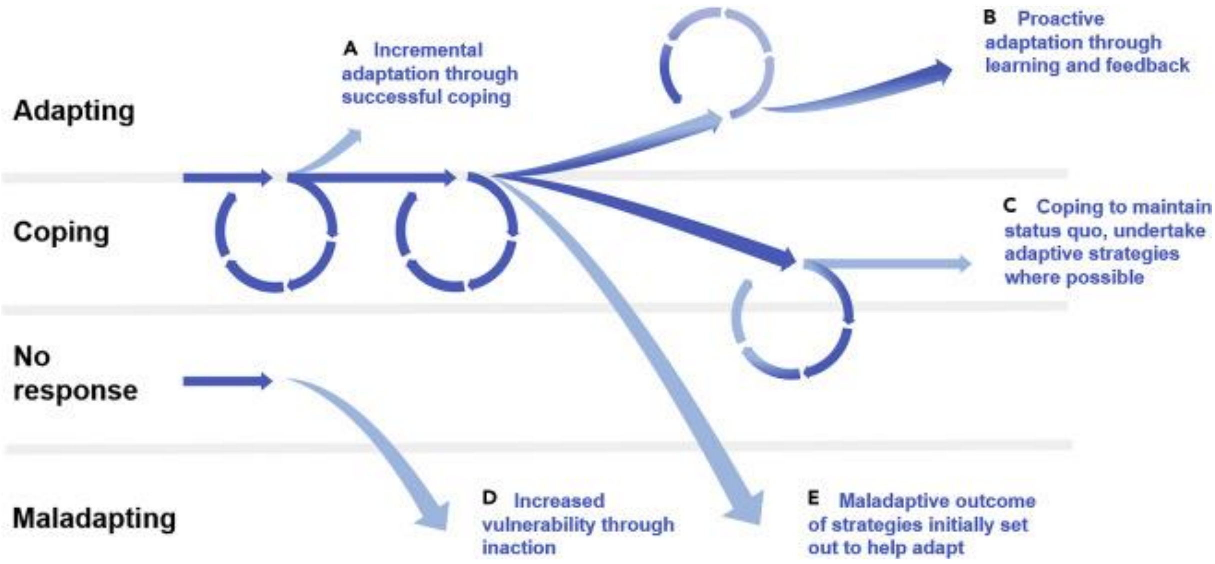

Figure 2.2: Conceptual diagram of adaptation outcomes over time (Schipper, 2020).

The green resilience paradox as proposed by Shokry et al. (2021) has, thus, been visualised in the later stages of Figure 2.2. This is where a point in time is reached and the outcome of an adaptation strategy turns out to be proactive adapting, maintaining the current situation, or maladaptive (Schipper, 2020). Wolch et al. (2014) discuss the paradox as a careful balancing act where a city and its neighbourhoods need to be 'just green enough'. They state that neighbourhood investments and green investments can lead to counterproductive effects through processes of green gentrification but also state the importance of green developments. Without any neighbourhood improvements, the inhabitants can face negative consequences as well through continued park poverty or poor living conditions. However, most of the effects of green gentrification in the U.S. takes place in the lower-income neighbourhoods, since a large quantity of new green spaces is being installed on run-down or abandoned infrastructure, which often runs through these low-income neighbourhoods (Ibid.). Moreover, gentrification is often rooted in a past of little to no investments in a neighbourhood, leading to relatively cheap land compared to other neighbourhoods in a certain city (CJJC, 2014). Additionally, it is driven by private corporations and landlords but supported by governments that allow displacement to happen through their policies (Ibid.). Even though enhancing processes of gentrification, and with that displacing vulnerable communities, is a big risk of investing in nature-based solutions, there are ways in which it can be prevented as well (CJJC, 2014).

2.5 Resisting gentrification and displacement

Although gentrification is driven globally through market forces, most regulations and decisions are made at the local level, allowing local governments to resist gentrification and displacement (CJJC, 2014). Here, 'just green enough' strategies and citizen participation play an important role (CJJC, 2014; Wolch et al, 2014). The strategy of making a city 'just green enough' takes a step back from the either market-driven or ecologically driven approaches of greening the city, taking spatial justice as a central concept as well (Wolch et al., 2014). In these cases, local community activism is needed to protect the desires, needs, and concerns of the community (Ibid.). Moreover, community organising, bottom-up decision making and leadership development can be seen as a fundamental part of all anti-displacement strategies (CJJC, 2014).

An example of this is researched by Curran & Hamilton (2012) who explored the cooperation between the working-class residents and city planners at a greening project in Brooklyn, New York. In that case, plans targeted to clean up a toxic creek and develop new urban green spaces near the industrial area and the working-class neighbourhood. Activists were able to have the plans counter environmental hazards as much as possible while maintaining industrial jobs to serve the working-class population, rather than implementing green space in a more mainstream way, often targeted towards the middle-class. Moreover, this case has shown that the power of the people are able to reshape state intervention as well as the ability of the people to form powerful alliances allowing a more democratic voice to be heard (Ibid.). However, in order for the community to be heard in the process, it is important for them to know the ways of the political arena (Toxopeus et al., 2020). Especially marginalised communities struggle to get their voice heard in the political world, indicating the need for scientific professionals to work with local communities to make sure their needs are expressed (Ibid.). Additionally, the Just Cause organisation (2014) state the importance of needing multiple policies to do justice to the complex problem of gentrification and displacement. Due to the different actors and forces involved, as well as the different levels of governments that can impact displacement with their decision-making, multiple policies are needed specifically made for each specific context (Ibid.).

2.6 Conceptual model

In this chapter, I have so far presented relevant theories and concepts on spatial justice, nature-based solutions and maladaptation as it aimed to provide an overview of the complexity of relevant literature. Conclusions with respect to the theory are drawn as I integrate the relations between these concepts into a conceptual model. The way that these can be related is visualised in the conceptual model of Figure 2.3. The model visualises how the process of adaptation through nature-based solutions can be seen. It starts on the left describing the current situation of increasing pressure on spatial justice due to the uneven distribution of climate change impacts, impacting low-income and minority groups most. It shows that, without interference, these vulnerable population groups will stay in this situation where they become more vulnerable due to their exposure to increasing risks of climate change. The central point is that adaptation through nature-based solutions have proven to be a careful balancing act as its outcomes can be counterproductive (Wolch et al., 2014). As visualised in the model below, a situation where the vulnerable groups become less vulnerable and lead to a more just situation is reached when the balance between the increased liveability without accelerating processes of gentrification is just right. Efforts can be counterproductive when nature-based solutions enhance processes of green gentrification, leading to an influx of middle and high-income residents while displacing its most vulnerable residents. Therefore, nature-based solutions can have maladaptive effects regarding spatial justice, as those who are impacted most by climate change, low-income and minority groups, are the ones that are not able to profit from the positive effects that these solutions provide (Garcia-Lamarca, 2017; Shokry et al., 2020; Wolch et al., 2014). All in all, the conceptual model visualises the idea that intervention is needed to build resilience for climate change and, with that, tackle spatial justice issues. Moreover, nature-based solutions show to be able to be helpful in reaching greater justice when vulnerable groups are able to profit from the positive effects of nature-based solutions, but only when implemented carefully.

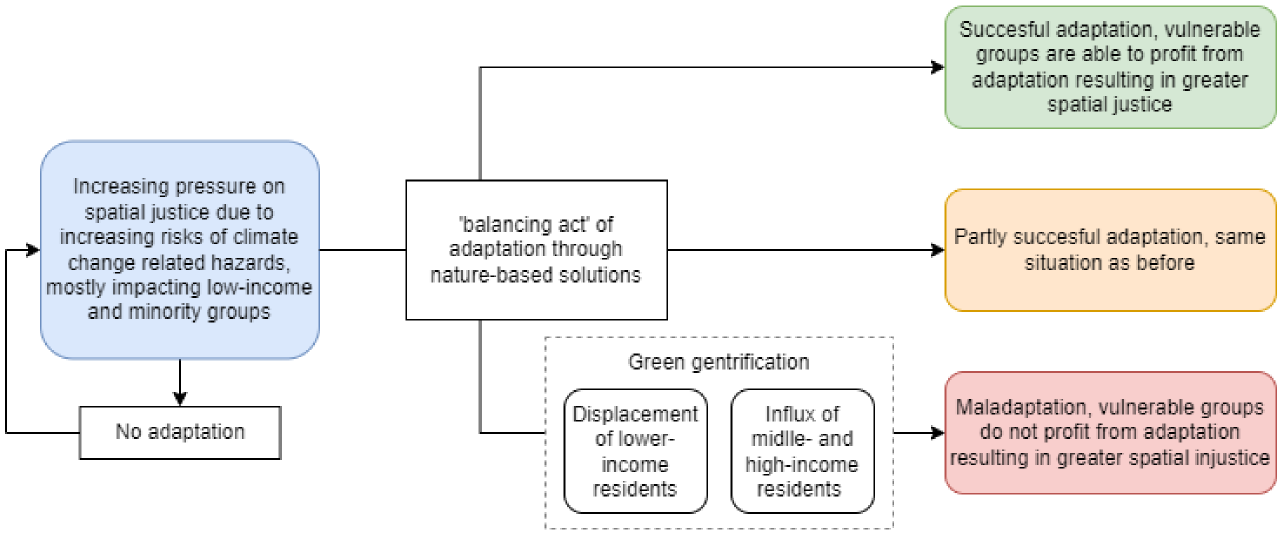

Figure 2.3 Conceptual model

3. Methodology

The first chapter described the topic of this research and presented the need for adaptation in order for cities to cope with climate change. It introduced the concepts of nature-based solutions, spatial justice and green gentrification. The second chapter discussed these topics, providing a better understanding of the potential and risks of planning for climate change resilience. The previous chapter was concluded with a conceptual model that visualised the relationships of the main concepts. This research aims to find out how these main concepts occur in the context of San Francisco, California. Therefore, this chapter will present the research strategy, data collection process and data analysis methods that were chosen to be relevant to answer the research question.

3.1 Research strategy

This research uses a case study, as this research method allows to look in-depth at different theories on a small-scale (Taylor, 2016). As stated before, San Francisco is a city that deals with the topics of (green) gentrification and climate change more than the average city, while the governor of California has signed an executive order to expand the use of nature-based solutions to build resilience for climate change (Chapple et al., 2021; Exec. Order No. 82-20, 2020; SFEnvironment, 2020). This case study can, therefore, be classified as an extreme case method as its case shows extreme values for gentrification and climate change risk (Seawright & Gerring, 2008). This research aims to explore the possible effects of one: nature-based solutions and climate change, on the other: green gentrification and spatial justice and can therefore be seen as an exploratory research method (Ibid). A case study is, thus, used in this research and aims to answer the main research question: *"How can nature-based solutions contribute to building resilience for climate change while reducing spatial injustice rather than increasing spatial injustice in San Francisco, California?"*.

To answer this question and its corresponding sub-questions, multiple different research methods were used. As shown in Table 3.1, in order to answer each sub-question, different relevant research methods were applied. Moreover, in order to increase the trustworthiness of research, triangulation can be used as it combines data about a similar issue but is collected through different methods (Taylor, 2016). Therefore, this research aimed to combine a literature review, content analysis and GIS analysis. First, desk research explored secondary data on the relevant concepts. Secondary data can be helpful as it can strengthen a study its rationale as it provides a context (Tyrrell, 2016). So is secondary data used to answer the sub-questions "What is the potential of nature-based solutions in reducing climate change related disaster risks?" and "What are the risks of maladaptation concerning spatial justice?" as previous research can contribute with meaningful insights. Moreover, secondary data can be useful when comparing context-specific research from own research to findings in existing literature, as it allows the researcher to discuss the findings in a wider context. Therefore, findings during the content analysis on spatial justice in San Francisco can be compared with debates in academic literature to answer the following sub-question: *"How do current debates on spatial justice relate to the city of San Francisco, California?"*. Another way in which secondary data is used is to analyse phenomena. When doing so, data that has been collected by someone else, such as census data or government data on green space, can be analysed in a similar way as primary data. An advantage of using secondary data here is the scale and precision that is often provided in these datasets that are simply impossible for a single researcher to obtain (Ibid.). A GIS analysis was used to answer the following sub-questions: *"Which areas in San Francisco have the highest risk regarding climate change impacts"* and *"How do these areas correlate with its urban nature and demographics?".* In this research, the GIS analysis allows illustrating the spatiality of relevant concepts, since such Exploratory Spatial Data Analysis can be helpful in discovering spatial patterns and identifying clusters (Delmelle, 2016; Wilson, 2016).

The main point of this research is to use the knowledge of processes happening on a global scale and look at it from a city perspective. Therefore, the desk research was not only on academic literature but looked into grey literature and policy documents as well. Moreover, by analysing data using GIS, arguments made in both academic and grey literature can either be strengthened or weakened. The methods this research used are a literature review, content analysis and a GIS analysis and its data collection is visualised in Table 3.1 below. Therefore, this research aimed to triangulate its research methods, and with that, strengthen its findings (Taylor, 2016).

3.2 Data collection

3.2.1 Literature review

First, a literature review provided an insight into relevant concepts and their relationships. Relevant literature has been presented in the theoretical framework as it eventually formed the foundation of the conceptual model in Figure 2.3. The literature discussed relevant articles from academic journals and was mainly obtained through SmartCat, the search engine of the University of Groningen. During this process, relevant concepts were used in the search bar and their abstracts were screened for relevance. By conducting this literature review, an overview was created regarding relevant concepts. Moreover, it was able to provide an answer to the sub-questions dedicated to finding out the potential of nature-based solutions in reducing climate change risk as well as the risks of maladaptation.

3.2.2 Selected documents

Second, a content analysis looked into relevant policies and reports to find out the ways in which theories discussed in the literature review correspond with what is written in the spatial context of San Francisco. As presented in Table 3.2, four different reports were used to help answer three different sub-questions. Two of these are provided by government institutions such as an executive order on the biodiversity crisis and the chapter on healthy ecosystems in San Francisco's Climate Action Plan 2021. The other two, on climate change adaptation and development without displacement, are acquired through Bay Area based organisations focused on multiple different urban issues.

Table 3.1 Data collection

Research questions	Information needed	Source	Analysis method	Output
What is the potential of nature-based solutions in reducing climate change risks?	Understanding of effects nature-based solution on climate change	Academic literature, policy documents, reports	Literature review, content analysis	Factors that reduce climate change related disaster risks
What types of climate change risks does the city of San Francisco face?	Context-specific climate change risks	Academic literature, policy documents, reports	Literature review, content analysis	Context-specific climate change risks
Which areas in San Francisco have the highest risk regarding climate change impacts?	Data on demographics, neighbourhoods, urban nature, road network, housing prices, surface heat, impervious surfaces	Governments websites, Third-party remote-sensing organisation	GIS, Exploratory Spatial Data Analysis	Spatiality of climate change, urban nature, demographics and justice
How do these areas correlate with is urban nature and demographics?	Output previous sub-question	Output previous sub-question	Spearman's rho correlation analysis	SPSS correlation output
What are the risks of maladaptation concerning spatial justice?	Overview of risks of maladapting nature-based solutions	Academic literature, reports	Literature review, content analysis	Possible negative outcomes of adapting for climate change

Table 3.2 Selected reports content analysis

Research question	Document	Reference
What is the potential of nature-based solutions in reducing climate change risks?	Executive Order No. 82-20 (on Californian biodiversity crisis)	Executive Order No. 82-20, 2020
	Healthy Ecosystems chapter in San Francisco's Climate Action Plan 2021	San Francisco Department of the Environment, 2021
What types of climate change risks does the city of San Francisco face?	Climate change hits home: Adaptation strategies for the San Francisco Bay Area	SPUR, 2011
What are the risks of maladaptation concerning spatial justice?	Development without displacement: Resisting Gentrification in the Bay Area	Causa Justa : : Just Cause, 2014

3.2.3 Spatial data

This research uses different types of spatial data to answer the sub-questions "Which areas in San Francisco have the highest risk regarding climate change impacts?" and "How do these areas correlate with its urban nature and demographics?". As visualised in Table 3.3, the data used has all been published relatively recently, with the most dated source being published in 2016. With the exception of data of the road network that was downloaded from the Esri website, all other sources have been published by governmental institutions, which allows for the greatest possible precision due to the high number of respondents or quality of data. This data will be used to represent the areas in the city that experience the highest risks regarding climate change as well as urban nature and demographics in each neighbourhood. Even though data as the flood risk zone is rather straightforward, satellite imagery on impervious surfaces is not. However, the assumptions can be made that neighbourhoods with a relatively high percentage of impervious surfaces are of higher risk due to the enhancement of the urban heat island and lack of ability of stormwater runoff (Dalton & Murti, 2013; Morabito et al., 2017).

To sum up, this research uses different types of data from different sources that all have been published relatively recently. In doing so, it aims to answer the relevant sub-questions as complete as possible. This research is, however, limited by the data that is available. For example, Kirkland et al. (2019) mentioned that the city is expected to struggle with worsened air quality as well. Since nature-based solutions are able to have a positive effect on the air quality as they can absorb and close off CO2 emissions (Cohen-Schacam et al., 2016, Toxopeus et al., 2020), making air quality interesting to take into account as well. However, due to this data not being available, this research is thus limited in the representation of climate change risks through the data, as air quality is not used as a proxy of climate change risk.

Table 3.3 Data used in GIS analysis

Data	Reference year	Source
Zip codes	2021	DataSF
Demographics (minorities, income, population density, English proficiency)	2019	United States Census Bureau
Road network	2016	Esri
Urban parks	2019	DataSF
100-year flood risk zone	2019	San Francisco Public Utilities Commission (SFPUC)
Impervious surfaces satellite image	2019	National Land Cover Database (NLCD)
Gentrification and displacement	2018	Urban Displacement Project

3.3 Data analysis

3.3.1 Content analysis

A content analysis was used to gain a deeper understanding of the relevant topics in the context of San Francisco. As shown in Table 3.2, four different documents were analysed focusing on nature-based solutions, climate change, and gentrification. During this process, the reports got coded by concepts based on the theoretical framework such as spatial justice, nature-based solutions, climate change, maladaptation and displacement. By doing so, insights were created on the popularity of used codes in the researched documents. Moreover, the overlap between the contents of these documents became visible. This allowed me as a researcher to look at the relevant concepts that are happening globally in the context of San Francisco.

3.3.2 GIS analysis and statistical analysis

GIS was first used to find the areas in the city that are at the highest risk regarding climate change impacts such as extreme heat and storm flood risk. Next to visualising these high-risk zones, the urban nature availability and demographics such as English language proficiency, minorities, population density and median income were visualised as well. This Exploratory Spatial Data Analysis can be helpful to identify and later visualise spatial patterns (Wilson, 2016). With that, it aims to measure which areas in the city are most vulnerable to climate change through their physical and demographical characteristics. This research then uses these findings on different areas of high vulnerability to test for correlation with different demographics and its availability to urban parks.

The GIS process regarding the visualisation of the neighbourhood demographics was rather straight forward. Due to the data being obtained in an Excel document, the only modification was the deleting of irrelevant rows and columns in the datasets. After this, the tables were exported to the ArcGIS file and joined to the zip-code shapefile through the mutual value of the zip code.

The process of determining the accessibility to urban parks, however, was more complicated. In order to discover this accessibility more than just the presence of an urban park in a neighbourhood was needed. For example, when an urban park is located in one zip-code area but close to the border of another, the presence of urban parks will show high values for one area and low values for the other even though both are within that park's service area. Therefore, a network analysis was conducted to calculate the service area of urban parks in San Francisco. Based on the argument of the World Health Organization (2017) that people should be able to access parks within a five-minute walk from their homes, and an average walking speed of around 4.5 kilometres per hour (Schimpl et al., 2011) a distance of 375 meters to a park entrance was used. Due to the network analysis needing point data to connect to the road network, the park polygons needed to be converted into points. Whereas the smaller parks could be automatically be converted to a single point, this would lead to inaccurate results at the bigger parks since this point might not be reachable within a five-minute walk even though the park itself is. Therefore, 523 points have been added manually representing the entrances of the bigger parks, performing the network analysis over a total of 718 points. The network analyses provided a service area polygon of the urban parks and made it possible to use the 'summarize within' tool to find out how much of the surface of each zip-code area was covered by this service area. Subsequently, this was divided by the zip-codes total surface area to determine the relative coverage of urban parks per zip-code area.

One way of looking into areas that are of higher risk regarding climate change impacts is looking at those that are most vulnerable when a storm happens. Therefore, the 100-year storm flood risk zone was downloaded to analyse which areas in the city are at the highest risk of floods at an extreme storm. The data maps the areas that are very likely to suffer 'deep and contiguous' flooding in a 100-year (SFPUC, 2019). The SFPUC explains that the chance that such a storm happens in a given year is one per cent and that these floods are at least 15 centimetres deep and half the size of an average city block (2019). Determining which neighbourhoods are of the highest risks of these floods was done similarly to the service area of urban parks. Accordingly, the 'summarize within' tool was used first followed by a straight forward calculation dividing a zip-codes total surface area by the area that was covered by the storm flood risk zone.

Another way of determining vulnerable areas is to look at the areas with the most impervious surfaces. Due to the high thermal conductivity and often low solar reflectivity of impervious surfaces urban temperatures rise, contributing to the effect of the urban heat island (Morabito et al., 2017). In the same matter, lower temperatures are shown in areas with more pervious surfaces (Ibid.). Therefore, the GIS analysis looked at the extent of impervious surfaces per neighbourhood, assuming that those with higher values experience a higher risk of climate change impacts due to the higher temperatures. The urban imperviousness raster layer by the National Land Cover Database was downloaded where each pixel holds one value of a percentage of imperviousness representing a 30 by 30 meter square (2019). Since the image covered the whole of the United States very precisely, the image needed to be clipped to the city of San Francisco to avoid technical problems. Moreover, due to this image being a raster layer, its analysis went differently than for all other data. The 'zonal statistics' tool was used to calculate the average raster value of the zip-area polygons. However, this data is still in raster format and, thus, hard to precisely read and not yet available in the same attribute table as the other data. Therefore, a single point was created for each zip-code area using the 'feature to point tool', followed by the 'extract multi values to points' tool to give each point the value of the raster layer. Subsequently, these values that were given to each point representing a zip-code area were able to join the polygon layer, giving each zip-code polygon a value for its imperviousness.

By doing this, all of the data that was collected separately now holds a value for each zip-code region, although some data were obtained as polygon data or raster data as they were originally collected to serve different purposes. Now, each zip-code region in San Francisco has a value for its demographics, urban park accessibility, flood risk, and imperviousness score. Therefore, these statistics now fit to be used in a Spearman's rho correlation analysis to see whether there is a significant correlation between the areas that have the highest risk regarding climate change and its urban park accessibility and demographics.

3.4 Ethical considerations

Since this research only used secondary data, the ethical considerations were more limited than when the data was collected personally, for example through interviews or questionnaires. However, data was only collected from sources that were publicly available and gave permission to download and use in research. Moreover, the only modifications made to the data was the deleting of irrelevant rows and columns in the dataset for practical reasons, not adjusting the dataset to reach different results.

Additionally, when visualising the data through maps, this was done in a way to create a picture as honest as possible. The data is shown as complete as possible, while not emphasising or belittling information. Finally, in describing the analysis process, this research is repeatable and other researchers are able to reproduce this research.

4. Results

The previous chapter discussed the research methods used in order to find out how nature-based solutions are able to build resilience for climate change and, with that, reduce spatial injustice rather than increasing spatial justice in San Francisco California. To do so, multiple methods were used, such as a literature review, content analysis, and a GIS and correlation analysis. Whereas the literature review presented an overview of relevant literature regarding nature-based solutions, spatial justice, and maladaptation, this section will present the results regarding the risk of climate change impacts specific to the context of San Francisco, California.

First, ways in which San Francisco struggles with climate change impacts will be discussed, followed by an overview of local views on nature-based solutions. Subsequently, this section reviews the processes of gentrification and displacement in the city. Based on the idea that low-income and minority groups are often most vulnerable to the effects of climate change (Shokry et al., 2021), this section then aims to present the spatiality of demographics and climate change risk in San Francisco.

4.1 The case of San Francisco

San Francisco is a city located in California on the west coast of the United States. Due to the challenges it faces, this city is suited to research processes that happen globally on the city level. The city faces challenges regarding (green) gentrification and climate change, whereas nature-based solutions are recognised by the authorities as a way to combat the climate crises (Chapple et al., 2021; Exec. Order No. 82-20, 2020; SFEnvironment, 2020).

4.1.1 San Francisco and climate change impacts

In their report on climate change and possible adaptation strategies, the San Francisco Bay Area Planning and Urban Research Association (SPUR, 2011) identifies three main impacts of climate change on San Francisco and the surrounding Bay Area: a rise in sea level, higher temperatures, and water uncertainty. Since 1900, the global mean sea level rose increasingly to around 21 cm, reaching its highest value in 2020 making sea-level rise a global problem (EEA, 2021). However, due to its geographical location, inhabitants of the San Francisco Bay Area experience higher risks of sea-level rise than the average citizen. Especially storms, combined with high tides can form major threats to the area (BCDC, 2011). Storms are not only able to rise tides even more due to low air pressure, but the onshore winds also cause bigger and more destructive waves. Moreover, the rain that falls during these storms is able to cause floods as well. Due to the geographical features of the Bay Area, around 40 per cent of all land of the state of California eventually drains to the San Francisco Bay. This means that when big storms happen, some areas in the San Francisco Delta, which leads into the San Francisco Bay, can experience a rise in water levels of around 130 centimetres lasting a full day (Ibid.).

Next to the rise in sea level, the city is expected to struggle with more extremely hot days as well. Whereas San Francisco experienced around 12 days of extreme heat every year in the second half of the 20th century, is this expected to grow to around 32 to 46 days per year in 2050 and about 70 to 95 days per year at the start of the 22nd century (Miller et al., 2008). These more extreme heats have a significant influence on the health of the urban resident, often putting the most vulnerable at risk (Frosch et al., 2009). In their research on inequalities regarding climate change impacts in the state of California, Frosch et al. (2009) see that the likelihood to struggle with heat-related illnesses or mortality is highest for the elderly, young children, and the poor. So is the projected heat-wave related mortality rate in Los Angeles for an African American resident almost twice as high as the city average (Ibid.). The increase in temperatures not only shows negative effects on humans but can lead to biodiversity loss as well. In the coastal region, however, it is expected to lead to more non-native species, moving away from the region's original flora and fauna (SPUR, 2011).

Next to an increase in sea level and temperatures, San Francisco also experiences the effects of climate change through water uncertainty (SPUR, 2011). More extreme storms can be responsible for overflowing the sewage systems, making urban floods from storms not only harmful in regards to property damage but to water quality and public health as well. Moreover, the higher temperatures are bound to challenge the city's freshwater supply. The snowpacks on the Sierra Nevada mountain range, that store a lot of the natural freshwater are expected to melt quicker. Moreover, due to increasing temperatures, plants will take up more water and evaporation will increase, leading to less water running into the reservoirs. The state is expected to struggle with storing the water during the dry season as well since it is expected that precipitation will increasingly fall in the form of rain rather than snow (Ibid.).

Moreover, as water becomes more of an uncertainty and droughts are expected to occur more frequently, it is expected to see more and extremer wildfires close by as well (SPUR, 2011). These wildfires are expected to have a negative effect on the air quality of the region and increase health risks. Therefore, the San Francisco Planning and Urban Research Association (2011), has advised the Bay Area Air Quality Management District to regionally review the air quality regularly and monitor increases in health risks (Ibid.).

To sum up, it becomes clear that the city of San Francisco faces climate change risks in multiple ways. First, the combination of the geographical location of the city in a bay, a rise in sea level, and more extreme weather events, make the city face flood risks (BCDC, 2011). Second, more days of extreme heat are expected to impact the health of the citizens (Frosch et al., 2009; Miller et al., 2008). Finally, the increasing risk of droughts increases the city's water uncertainty in the dry season (SPUR, 2011). Moreover, when these droughts lead to wildfires nearby, the city is expected a decrease in air quality as well (Ibid.).

4.1.2 Nature-based solutions in San Francisco

Although heat-related mortality and illnesses such as heat stress, heat exhaustion, and heat stroke have shown to be a challenge in California, strategic planning can reduce this significantly, even with scarce resources such as planting vegetation and using more reflective materials in construction (CCPHIARC, 2007). The idea that nature-based solutions can help in combating climate change is now recognised by the state of California as well. In his executive order, governor of California Gavin Newsom stated that the use of nature-based solutions needs to be expanded to build resilience for the impacts of climate change (2020). In doing so, the state builds on the multiple benefits that nature-based solutions have to offer, primarily its potential to positively contribute to the biodiversity crises and resilience building for extreme climate change related weather events (Ibid.). A major challenge for the city here is that nature should be added while accommodating a growing population as well (SFEI, 2020).

In the report on building urban biodiversity, the San Francisco Estuary Institute (2019) state the importance of combating climate change through nature as well. They acknowledge the point that the effects of climate change are exacerbated for vulnerable population groups but they do have a one-sided approach as they overlook the possible effects of maladaptation. This danger of maladaptation comes to light in the executive order (2020) by the Californian governor as well. He did state the importance of leaders in different levels of scale in stimulating the process of implementing nature-based solutions and, with that, restoring ecosystems and protecting communities from natural disasters. Nevertheless, topics regarding spatial justice, gentrification and displacement were not mentioned (Ibid.). Such a one-sided environmental approach can have maladaptive outcomes since societal factors are here forgotten (Sosa Silva et al., 2018).

However, in the chapter on healthy ecosystems in San Francisco's most recent climate change action plan (2021), the city does aim to take societal factors into account, opening the chapter the following way: *"Healthy ecosystems provide nature-based solutions to climate change … and provides a healthy environment that benefits all San Franciscans."* (p. 112). With this, the city goes a step further than the state as they not only acknowledge the environmental benefits that nature-based solutions can offer regarding the quality of air and ecosystems. In the proposed strategies regarding healthy ecosystems, they present the plan to maximise urban greening but also the strategy to enhance equitable participation from local communities. The city aims to educate Black/Indigenous People of Colour (BIPOC) regarding the positive effects that nature-based climate solutions can offer. Here, the city aims to use indigenous knowledge to create nature-based solutions that fit the environment of San Francisco. Although the city goes further than the state regarding the involvement of local communities, the reasoning of the city is still lacking. Whereas the city wants to increase the involvement of BIPOC communities, their reasoning is based on their knowledge of traditional ecological knowledge, rather than the possibility of gentrification and displacement (Ibid.).

4.1.3 Gentrification and displacement in San Francisco

The term green gentrification is used when processes of gentrification are started or boosted by investments in green spaces (Gould & Lewis, 2012). In such cases, the investment in urban nature led to a rise in property values, displacing the most vulnerable residents and with that, nature is distributed to those who can afford it (Ibid.). Moreover, San Francisco is a city that is already struggling with the effects of gentrification. In their report on gentrification and disinvestment, the National Community Reinvestment Coalition (2020), found that San Francisco is the United States' most intensely gentrified city during the period of 2013 till 2017. In San Francisco, the median price for a house is almost four and a half times more expensive, around 1.18 million US dollars (Bay Area Council Economic Institute, 2021). Hence, the city faces not only challenges regarding the consequences of climate change, but its inhabitants struggle with the effects of gentrification as well. Therefore, nature-based solutions can not only be a mitigating factor for climate change risks but can also be an aggravating factor for gentrification (SFEI, 2019; Wolch et al., 2014).

The first wave of gentrification in San Francisco happened in the 1980s and was caused by the city investing hundreds of millions of dollars into the Silicon Valley area, attracting multiple tech start-ups (CJJC, 2014). The prosperous technology sector was able to capitalise on the rent gap created in some neighbourhoods, leading to an intensified increase in rent. This enlarged during the 'dot com boom' between 2000 and 2003 resulting in an increase of over seventeen per cent in overall income between San Fransisco residents. With the housing crisis of 2008, the second wave of gentrification happened in San Francisco, especially in working-class neighbourhoods. Where speculation rose up prices many long time residents drove out. Whereas some left after taking a bid for their home and moving to a cheaper suburban neighbourhood, many were not able to afford the increasingly expensive neighbourhoods anymore. The large magnitude of working-class neighbourhood investments ended up worsening the situation of long time residents, often displacing them. Whereas the first wave of gentrification was partly powered by the 'dot com boom', the city is currently undergoing a third wave exacerbated by large companies in the technology sector, leading to pressures on San Francisco housing (Ibid.).

In order to better understand the current situation and predict gentrification and displacement and in which areas this is happening, the city of San Francisco collaborated through its Mayor's Office of Housing and Community Development with the Urban Displacement Project (UDP, 2018). These findings are visualised in Figure 4.1 below and show different values for displacement, gentrification and exclusiveness. It becomes clear that most

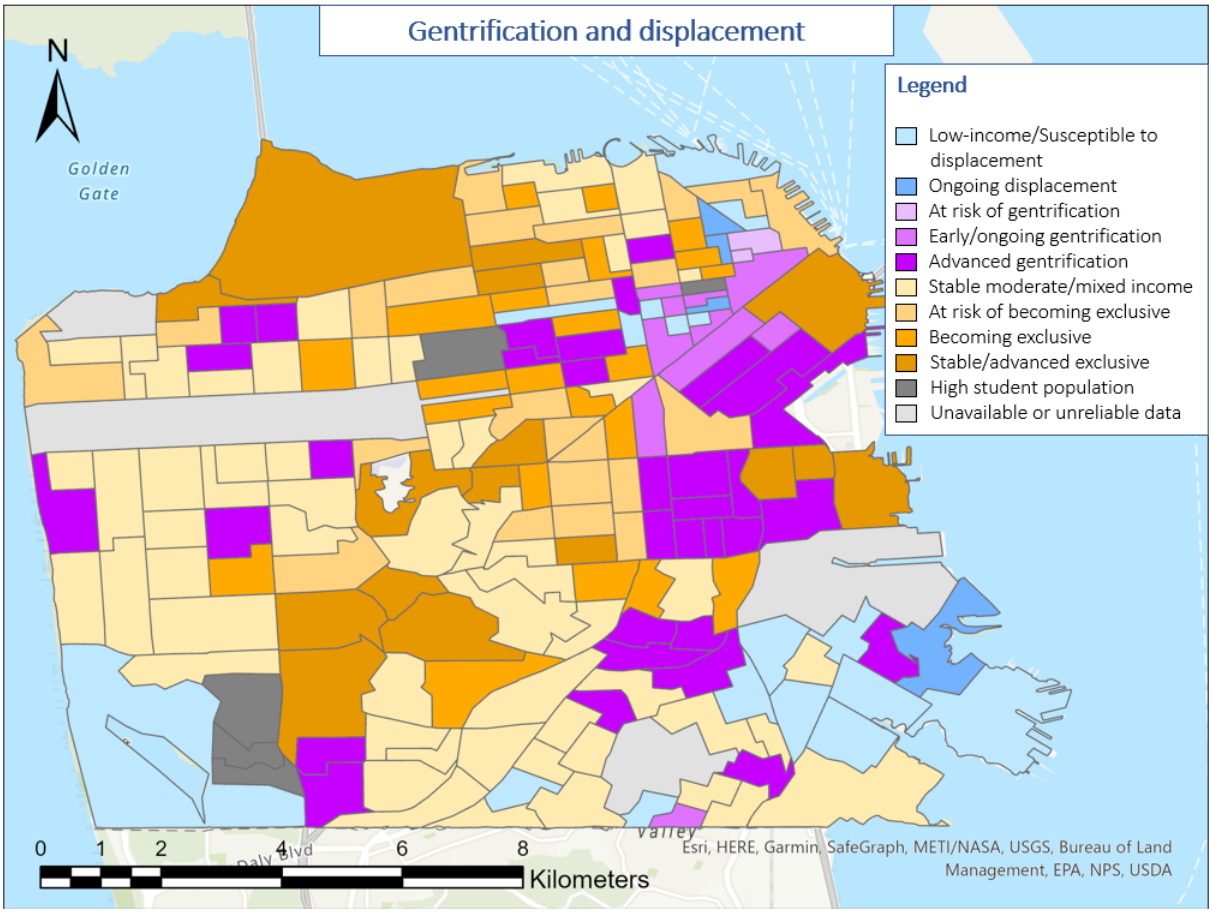

Figure 4.1: Gentrification and displacement in San Francisco

gentrification is going on in the east of the city, while a rather large part of San Francisco is either already exclusive or (at risk of) becoming exclusive. The extreme gentrification has led to an anti-gentrification movement in San Francisco, which mainly presents ideas about development without displacement (CJJC, 2014). People that support the anti-gentrification are often in favour of rent stabilisation, affordable housing and housing trust funds, and often prefer small-scale bottom-up green space strategies rather than big projects (Wolch et al., 2014). Moreover, the CJJC organisation which focuses on justice for low-income San Francisco and Oakland residents, state the importance that governmental developments benefit the working-class communities, rather than hurting them through displacement (CJJC, 2014).

4.2 Spatial differences

After collecting relevant data described in the methodology section, I used GIS to visualise the spatiality of this data. This section will first look into the demographics of the different areas in the city, followed by the output of the analysis on urban park accessibility, flood risk and impervious surfaces. In doing so, an overview is created about the possible connections between demographics such as income and minority groups, and climate change risk.

Figure 4.2 on the right shows the different districts of San Francisco. However, since data is not collected on the district or neighbourhood level, this research analysed data on the zip-code level. Unlike the neighbourhoods, these are officially set administrative boundaries and allowed data to be collected and analysed with the highest precision possible.

Figure 4.2 Districts of San Francisco

In order to translate the risk to climate change and the communities that are most vulnerable to these risks, different proxies were used. As displayed in Table 4.1 below, data on the flood risk zone and the imperviousness of the surface were used to represent the risk to climate change. Moreover, median income, ethnic minorities, English language proficiency, and the urban park availability are used to locate the communities that are most prone to climate change.

Table 4.1 Data used as a proxy for climate change risk

Proxy	Risk to climate change
Median income	Risk for low-income communities
Ethnic minorities	Risk for minority groups
English language proficiency	Risk for minority groups enhanced without English language proficiency
Urban park availability	Risk without access to urban parks
100-year storm flood risk zone	Risk to climate change through floods
Impervious surface score	Risk to climate change through extreme urban heat

4.2.1 Demographics

The data on demographics are shown to give an overview of the city and the way its people are distributed throughout the city and are created to visualise the spatiality of justice in the city. As Figure 4.3 shows, the downtown area is located in the north-east of the city, showing the highest population density.

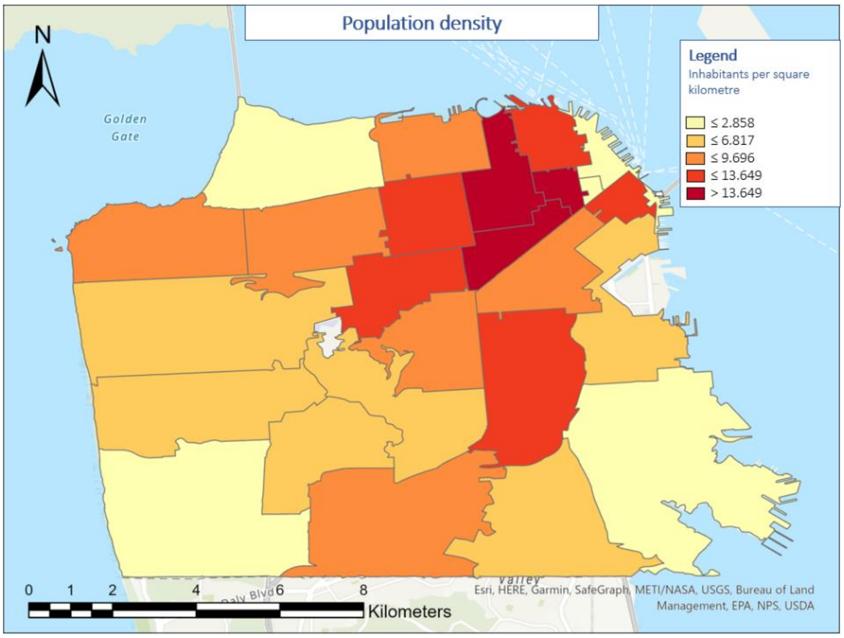

Figure 4.3: Population density

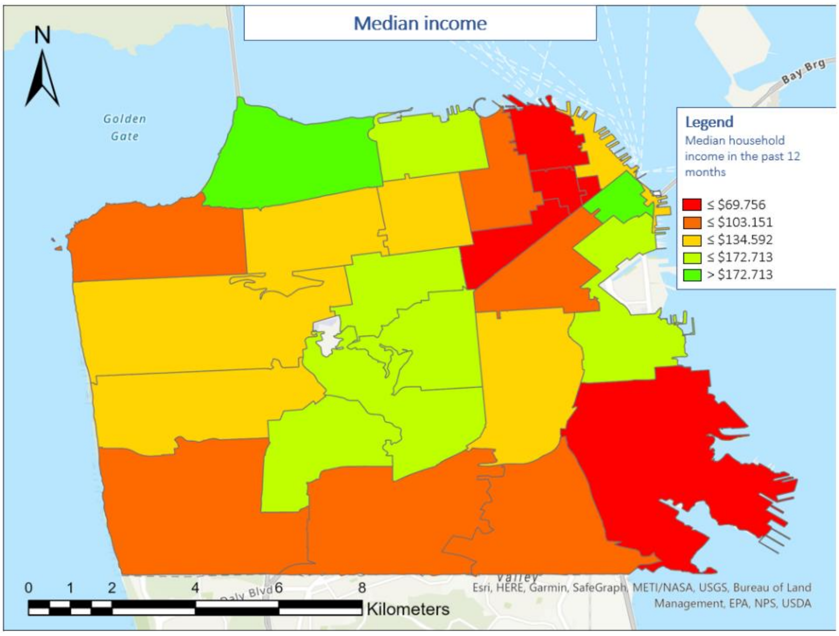

Figure 4.4: Median income

The lowest values are located in the north-west, north-east, south-east and south-west of the city, due to nature in the north-west, a harbour in the north-east, a shipyard in the south-east and a lake in the south-west of the city. Figure 4.4 was created to show the distribution of wealth. Due to the idea that poor communities are more vulnerable to climate change, this map can be a part of explaining the areas in the city where the people experience the highest risks. This can be due to multiple reasons such as lack of neighbourhood investments, air-conditioning availability or indirectly through food insecurity when food prices rise (CCPHIARC, 2007; IPCC, 2015). In Figure 4.4, which presents the median income per zip-code area, a partly different pattern becomes apparent. Although the recreation hub near the Golden Gate bridge in the north-west and the shipyard in the south-east of the city both have a relatively low population density, the first shows to house some of its most affluent residents, whereas the latter show a relatively low median household income. Moreover, the other zip-code region that shows a high median income is located in the financial district in the north-east of the city while it showed a high population density. However, when first looking at Figures 4.3 and 4.4 it does show that there where the population density the highest is, in the north-eastern parts of the city, the median income is relatively low. Nonetheless, San Francisco is a relatively rich city, with the median household income in the U.S.A. in 2019 being $69.560 and in California $75.235 (USCB, 2020), which would map red and orange respectively in Figure 4.4.

Figures 4.5 and 4.6 present the percentage of inhabitants with limited English proficiency and the percentage of inhabitants that belong to an ethnic minority, where work by Wondmagegn et al. (2019) suggest that minorities are often more exposed to extreme heat. In the figures, its similarities become very clear as both show high values in the south-east zip-code areas and near Lake Merced in the south-west as well as the densely populated areas in the north-east of Nob Hill and Chinatown. Moreover, resemblances in distribution can be seen in Figure 4.4 as well, showing a relatively low household income in the areas in the south and north-east of the city.

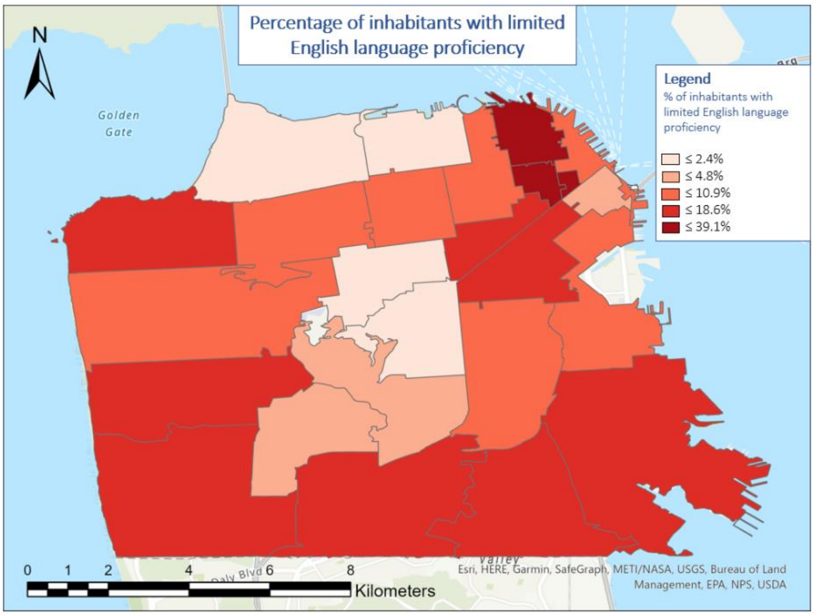

Figure 4.5: Percentage of inhabitants with limited English proficiency

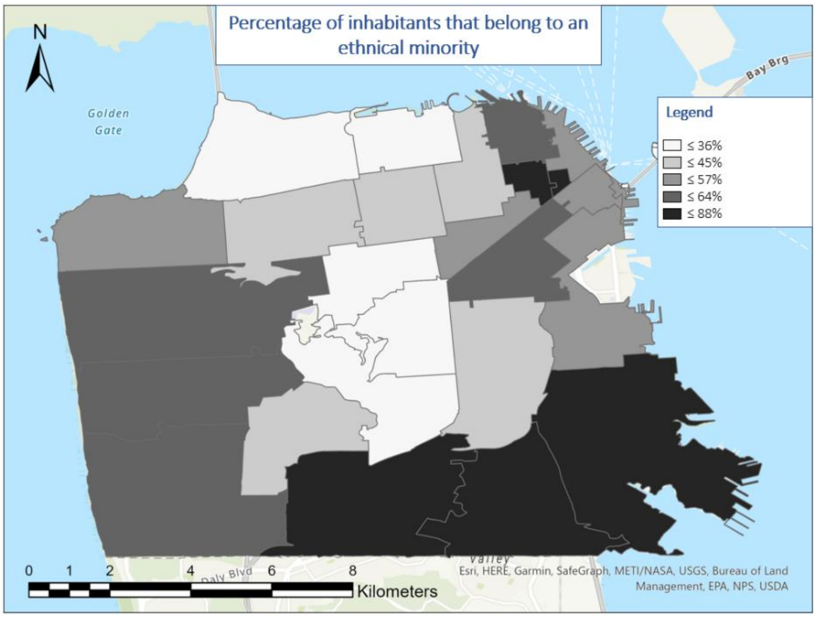

Figure 4.6: Percentage of inhabitants that belong to an ethnical minority

On the one hand, do the demographics show recognisable patterns regarding household income, English proficiency and ethnic minorities. On the other hand, this pattern is only partially recognisable when looking at the population density, where only the areas in the north-east are densely populated but those in the south of the city are not so much. However, the population density is partially influenced by the scale in which the data was available since two of the four zip-code regions in the south of the city consist partly of uninhabitable areas: a lake and a shipyard. Whereas this section solely displayed data on the demographics of each zip-code region, the following section will go further and analyse the urban park availability and vulnerability to impacts of climate change for each region.

4.2.2. Urban nature and climate change risk

This research has built on the grounds that urban parks, with their pervious surfaces and as a form of nature-based solutions, are able to cool down the city by reducing the effects of the urban heat island (Czubaszek & Wysocka-Czubaszek, 2016; Depietri & McPhearson, 2017). Moreover, during summer days, the shade in parks allows residents to cool down through less direct heat impact to the body as well as less emitted and reflected heat from the ground (Middel et al., 2021). Therefore, it is important to look at the accessibility residents have to urban parks as well. Figure 4.7 shows the service area of urban parks in San Francisco based on a five-minute walk along the road network. It shows that there are still quite some areas in the city from which a resident cannot reach an urban park within a five-minute walk, contrary to the advised requirement of the World Health Organization (2017).

Figure 4.7: Service area urban parks

Figure 4.8 aimed to convert these findings of the network analysis to data on the level of each zip-code area, showing relatively high coverage in the north and middle of the city, and relatively low values in the south and east. A slight downside of this network analysis is that it is limited to the coverage of the road network. Whereas the Golden Gate Park is fully covered by its service due to the roads and walking paths that run through it, the entrances of the park in the south-west of the city seem to be poorly accessible. This is mainly due to the large body of water within this neighbourhood. So even though the neighbourhood itself consists of a large urban park, the entrances are not easily accessible by foot showing a relatively small percentage of coverage for its service area. Moreover, when comparing the spatial pattern shown in Figure 4.8 with the patterns of the demographics, similarities can be seen with the

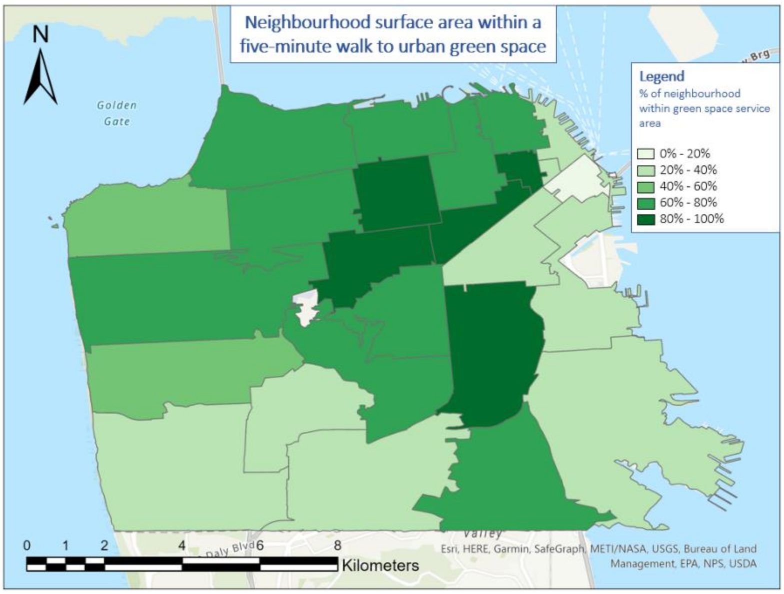

Figure 4.8: Neighbourhoods surface area within a five-minute walk to urban green space

percentage of minorities in a neighbourhood and the population density. Where relatively the least minorities live near the geographical centre and north of the city, showing high coverage of urban parks, and where the most densely populated areas are near the north-east of the city, showing high coverage of urban parks as well.

In order to find the areas that have the highest risk regarding climate change impacts, one of the factors that need to be analysed is the risk for storm floods since storms, especially in combination with high tides, can form major threats for the Bay Area expecting to become more extreme later in time (BCDC, 2011). Figure 4.9 presents the 100-year storm flood risk zone, the areas in the city that would be flooded at least 15 centimetres deep and at least half the size of an average city block, where the chance that such storm occurs in a given year is 1% (SFPUC, 2019). When looking at this risk zone, it instantly becomes clear that there are two large risk zones at the low-lying areas in the east of the city, while multiple little zones are scattered throughout the whole city.

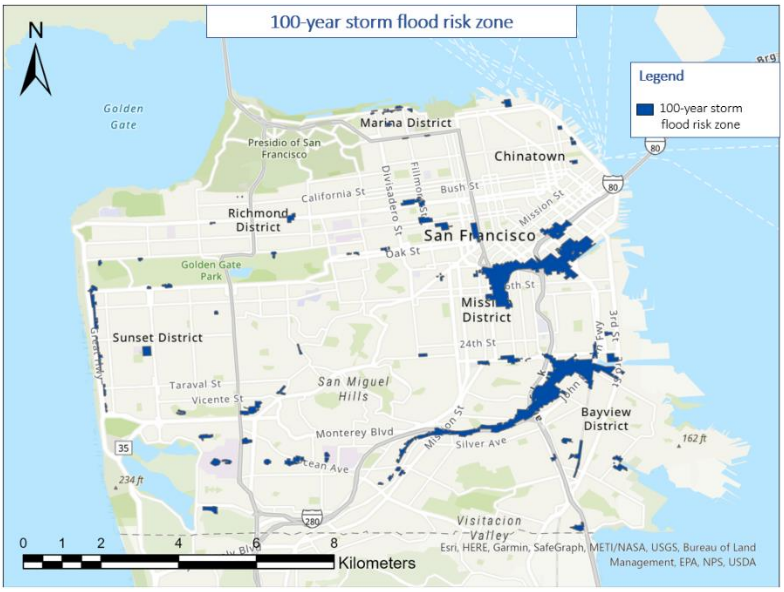

Figure 4.9: 100-year storm flood risk zone

However, when converting these zones to a percentage of a zip-code region in Figure 4.10, the general picture changes a bit. Due to the larger zones, especially the one in the south-east, moving through multiple neighbourhoods, Figure 4.10 shows relatively high values for most areas in the east and south-east. Moreover, since the areas are now summarised within the administrative boundaries of the zip-code regions, the 100-year storm flood risk looks less extreme. Whereas Figure 4.9 shows two large zones that could suffer severe climate impacts, Figure 4.10 shows that in no San Francisco zip-code region more than 16 per cent of its surface area is at risk. This way, the zones that are at risk are divided across different zip-code areas, showing relatively low risk in many neighbourhoods rather than a high risk in a smaller area.

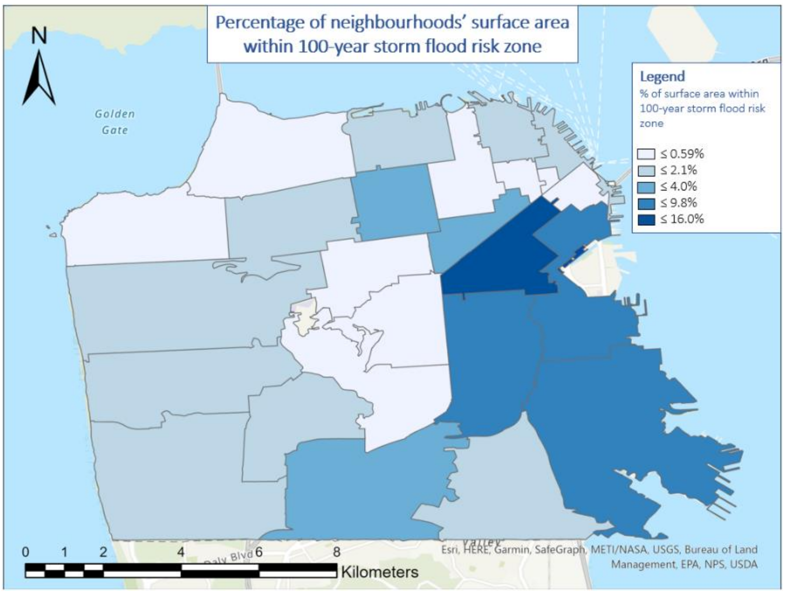

Figure 4.10: Percentage of neighbourhoods' surface area within 100-year storm flood risk zone

Next to the areas that are of higher risk regarding storm floods, the areas with the most impervious surfaces are more vulnerable to the impacts of climate change as well. Impervious surfaces contribute to the urban heat island effect through their high thermal conductivity and low solar reflectivity, whereas lower temperatures occur when there are more pervious surfaces (Morabito et al., 2017). With that, the areas with the least pervious surfaces can be expected to suffer more from heat-related illnesses and mortality, something that is already more likely for low-income groups and the elderly (Frosch et al., 2009; Wondmagegn et al., 2019). Figure 4.11 presents the impervious surface score per neighbourhood based on the satellite image shown in the inset on the right. It shows high scores impervious surfaces in the densely populated north-east of the city, whereas the green areas near the Golden Gate Bridge, the Golden Gate Park, and Lake Merced in the south-east have relatively low values for its imperviousness. However, a low population density does not necessarily result in a low impervious surface score. The area located in the south-east of the city, for example, showed a low population density in Figure 4.3 but still a high impervious surface score in Figure 4.11. The impervious surface score per neighbourhood shows a lack of resemblance with the accessibility to urban parks in Figure 4.8. That map still showed good accessibility in the densely populated areas in the north-east of the city, whereas Figure 4.11 displays that those areas have some of the highest scores for their impervious surfaces.

All in all, Figures 4.10 and 4.11 show which areas of San Francisco face the most risks regarding climate change impacts. Here, the percentage of a zip-code area that is covered by the 100-year flood risk zone and the impervious surface score are seen as proxies for the risk of climate change. The maps show the highest values in the east of the city, with some overlay in the north-east. Therefore, it can be expected that the areas in the east and north-east of the city are those that experience the highest risk of climate change impacts in San Francisco.

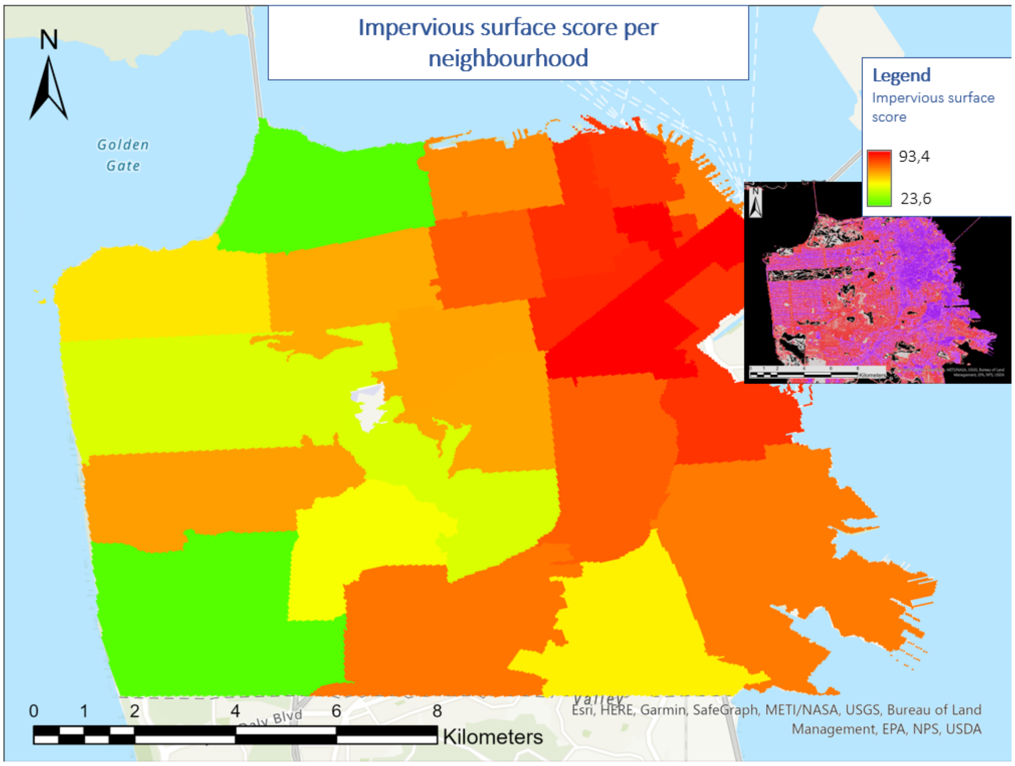

Figure 4.11: Impervious surface score per neighbourhood

4.3 Correlations

The previous sections looked into the climate change impacts, nature-based solutions and gentrification and displacement in San Francisco, followed by multiple maps on demographics and climate change risk in the city. These maps provided an insight into the spatiality of these topics. Income and minority groups were used as a proxy as work by Shokry et al. (2021) suggest that these groups are most vulnerable to climate change. Moreover, accessibility to urban parks was used as a proxy as well, as those that live near green spaces are expected to experience fewer problems regarding extreme heat (Czubaszek & Wysocka-Czubaszek, 2016; Depietri & McPhearson, 2017).

In order to find out if and how the areas in San Francisco with the highest risk regarding climate change impacts correlate with the city´s urban nature and demographics, a Spearman's rho correlation analysis was conducted. Here, the impervious surface score and the percentage of the zip-code region that was covered by the 100-year flood risk zone was used as the dependent variable and tested against multiple demographics and park accessibility, of which the full output can be seen in Appendix A.

Although multiple factors can influence the risk of climate change impacts, not all are transferable into suitable data. Whereas the storm flood risk zone translates quite literally into the climate change risk of floods, this is less the case regarding the imperviousness of the surface. However, due to the inability of impervious surfaces to allow water to seep into the ground and its contribution to the urban heat island, there can be assumed that the areas with a relatively high percentage of impervious surface are at a higher risk of climate change (Dalton & Murti, 2013; Morabito et al., 2017).

The output shows that only two results are statistically significant, which both correlate to the impervious surface score, as can be seen in Table 4.2 below. According to the output, an increase in imperviousness in a zip-code area in San Francisco will lead to a smaller surface area and a higher population density with results of -,630** and ,600** respectively. The correlation between the imperviousness score and the population density could be expected due to the similar patterns seen in their maps of Figures 4.10 and 4.2, where the highest values were shown in the north-east of the city. Moreover, the idea of a potential correlation between the population density and surface area was already displayed in Figure 4.2 on population density, showing relatively higher density in smaller neighbourhoods and lower density in larger neighbourhoods. Therefore, it can be explained that in this context of San Francisco the highly impervious and densely populated areas are smaller in surface area than those with a lower impervious score.

However, no significant correlations with other factors were found, although discussed literature suggested otherwise. For example, this research also tested the correlation between these areas of higher risk and the accessibility to urban parks. This was based on both Czubaszek & Wysocka-Czubaszek (2016) and Depietri & McPhearson (2017) who stated that nature is able to cool down the city by reducing the urban heat island effect and, thus, making areas less vulnerable to climate change. However, the test shows no correlation between these areas of higher risk and the accessibility to an urban park in San Francisco.

Table 4.2 Spearman's rho correlation impervious surface score & flood risk zone and demographics & neighbourhood characteristics

		Impervious surface score	% neighbourhood within 100-year flood risk zone
Limited English proficiency	Correlation Coefficient	,350	,194
	Sig. (2-tailed)	,086	,354
	N	25	25
Surface area	Correlation Coefficient	-,630**	,316
	Sig. (2-tailed)	,001	,124
	N	25	25
Population density	Correlation Coefficient	,600**	-,042
	Sig. (2-tailed)	,002	,843
	N	25	25
Median income	Correlation Coefficient	-,358	-,166
	Sig. (2-tailed)	,079	,428
	N	25	25

*. Correlation is significant is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Although there is very strong evidence for the correlation between the imperviousness score and the surface area and population density at a significance level of 0.01, weak evidence can be found for other factors. To wit, when looking at a significance level of 0.1, the level of English proficiency and the median income can be taken into consideration as well with p-values of ,086 and ,079 respectively. The correlation coefficient for the limited English proficiency is ,350, suggesting that in neighbourhoods where the risks for the effects of climate risk is higher, more people struggle with the English language. Moreover, the correlation coefficient for the median income is -,358, showing that the median income in an area is lower when this is area is more vulnerable to the effects of climate change. Although these results are statistically weak, they do coincide with expectations based on discussed literature. For example, both Frosch et al. (2009) and Wondagegn et al. (2019) came to the conclusion that low-income groups struggle more with heat. Especially since this test used the imperviousness score as the dependent variable, seeing extreme heat as the risk factor, it was expected to find a significant result regarding the median income.

However, these results can only be found when the impervious surface score was the dependent variable. No significant correlation was found between the 100-year flood risk zone and all other factors, exposing the possible limitations of this research. Due to the need for data to be at the same spatial level, some precision is lost when confirming flood risk zones to relative risk per zip-code area. Moreover, a neighbourhood's elevation is important when it comes to flood risk as well, expecting risk areas to be in low lying areas. Nonetheless, especially due to the increasing risk of large storms and the ability of nature-based solutions to regulate stormwater runoff, arguments could be made to expect a correlation between the 100-year flood risk zone and park accessibility and imperviousness.

To sum up, the only significant correlations were found when the impervious surface score was seen as the dependent variable. Here, the only significant scores were regarding a neighbourhood's surface size and population density, showing a smaller neighbourhood size and higher population density when the impervious surface score increases. While reserving judgement, however, weak arguments could be made that in the most impervious neighbourhoods both the English language proficiency and median income decreases. On the contrary, no significant correlations were found when the 100-year flood risk zone was used as the dependent variable and tested against the demographics. Therefore, such a correlation might not exist in the city of San Francisco, whereas it is also possible that the used variables aimed to represent such phenomena are not fully sufficient. As a result, most of the data on demographics and urban parks that was tested for a correlation between climate change risks did not show to be significant in San Francisco.

5. Discussion

One of the main reasons this study was conducted was because of the one-sidedness in research on nature-based solutions, maladaptation, and gentrification. Although these concepts have been studied separately before, combining these and seeing how gentrification and displacement can be resisted is relatively new. Through the spatial context of San Francisco, this research has aimed to find ways in which nature-based solutions can contribute to building resilience for climate change and with that, reduce spatial injustice in the city rather than increasing spatial injustice. In doing so, a better understanding of the complexity of the problem can be reached, leading to a more inclusive and just way of implementing nature-based solutions. This section aims to give meaning to some of the results that were presented in the results section by analysing and interpreting the findings.

5.1 Nature-based solutions to build resilience for climate change in San Francisco

As discussed in the results section, climate change risks face the city of San Francisco in multiple ways. The city will increasingly face risks of water uncertainty, floods, and extreme heat (BCDC, 2011; Frosch et al., 2009; SPUR, 2011). However, this research has shown that nature-based solutions are able to reduce these risks.

The risks that the city faces of water uncertainty and droughts can be seen as a problem that needs to be tackled on a global scale. Higher global temperatures threaten the melting of the snowpacks in the Sierra Nevada mountain range, pressuring the freshwater supply of the city (SPUR, 2011). This is, however, a problem that needs to be tackled globally where nature-based solutions in San Francisco by themselves are not able to prevent the rapid melting of the snowpack. Nevertheless, nature-based solutions can contribute to resisting climate change on a global scale as well, as long as efforts are made across multiple levels of scale (Cohen-Schacam et al., 2016, Toxopeus et al., 2020).

Flood risks, however, are able to be reduced more effectively on the city scale by nature-based solutions. In general, due to their pervious surfaces, nature-based solutions can share the ability of collecting, storing and transporting water with traditional grey infrastructure (Dalton & Murti, 2013). Moreover, nature-based solutions can be designed in a way within the urban environment designed to tackle a specific problem (Depietri & McPhearson, 2017). In reducing the risk of floods, nature-based solutions such as bioswales and rain gardens can be seen as a direct solution to tackle flood risk (Ibid.).

Next to flood risk, extreme heat can be seen as a big risk as well due to the urban heat island effect, especially in cities located in warm climates. The high conductivity of the built environment as well as heat from ventilation and traffic cause higher temperatures in the most built-up areas (Czubaszek & Wysocka-Czubaszek, 2016). Whereas combating flood risk is most effective with specific planning measures, reducing the urban heat island effect can happen in multiple different ways. Nature-based solutions are able to reduce the most extreme heat through evapotranspiration and the providing of shade and, with that, protect the urban resident from heat-related illnesses and heat-related mortality (Middel et al., 2021).

The content analysis on San Francisco's Climate Action Plan and the executive order on the biodiversity crisis shows the recognition of this potential by the city. The Climate Action Plan (2021) presents the city's strategy to create a healthier environment through nature-based solutions. In the Climate Action Plan, the main driver for implementing nature-based solutions is to restore ecosystems and restore biodiversity and, with that, collect CO2 to stop it from entering the atmosphere (Ibid.). Although the action plan mentions that nature-based solutions can provide a large share of the mitigation needed to prevent global temperature rise, it fails to argue its potential to tackle city-specific problems. In the executive order (2020), however, the governor of California implemented the increase in nature-based solutions to combat biodiversity loss as well as building resilience for extreme weather events due to climate change. Therefore, the city recognises the positive effects nature-based solutions have to offer as well as its potential to build resilience for the city-specific climate change risks such as water uncertainty, floods, and extreme heat.

5.2 Spatial differences in San Francisco

When looking at the spatial distribution of demographics in San Francisco, similarities between median income, English language proficiency, and minority groups became apparent. This is in line with the findings by CJJC (2014) who state that most of the communities in the Bay Area are wealthy and white, together with a small percentage of Asian Americans, whereas many BIPOC communities are concentrated outside the administrative boundaries of San Francisco. Moreover, this report by CJJC states that most of the people that are being displaced due to processes of gentrification belong to minority groups, often African American, Latino, or Filipino. These groups struggle most in placing competitive bids in the housing markets, while a larger percentage of minority groups did not have the means to buy in the first place. Therefore, in San Francisco, these groups have to either rent and be susceptible to rises in rent or struggled to pay their mortgage during the housing crisis (Ibid.)

The analysis has shown that these low-income minority groups either live in the densely populated north-east of the city or in the neighbourhoods in the south of the city. Although the neighbourhoods in the north-east of the city score very high on the impervious surface score, those in the south are quite mixed where two score relatively high and two relatively low. These findings are partly supported by the Spearman's rho correlation analysis. In this analysis, the impervious surface score was seen as the dependent variable representing the risk to climate change as it indirectly shows what percentage of the surface is covered by pervious surfaces, its inability to regulate stormwater runoff, and its contribution to the urban heat island effect (Morabito et al., 2017). The research aimed to research the possible correlation between low-income and minority groups with climate change risk but the findings in San Francisco do not match the results of previous research by Shokry et al. (2021). In their case study in Philadelphia, Pennsylvania, they found that low-income and minority groups are more vulnerable to the risks of climate change as they experience the benefits of nature-based solutions the least (Ibid.). In San Francisco, this was only found in the neighbourhoods in the north-east as these score high for the impervious surfaces score and have a relatively high percentage of minority groups, whereas the neighbourhoods in the south that house a high percentage of ethnical minorities show a relatively low impervious surface score.

A significant correlation, however, was not found between the impervious surface score and median income, although previous research by Frosch et al. (2009) and Wondmagegn et al. (2019) suggest otherwise. In their work, Frosch et al. (2009), who researched the climate gap in California through large-scale data analysis of state-wide census data, that the poor will be hit the worst by the consequences of climate change. Not only do these communities struggle most to cope with the effects already, but they are aso at risk indirectly through price increases of basic necessities and the threats of losing their jobs (Ibid.). Wondmagegn et al. (2019) focused on heat-related healthcare costs in the United States and Australia and found both low-income groups and ethnic minorities as population groups with the highest healthcare costs. This correlation between climate change risk and median income, however, was not found in this research. A reason for this could be the differences in methods. Whereas Frosch et al. (2009) and Wondmagegn et al. (2019) researched on a state-wide and country-wide scale, I was able to perform research on the city scale, making it harder to find significant results. Moreover, it is important to recognise that climate change and the vulnerability to climate change is a complex problem and is not fully represented in data on imperviousness. Additionally, in order to include polygon data in a statistical test, GIS was used to transform the spatiality of this data to the neighbourhood level, losing some of the precision that polygon data offers. However, the test does show some weak evidence to assume that the link between income and climate change vulnerability exists in San Francisco due to the significance levels of ,079 between the impervious surface score and median income.

When looking into urban parks, this research aimed to overcome the limitations of neighbourhood boundaries. When someone lives close to a large urban park for example, but in a different administrative neighbourhood than the one where the park is located in, data might show poor park availability in that neighbourhood, although one in a different neighbourhood might be within reach. In order to overcome this problem, this research looked at the service area of those parks, presenting areas of the city that can reach a park within a five-minute walk. Based on the work by Middel et al. (2021), urban parks are able to reduce the risk of extreme heat as they can cool a place down through evapotranspiration as well as provide shade. By computing this service area, the percentage of each zip-code region that is within the service area of urban parks could be measured, expecting lower risk to climate change in neighbourhoods where more can easily reach a park. The problem here, however, is that even in neighbourhoods that are not green at all, such as the Civic Center, Nob Hill, Chinatown, and the Financial District, which are very impervious, can still have good coverage. In these cases, a limited number of relatively small parks can serve these densely populated areas while these have a minimal effect in reducing the urban heat island effect (Czubaszek & Wysocka-Czubaszek, 2016). Together with the limitations of the road network in determining the service area, for example, poor accessibility was shown in a neighbourhood that consisted of a big lake, the lack of significance with the impervious surface score can be explained.

5.3 Resisting gentrification and displacement in San Francisco

Ways in which a more just situation can be reached in San Francisco through the implementation of nature-based solutions boils down to a green resilience paradox, as proposed by Shokry et al. (2021). The paradoxical process that happens here is that nature-based solutions are implemented to provide a better situation for vulnerable communities, while in reality, their situation worsens due to processes of displacement (Ibid.). Therefore, planning for nature-based solutions can lead to a more just situation when implementation goes right. Hence, it is important to find ways in which a nature-based solution is able to benefit all. However, adaptation strategies can have counterproductive results as well and turn out to be maladaptive (Schipper, 2020).

Such processes of maladaptation are what worries justice organisations in San Francisco as well. Even though their scope is broader than the implementation of nature-based solutions towards all neighbourhood investments, they state that the investments made often appeal to the people outside the neighbourhood (CJJC, 2014). Therefore, the wishes and needs of the neighbourhood's residents are not being served. In order to decrease the risk of displacement and, therefore, allow vulnerable groups to profit from investments, involvement of the community, developing leadership, and community organisation need to be the main points of anti-displacement strategies (Ibid.).

The importance of the involvement of vulnerable communities, often existing of people of colour, thus, need to be recognised by both these communities as well as the local government. Involving BIPOC communities is presented as a focal point in San Francisco's Climate Action Plan (2021) in designing new nature-based solutions and can be seen as a step in the right direction. The downside, however, is the reasoning of the city is still from an environmental perspective as they highly value their knowledge regarding native flora and fauna, while still undermining societal factors.

Hence, the main challenge for the city is to make sure that their nature-based solutions benefit all. After prioritising the need for implementing nature-based solutions to create resilience for climate change, the societal factors need to be taken into account as well. In doing so, they need to make sure that in order to create a better city that benefits all communities, they need to create it with all communities.

However, in order for the community to be heard in the process, it is important for them to know the ways of the political arena (Toxopeus et al., 2020). Especially marginalised communities struggle to get their voice heard in the political world, indicating the need for scientific professionals to work with local communities to make sure their needs are expressed (Ibid.). This is also a problem that the San Francisco based organisation Causa Justa : : Just Cause (2014) recognises. The same injustices that occur on the free market, happen in politics as well, giving the upper class more political power. This does not only happen through lobbying and campaigns but through the knowledge on how to manoeuvre in the political space as well (Ibid.). However, the fact that grassroots organisations like Causa Justa : : Just Cause and San Francisco Rising work from within the working-class communities shows the potential there is in mobilising the marginalised communities since the networks are already in place (CJJC, 2022; SFR, 2022). Through education, organisations like this are able to give working-class communities political power. Moreover, through their diverse team, they know their ways in both the academic and political world, making their voices stronger (Ibid.).

To sum up, it shows that the ‘balancing act’ needed for successful adaptation as proposed by Wolch et al. (2014), which formed a central role in the conceptual model of chapter 2, is rather complex. Adaptation is needed but is not necessarily successful. Even though it is important to recognise the importance of implementing nature-based solutions to build resilience for climate change, the focus should not solely be on the environmental factors of adaptation but on the societal factors as well. To reach successful adaptation, collaboration between multiple fields is needed. Professionals such as planners, ecologists, and architects need to be actively involved while community groups, local stakeholders, and local government need to work closely together (Ibid.).

6. Conclusion

This study aimed to provide insights into the complexity of climate change adaptation through nature-based solutions. Through the assessment of both the potential and risks of climate change in San Francisco, a better understanding of the two-sidedness of climate change adaptation can be reached. Therefore, the main question of this study was: *"How can nature-based solutions contribute to building resilience for climate change while reducing spatial injustice rather than increasing spatial injustice in San Francisco, California?"*. This chapter will discuss each of the sub-questions, followed by an answer to the main research question. After that, this chapter will provide some recommendations for future research.

In order to answer the main research question, five sub-question were developed as these gave structure to answering the main research question. The balancing act of making a city ´just green enough´ as proposed by Wolch et al. (2014) was explored through these sub-questions as well as the current situation regarding climate change risk in San Francisco.

By answering the first sub-question an understanding of the potential of nature-based solutions in reducing climate change risk was provided. A literature review has shown that nature-based solutions have been shown to help cities in building resilience for climate change through reducing urban heat, recovering the quality of urban nature, and regulating stormwater runoff as nature allows water to seep into the ground as well as cool the city down through processes of evapotranspiration.

The second sub-question looked into the climate change risks that the city of San Francisco faces. A content analysis has shown that the city already faces climate change risks in multiple ways. Due to the city being located in a bay, along with more extreme weather and a sea-level rise, the city faces flood risks. Additionally, extremely hot days in the summer can lead to heat-related illnesses. Finally, the city is expected to face more periods of droughts and, therefore, water uncertainty as well.

Mapping the areas of the city that are most prone to those climate change effects was the goal of the third sub-question. Here, it became clear that especially the Civic Center, Financial District, SoMa, Nob Hill, and Chinatown districts, located in the east and north-east of the city, have the most risk regarding climate change. These were also the areas where some overlap in high-risk zones between the two determinants of climate change, flood risk and impervious surface score, was found.

If and how these relate to urban nature and demographics is what the fourth sub-question was set up for. In the city of San Francisco, there are not many significant correlations between climate change risk and its urban nature and demographics. The only statistically significant results occurred between the impervious surface score, where the size of a neighbourhood decreases and the population density increases, the higher the score for its imperviousness. Moreover, weak arguments can be made for a correlation between imperviousness and language proficiency and median income, expecting fewer people to speak English and a lower income in the more impervious neighbourhoods. However, no significant correlations at all were found regarding the 100-year flood risk zone and the city's nature and demographics.

The final sub-question countered the often one-sided approach towards nature-based solutions. In these cases, the focus is often on the positive environmental effects that they can offer, whereas this sub-question looked into the risks that their implementation can bring along. The nature-based solutions are most needed by low-income and minority groups since these groups are often most vulnerable to the effects of climate change. The main risk of adaptation through nature-based solutions is that those who need it most, do not get to experience the benefits that these solutions bring. Hence, stating the importance of finding ways in which adaptation through nature-based solutions can happen that benefits all. Oftentimes, processes of green gentrification push up property prices near such investments. Subsequently displacing the most vulnerable communities while a new group, often existing of the middle class, moves into the neighbourhood. Therefore, the benefits of these nature-based solutions are not experienced by those who need it most but by those who can afford it.

Coming back to the main research question, this research aimed to find out how nature-based solutions can contribute to building resilience for climate change while reducing spatial injustice rather than increasing spatial injustice in San Francisco, California. It becomes clear that the risk to climate change effects is distributed unevenly, affecting low-income and minority communities most. Moreover, nature-based solutions are able to reduce this risk in different ways. However, when maladaptation occurs, such a solution can result in an increasingly unjust situation. As presented in the conceptual model in chapter 2, adaptation outcomes can be divided into three main categories. Here, successful adaptation will lead to a more just situation, the situation will stay roughly the same when the adaptation is partly successful, and unsuccessful adaptation will result in a more unjust situation. Moreover, when no adaptation happens, pressure on spatial justice will keep increasing due to the increasing risks of climate change related hazards, especially impacting low-income and minority groups.

It became evident that, in order to resist gentrification and displacement while adapting through nature-based solutions, the focus should not only be on the environmental factors but on the societal factors as well. The size of an adaptation needs to be taken into account as well as huge investments in low-income neighbourhoods are ought to enhance gentrification processes. Here, strategies of making a city ‘just green enough’ have proven effective in limiting gentrification, making adaptation strategies a true balancing act. Moreover, in order to serve a local community and their desires, needs, and concerns, their activism is needed. Additionally, in anti-displacement strategies, bottom-up decision making, community organising and leadership development should be a central point. Finally, it is important to recognise the gap between politicians and marginalised communities. Especially these communities find it hard to get their voice heard in the political world as they do not know their ways in the political arena.

Marginalised communities in San Francisco, however, are supported by large grassroots organisations fighting for more political power for working-class communities. These teams also consist of multiple scientists who know their way in the academic and political world as well. Additionally, the city does recognise that vulnerable communities are at risk of climate change effects but fail to empower them through the networks that are already in place.

Moreover, the focus of the city is still on the environmental factors, assuming that nature-based solutions can serve all neighbourhood inhabitants, overlooking the effects of maladaptation.

All in all, this study added to the field of research as it provided an understanding of the complex problems regarding climate change adaptation, nature-based solutions and maladaptation as it shows the importance of broadening the focus of research from only environmental factors towards societal factors as well. It has shown that nature-based solutions can form a vital part in building resilience for climate change. However, when implementing this, societal factors should play a central role in the planning process in order to maximise the chances of vulnerable communities to experience the benefits that nature-based solutions provide. Through bottom-up decision making and empowering these communities, San Francisco can make important steps in making the city 'just green enough' where all citizens benefit.

7. Reflection

7.1 Strengths and limitations

One of the main strengths of this research has been researching the context of San Francisco, which is known as a place in which the used concepts are all relevant. The city faces multiple risks to climate change, wants to focus more on nature-based solutions, and has been struggling with gentrification and displacement. Additionally, the city is aware of the uneven distribution of climate change risks on a population, putting the most vulnerable communities at risk.

Moreover, in this research, I was able to use different data collection and analysis techniques to answer its sub-questions. By using a literature review, content analysis, and statistical analysis through GIS and SPSS, I aimed to triangulate the methods used in this research. As a result, strengthen the findings and answer the research question as completely as possible. These methods were chosen due to the availability of high-quality data in a city where the concepts of climate change adaptation, spatial justice, and nature-based solutions are very relevant. However, adding to this by conducting interviews with local experts could have led to interesting San Francisco specific insights.

Due to the availability of census data for each zip-code region, data of high quality from relatively small areas could be used. Additionally, Shokry et al. (2021) found a relationship between climate change risk and demographics such as minority groups and income. Data on these demographics were available in this census data leading to high-quality data on the exact topic. Therefore, this data can be seen as an accurate proxy of communities that are more vulnerable to climate change risks.

On the contrary, the available data has also led to a limitation in this research. Climate change and the risk to climate change can be seen as a complex topic and is, thus, not easily fully represented by a single dataset. Therefore, this research conducted an impervious surface score and used the 100-year flood risk zone provided by the San Francisco Public Utilities Commission (2019). Here, the impervious surface score represented climate change risk through its contribution to the urban heat island, low percentage of nature, and its inability to allow water to seep into the ground.

However, this impervious surface score, which was used as one of the dependent variables, is also able to influence the flood risk, which was used as the other dependent variable, as the risk in low-lying areas increases when its adjacent areas are relatively impervious. Moreover, to allow statistical testing for a correlation between the flood risk zone and relevant demographics, the data needed to be transformed for it to represent a zip-code area. This data was originally a polygon layer, mainly showing flood risk in two areas of the city. Due to the conversion of this layer to what percentage of the flood risk zone exists within each zip-code region, the two zones are now apparent in seven different zip-code regions, while showing a relatively low percentage for each region.

In addition to this, although the city of San Francisco has proven to be relevant in researching the topics of climate change, nature-based solutions, and maladaptation, researching on the city level also has its limitations. In this research, zip-code regions were the smallest regions on which relevant data was available. Therefore, 25 regions were used in the statistical analysis, possibly making it harder to find statistically significant than when using a higher N. Moreover, it can be assumed that the processes of gentrification and displacement are bigger than the city. San Francisco is already a gentrified city, being the most gentrified city of the United States in 2000 (Mitchel, 2001). People that are displaced from their San Francisco neighbourhood, are not necessarily displaced to a different neighbourhood in San Francisco, as all San Franciscan neighbourhoods might have become too expensive. Therefore, chances are that displaced households from San Francisco are now living somewhere in the urban sprawl of the Bay Area, and are not being represented by the data in this research.

7.2 Recommendations for future research

In academic literature, there is a lot of discussion on the potential of nature-based solutions in combating climate change. Less is written on the processes of green gentrification and displacement when these investments turn out to be maladaptive. The real gap, however, exists where these topics are combined as literature on resisting gentrification and displacement while adapting through nature-based solutions is very limited. Therefore, interesting new findings can be acquired when delving into anti-displacement strategies while adapting to climate change through qualitative research.

Moreover, climate change risk is something that is hard to measure. It consists of multiple different variables that all partly but not fully represent the risk of climate change. In this research, the calculated impervious surface score presented the most inclusive picture of climate change risk as this directly represents the contribution to the urban heat island effect but indirectly flood risk, biodiversity, and air quality as well. However, a combination of proxies could show a more authentic representation of climate change risk. Hence, further research on the calculation of such climate change risk could lead to more accurate findings.

Additionally, expanding the scope of this research to the context of multiple different cities around the world could strengthen its findings. This way, statements regarding correlations and spatial patterns can be made on a global scale as well as compared between cities.

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Appendix A. Spearman's rho output

Table A. Full Spearman's rho correlation impervious surface score & flood risk zone and demographics & neighbourhood characteristics

		Impervious surface score	% zip-code within 100-year flood risk zone
Limited English proficiency	Correlation Coefficient	,350	,194
	Sig. (2-tailed)	,086	,354
	N	25	25
Percentage of white inhabitants	Correlation Coefficient	-,237	-,258
	Sig. (2-tailed)	,253	,214
	N	25	25
Surface area	Correlation Coefficient	-,630**	,316
	Sig. (2-tailed)	,001	,124
	N	25	25
Percentage surface area neighbourhood within a 5-minute walk to a park	Correlation Coefficient	-,122	-,175
	Sig. (2-tailed)	,563	,404
	N	25	25
Percentage surface area neighbourhood within 100-year flood risk zone	Correlation Coefficient	,178	1,000
	Sig. (2-tailed)	,396	.
	N	25	25
Population density	Correlation Coefficient	,600**	-,042
	Sig. (2-tailed)	,002	,843
	N	25	25
Total population	Correlation Coefficient	-,144	,243
	Sig. (2-tailed)	,493	,241
	N	25	25
Median income	Correlation Coefficient	-,358	-,166
	Sig. (2-tailed)	,079	,428
	N	25	25
Impervious surface score	Correlation Coefficient	1,000	,178
	Sig. (2-tailed)	.	,396
	N	25	25

*. Correlation is significant is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).