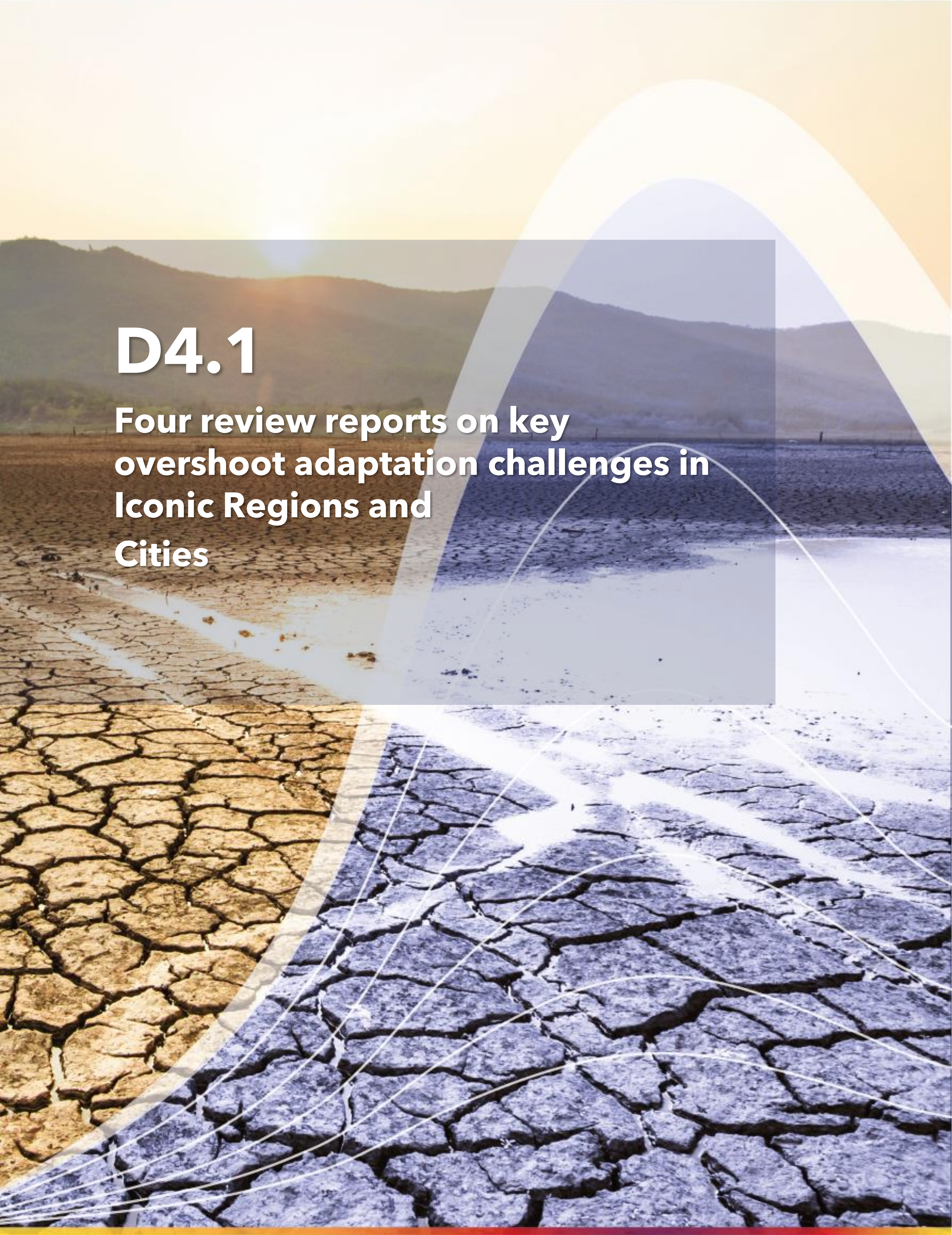
PROVIDE



D4.1

Four review reports on key overshoot adaptation challenges in Iconic Regions and Cities

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D4.1 Four review reports on key overshoot adaptation challenges in Iconic Regions and Cities

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Abstract:

Impacts of overshooting the Paris Agreement temperature thresholds will materialise globally but be particularly consequential for vulnerable regions. This report represents the initial stocktaking of overshoot adaptation challenges in the four Iconic Regions and Cities in focus for PROVIDE: Arctic Fennoscandia, with a focus on Bodø, Norway; Iberian Mediterranean, with a focus on the Lisbon Metropolitan Area; the Upper Indus Basin, with a focus on Islamabad; and The Bahamas, with a focus on Nassau.

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Glossary

Unless otherwise stated, the terminology in the report follows conventions developed by the IPCC WGII.

CONCEPT	DESCRIPTION
Adaptation challenges	Factors that make it harder to plan and implement adaptation actions.
Adaptation opportunities	Factors that make it easier to plan and implement adaptation actions, which expand adaptation options, or that provide ancillary co-benefits.
Adaptive capacity	The ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences.
Ecosystem service	Ecological processes or functions having monetary or non-monetary value to individuals or society at large. These are frequently classified as (1) supporting services such as productivity or biodiversity maintenance, (2) provisioning services such as food, fibre, or fish, (3) regulating services such as climate regulation or carbon sequestration, and (4) cultural services such as tourism or spiritual and aesthetic appreciation.
Exposure	The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected.
Hazard	The potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
Limits to adaptation	A limit to adaptation is reached when adaptation efforts are unable to provide an acceptable level of security from risks to the existing objectives and values and prevent the loss of the key attributes, components, or services of ecosystems.
Overshoot	Pathways that first exceed a specified global warming level (usually 1.5°C, by more than 0.1°C), and then return to or below that level again before the end of a specified period of time (e.g., before 2100). Sometimes the magnitude and likelihood of the overshoot is also characterized. The overshoot duration can vary from at least one decade up to several decades.
Risk	The potential for adverse consequences for human or ecological systems, recognising the diversity of values and objectives associated with such systems. In the context of climate change, risks can arise from potential impacts of climate change as well as human responses to climate change.
Tipping point	A level of change in system properties beyond which a system reorganizes, often abruptly, and does not return to the initial state even if the drivers of the change are abated.
Vulnerability	The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

Executive Summary

The 1.5°C Paris Agreement long-term temperature goal sets ambitions for global climate action to avoid the most devastating impacts of climate change. However, under current emissions trajectories, overshooting 1.5°C is a distinct possibility.

Even if we only temporarily exceed 1.5°C in the near term, we could still cross climate thresholds in ways that would severely limit our adaptation options. This would impact people and places around the world, but nowhere will this be felt more than in vulnerable regions.

To date, adaptation and urban planning do not routinely consider the implications of temporary overshoot of 1.5°C and what this would mean for sea level rise, extreme heat, extreme weather events, flooding and their impacts locally or for whole regions. To bridge this gap, the PROVIDE project is undertaking research on temperature overshoot scenarios and their expected impacts, so we can better understand under which conditions these impacts can be avoided.

This report looks at adaptation challenges in four iconic case study regions and cities:

- Arctic Fennoscandia, with a focus on Bodø, Norway.
- the Iberian Mediterranean, with a focus on the Lisbon Metropolitan Area.
- the Upper Indus Basin, with a focus on Islamabad.
- The Bahamas, with a focus on Nassau.

The findings are based on the review of relevant literature and stakeholder workshops undertaken by in-region experts, along with analyses of the structural profile of the urban environments in focus.

The four regions are very different, both in climatic and socioeconomic settings, but all are experiencing the consequences of climate change, including risks connected to more frequent and more serious severe weather events. Examples range from deadly heatwaves, hot and dry summer with forest fires, and extreme precipitation events that lead to flooding and increased risk for landslides (and avalanches). Whole ecosystems are also changing and could eventually vanish in response to shifts in the climate, including snow and ice habitats, agroforestry, and coral reefs. In the cities in focus, the built environment has often reduced the capacity of the natural environment to buffer the impacts of climate change, including intensive precipitation and extreme heat.

A common feature for all iconic regions – despite their differences – is that impacts from a changing climate are exacerbated by socio-economic factors, such as inequalities and lack of financial and human capital. Furthermore, pressures from urbanisation and migration makes adaptation more challenging. Lack of adequate adaptation governance and incentives is another common feature. These social factors affect adaptive capacity and thus create “soft” limits of adaptation.

There are also significant similarities between the adaptation challenges faced by the iconic cities. In all four cities, vulnerability to various climatic risks have increased because of anthropogenic activity, such as the urbanization of coastal areas, construction leading to discontinuity of green-blue structures, and the intensity of the built-up space. All four places have possibilities to address their respective climatic risks, but they also face challenges related to a high degree of private land ownership along with governance regimes without sufficient coherence for the needs related to climate adaptation and mitigation.

Arctic Fennoscandia and Bodø Municipality, Norway

The circumpolar Arctic is warming three times as fast as the global average. While the rate of warming varies across the regions, Arctic Fennoscandia is facing very rapid warming with shorter and more unpredictable winters as well as increasing precipitation. The long-term implications for subarctic ecosystems are severe and affect all the services that they provide in terms of food, materials, and health.

Key climate hazards and adaptation challenges:

- Increased precipitation and runoff.
- Warmer and drier summers, followed by the increased frequency of forest fires.
- Changing marine ecosystems with impacts on fisheries.
- Multiple pressures on the landscape and increasing competition for land, where reindeer herding is particularly vulnerable.
- New pathogens and diseases.

Local and regional impacts of climate change have the potential to affect national economic interests (forestry and fisheries), but stakeholders also highlight non-economic losses related to culture and wellbeing, such the loss of winter leisure activities.

In general, adaptive capacity is high and some adaptation efforts are underway but there are concerns about lack of awareness, lack of appropriate incentives and directives, and lack of action. Participants in the regional stakeholder workshop also raised concerns that the pace of change could challenge the capacity for both funding and innovation.

While web-based tools are available to access locally relevant information about climate impacts, there is a need for more knowledge support for adaptation, especially at the local level. The major policy instrument for adaptation is spatial planning, with specific local and regional responsibilities.

Adaptation must account for multiple pressures, including expansion of renewable energy production and mining, and conflicting interests. Limits of adaptation are often shaped by a combination of biophysical and social factors.

The analysis of urban spatial structure has focused on the city of Bodø, Norway. Bodø is a small and compact city surrounded by coast, high mountains, and forests. It has a multifunctional built-up centre, and peripheral residential areas with a suburban structure. Bodø is planning a new urban quarter on the former grounds of a military airport, which will radically change the structure of the town and create opportunities for sustainable and climate-resistant development.

As of today, the city's green space is very fragmented and mostly private, but it could play a big role in mitigating potential risks, for example, flooding from extreme levels of precipitation. The creation of strong green-blue corridors could play an important role in buffering the flow of water and help its infiltration into the ground, but the fragmentation of available spaces makes this a complex task.

Iberian Mediterranean and Lisbon Metropolitan Area

The Iberian Mediterranean is a recognised hotspot of climate change vulnerability. Along with increasing temperatures and decreasing precipitation, the region is home to an increasing concentration of people along coastlines and in metropolitan areas.

Growing levels of desertification and an ageing population in the interior areas have led to a reduction in agroforestry activity and increased the risk of forest fires. Intense seasonal population movements associated with summer tourism further increases the vulnerability in areas already very sensitive to droughts and water scarcity.

Key climate hazards and adaptation challenges:

- Extreme temperatures and heatwaves.
- Heavy precipitation events and floods.
- Droughts and water scarcity.
- Forest fires.
- Loss of agricultural yield.
- Species loss.
- Sea level rise and storm surges.
- Hurricanes.

These hazards often occur within a combination of interacting physical processes, creating ‘compound events’ which pose additional challenges for climate adaptation and resilience in the region.

The strong concentration of people, infrastructure and economic activities in the Lisbon Metropolitan Area makes it highly vulnerable to scenarios of increasing climate-related risks.

Increasing temperatures and heatwaves, flash floods, droughts, storms, and wildfires are already responsible for major disruptions, and are the focus of attention of several adaptation initiatives and strategies. Longer and more frequent heatwaves and droughts are expected and will lead to increasing risks in both urban and rural areas, especially for agroforestry, tourism, health, energy, and infrastructures.

Adaptive capacity in the region is dampened by still emerging adaptation governance structures, poor administrative coordination, fragmented approaches, weak incentives, and the lack of local economic capacity. Shortage of specialised human capital, technical and financial limitations, and the lack of proper governance models were raised in the Lisbon Metropolitan Area local stakeholder workshop as key constraints for adaptation.

Transboundary risks, such as those related with the management of shared water resources, pose additional challenges and potential for conflicts and serve as an example of current limits to adaptation in the region.

The mainstreaming of climate action into spatial planning was highlighted as an opportunity for improvement. Some decision-making tools are available and in use, but workshop participants pointed out that overshoot scenarios are not yet included in risk assessments and could be of relevance to the region.

The structural profile analysis highlighted five preliminary priorities for adaptation:

1) Reorganising existing agricultural (cropland and pasture) land uses and land covers.
2) The need for a territory-wide cooling project.
3) Adapting the network of industrial and commercial units.
4) Retrofitting and installing cooling devices in the urban landscape, according to the degree of built-up intensity.
5) The reconfiguration of current protection regimes, governance structures and ownership patterns (particularly of large non-built-up spaces and transport nodes) to allow for adaptation measures.

The Upper Indus Basin and Islamabad

The Upper Indus Basin (UIB) is one of the recognised climate hotspot regions, with significant spatial and temporal variability. Most of UIB features the high mountain ranges of the Hindukush-Karakoram-Himalaya (HKH) region, which contains the highest number of glaciers in the world outside the polar regions. It is the primary source of water for Pakistan, since three-fourths of the estimated UIB discharge results from melting snow and ice. Increasing temperatures and changes in precipitation patterns are expected to alter the hydrological regime of this region. Climate induced extremes already affect livelihoods and claim lives of the inhabitants in the region.

Key climate hazards and adaptation challenges:

- Extreme temperatures resulting into intense and prolonged heatwaves.
- Heavy precipitation events causing torrential or flash floods.
- Faster glacial melt initiating Glacial Lake Outburst Floods (GLOFs) and riverine floods.
- Water scarcity and drought, linked to crop failure and agricultural loss.
- Forest fires and loss of biodiversity.
- Sea level rise with frequent tropical cyclones.

Agriculture, the backbone of the country's economy, is highly vulnerable to climate change as water resources fluctuate and rising temperature affects yield, posing dire threats to national economic growth and food security. Other economic losses resulting from these climate extremes further stress the already vulnerable economy, while impacts on cultural and religious practices contribute to non-economic losses. Despite the dearth of literature on loss and damage, expected increase in frequency, intensity, and persistence/duration of these extreme events are likely to cause human and other ecosystems to be pushed towards the limits to adaptation.

The region has currently limited adaptive capacity in terms of policy and programs, mainly due to lack of relevant knowledge and insufficient expertise. Additional economic constraints have further hampered effective adaptation efforts. During the initial stakeholder workshop, the complex climatic and geopolitical nature of UIB was highlighted along with the challenges of transboundary water resource management and the large uncertainties in regional climate projections. Additionally, lack of communication and fragmented approaches in various administrative institutions were described as having the potential to promote inadequate adaptation planning.

Other priority areas identified in the workshop were:

- Involvement of stakeholders such as research institutes and private sector in planning.
- Coordination between planning and implementation authorities.
- Capacity building of disaster management authorities to promote faster response times.
- Need-based Heat Action Plans for major cities, including Islamabad.
- Focus on low-cost solutions for energy needs such as switching to renewables.
- Promotion of nature-based sustainable solutions like Miyawaki forests for urban areas.

Though a Climate Change ministry exists at federal level, the implementation of climate change resilience and adaptation is a provincial responsibility. However, due to lack of resources and ambiguity in institutional roles, not much progress has taken place. For example, Pakistan has yet to develop its National Adaptation Plan. Furthermore, gaps in time series data hinder vulnerability assessments and effective adaptive planning. Current efforts focus on the inclusion of climate change impact assessment in major economic sectors. Awareness raising and capacity building are taking place to improve the resilience of vulnerable communities.

Islamabad is one of the very few planned cities in Pakistan. The urban area consists of a grid structure with square sectors, separated from each other by generously sized traffic infrastructure. The natural river valleys have been kept free of construction. These run as green-blue corridors through the built-up area.

Islamabad has low density and high green infiltration. The rapid development and expansion of the city however is putting pressure on the green structure. Green-blue corridors have been narrowed or fragmented by traffic infrastructure and (often informal) settlements. The open space around the city is also becoming increasingly urbanized.

Specific climate risks in Islamabad are heat, drought, and flooding. The recent rising trends in temperature has increased the incidence of flash floods and heatwaves, affected public health and lowered labour productivity. The way the city's spatial structure is evolving increases these risks and makes spatial adaptive measures more difficult.

The Bahamas

The Bahamas is an archipelagic small island developing state (SIDS) with high levels of climate change risk. More than 70% of the Bahamian population resides on the capital island of New Providence, concentrating much of the population and assets in a small geographic space of 207km^2.

Key climate hazards and adaptation challenges:

- Increased intensity of tropical cyclones.
- Sea level rise.
- Ocean acidification and warming.
- Flooding.
- Increased atmospheric warming.

High exposure to these hazards is related to the entire nation being classified as a coastal zone due to low elevations and small land area of the islands.

The Bahamas has limited adaptive capacity, which also contributes to high levels of risk. Adaptation constraints, including economic and financial challenges, make it difficult for individuals and government actors to adapt, while weak institutional capacities have led to fragmented and ad hoc adaptation approaches. The stakeholder workshop highlighted that a particularly pressing constraint is lack of capacity. While there are efforts being made within various government agencies to consider climate change, there is a lack of trained personnel that is experienced and knowledgeable about the particular aspects of climate change that are relevant for each of the various sectors. Limited progress in implementing the National Adaptation Policy as well as the lack of a national adaptation plan were also identified as key constraints for adaptation.

The range of observed impacts in the country exemplify how soft limits to adaptation have already been reached. Recent hurricanes have caused catastrophic damage, injustices and loss of lives and livelihoods on islands throughout the country. In 2019, Hurricane Dorian caused damages of USD 3.4 billion, over a quarter of annual GDP. The focus of adaptation efforts on ecosystem-based adaptation, such as coral reef and mangrove restoration, may face hard limits to adaptation if global warming exceeds 1.5°C.

The analysis of urban spatial structure has focused on the island New Providence and the capital Nassau. The urbanized area of New Providence is located on the eastern half of the island, along the coastal zone. Nassau city is a low-rise sprawl. Nassau's modern growth began just over 200 years ago as the population grew along with the built-up areas. When the tourist economy began to develop, population levels and the city expanded along the east coast of the island and today the urbanized area covers more than one-third of the island. The mobility network on the island is challenged by a lack of room to expand and a lack of public transport network.

New Providence is a low-altitude island mainly composed of sand, coral, lakes, and ponds and with many areas of high ecological value, where inland wetlands play an important role in water management by collecting and store rainwater away from homes and roads. However, uncontrolled urbanization and a lack of long-term urban planning leads to increasing risks that surface water features become polluted by industrial and urban runoff. During the rainy season, buildings along these shallow basins affect their ability to prevent flooding and because of its low relief and large urban areas, New Providence is often inundated.

The urban structure in the coastal zone also makes New Providence more vulnerable to the impacts of hurricanes and other tropical storms that cause extensive flood and wind damage. The coastline and its storm and flood security under a rising sea level should be further investigated.

1. Introduction

1.1. The PROVIDE project

Overshooting the Paris Agreement temperature thresholds is a distinct possibility. Potential impacts would be global in scope, with consequences which may be particularly severe where changes are abrupt, irreversible, or adaptation limits are exceeded. The aim of the EU-funded project, *Paris Agreement Overshooting – Reversibility, Climate Impacts and Adaptation Needs* (PROVIDE), is to create climate services that incorporate comprehensive information on impacts under overshoot pathways from the global to the regional and local urban level, directly feeding into adaptation action. This includes:

- Producing global multi-scenario, multisectoral climate information that integrates and quantifies impacts across scales.
- Providing comprehensive risk assessments of overshooting by assessing climate system uncertainties and feedbacks, and the potential (ir)reversibility of climate impacts.
- Co-developing a generalizable overshoot proofing methodology for adaptation strategies to enhance adaptation action in response to overshoot risks.
- Identifying and prioritizing overshoot adaptation needs in four highly complementary case study regions.
- Integrating the project outcomes into a PROVIDE Climate Service Dashboard, designed to complement established climate service platforms.
- Interacting and collaborating with a wide variety of stakeholders, to ensure usability and wide dissemination of project results and outputs.

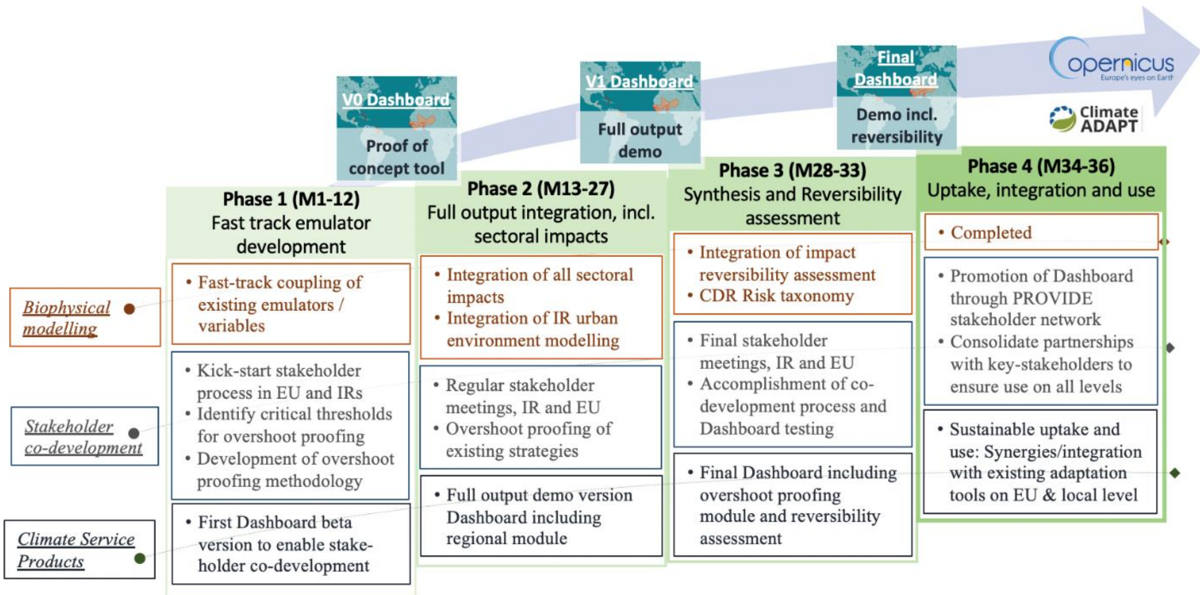

Figure 1.1. The PROVIDE project at a glance.

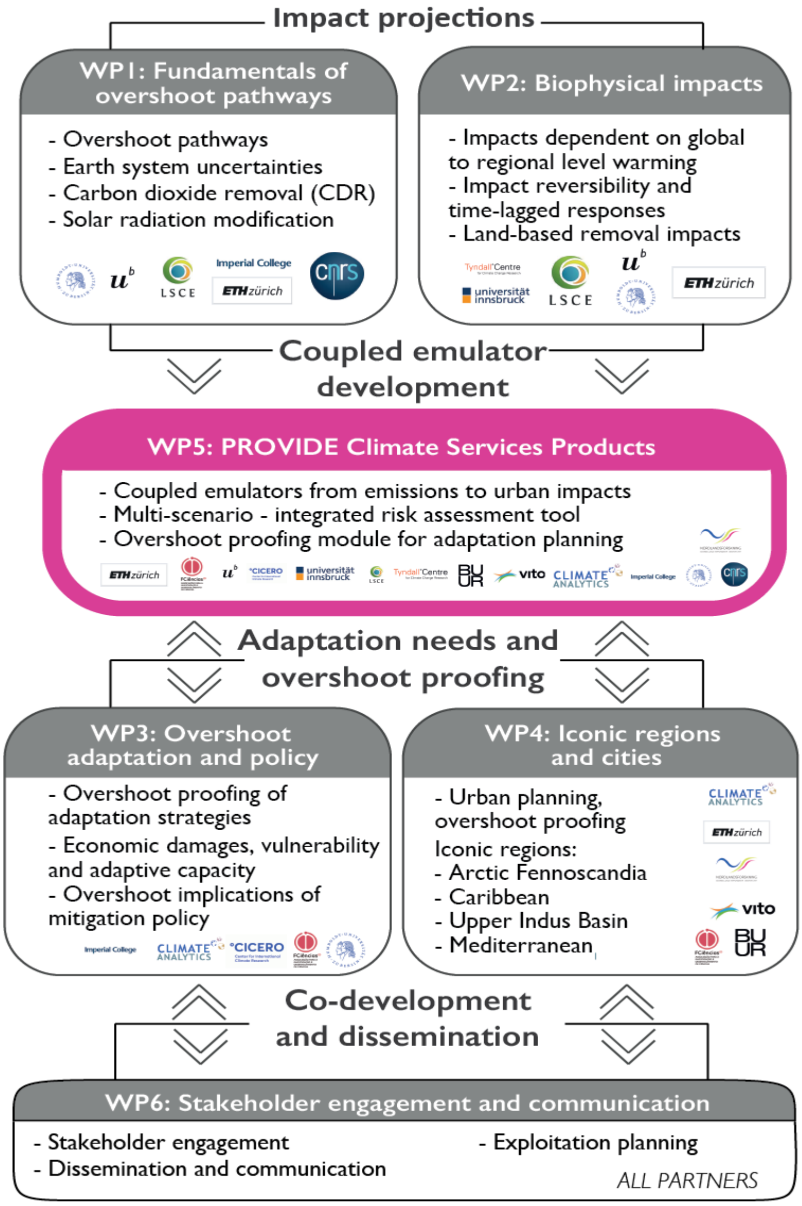

Figure 1.2. PROVIDE is organized in interlinked work packages.

1.2. Iconic Regions and Iconic Cities (WP4)

PROVIDE assesses regional and local impacts of overshoot pathways and the required adaptation responses in four Iconic Regions (IR), including a focus on selected urban environments within those regions. These regions and cities are places where physical risks overlay with specific socio-economic vulnerabilities. The Iconic Cities (IC) were selected to serve as places where the PROVIDE Overshoot Proofing Methodology can be co-developed with local and regional stakeholders. They will provide entry-points for raising awareness about the need for enhanced adaptation action under overshoot scenarios and offer a practical testbed for generalisable urban planning approaches.

Figure 1.3. Region in focus for PROVIDE.

The regions and cities in focus for PROVIDE are:

1. Arctic Fennoscandia, with a focus on Bodø, Nordland County, Norway.
2. Iberian Mediterranean, with a focus on the Lisbon Metropolitan Area, Portugal.
3. Upper Indus Basin, with a focus on Islamabad, Pakistan.
4. The Bahamas, with a focus on Nassau.

The IRs span over diverse climate zones, different environments, and different social and cultural contexts. They thus represent different adaptation challenges. Nevertheless, some conclusions are relevant across the regions, which will be particularly important for developing a generalizable overshoot proofing methodology and a Climate Services Dashboard that is credible and useful in a wide range of contexts.

1.3. This report – D4.1

This report is the result of the initial stocktaking of the four Iconic Regions and Cities. It represents the initial results from Work Package 4 (Task 4.1) and constitutes Delivery 4.1*. Four review reports on key overshoot adaptation challenges in Iconic Regions and Cities*.

The report is based on a combination of literature review, insights from the first set of local and regional stakeholder consultations, and initial assessments of the spatial structural profile and urban strategic structure of each of the Iconic Cities. The aim of the report is to identify adaptation challenges in the Iconic Regions and Iconic Cities, including issues that are particularly relevant in relation to overshoot proofing. These include the identification of the urban spatial potential, opportunities, and conditions for integrating future adaptation measures. The report's main purpose is to inform further work in PROVIDE, especially regarding the overshoot proofing methodology and the development of the Climate Service Dashboard. The description of the four regions follows a common logic but with flexibility to reflect the unique social and environmental characteristics of each region and city.

The body of the report is divided into two parts: Part I (Chapters 2 to 6) includes the results of a review of scientific and grey literature, result summaries from the first local or regional stakeholder workshops and summaries of the structural and strategic profiles of the four Iconic Cities. Chapter 6 summarizes the insights from these reviews. Part II (Chapters 7 to 12) includes the detailed analysis of the structural and strategic profiles of the Iconic Cities, along with a description of the methodology (Chapter 7), and a summary of insights from this initial spatial analysis (Chapter 12).

I. Insights from four Iconic Regions and Iconic Cities

2. Arctic Fennoscandia and Bodø municipality, Norway

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2.1. Introduction to Arctic Fennoscandia

Arctic Fennoscandia is here defined as the northernmost counties of Norway (Troms and Finnmark,[1] and Nordland), Sweden (Norrbotten and Västerbotten) and Finland (Lapland). In the west, northern Norway faces the Norwegian Sea and in the north the Barents Sea. In the east both Norway and Finland share borders with Russia. Despite the high latitude, the climate is sub-Arctic, with mean annual temperatures ranging from -2°C inland to up to +6°C along the west coast (1960-2015) (Eide et al. 2017). The seasons are distinct with snow and ice in the winters. Sunny summer days often reach +20°C, but occasionally feature temperatures close to +30°C.

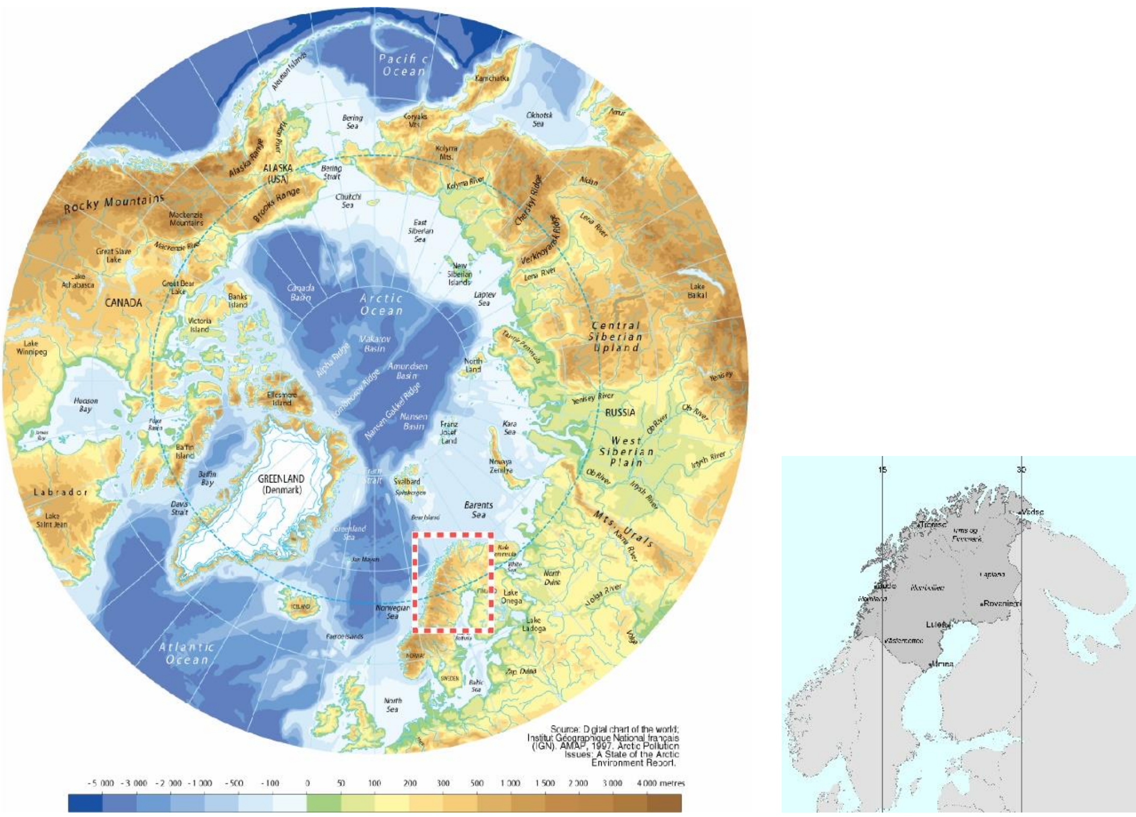

Figure 2.1. The circumpolar north (left) and Arctic Fennoscandia with the northernmost counties of Norway, Sweden and Finland (right). Based on maps produced by AMAP and barentsinfo.org.

2.1.1. Landscapes, ecosystem services, and natural resources

The region's landscape is shaped by the last glaciation with deep fjords along the western and northern coasts, and the inland rich in lakes and wetlands. The western areas are mountainous and include mountain glaciers, which have been receding in recent years

[1] The two counties of Troms and Finnmark were merged in 2020. Earlier statistics list data separately.

(Benestad et al. 2017). The terrestrial biomes include tundra in the inland north but is otherwise dominated by boreal forest. For a detailed description of the region's physical and ecosystem features, see Eide et al. (2017).

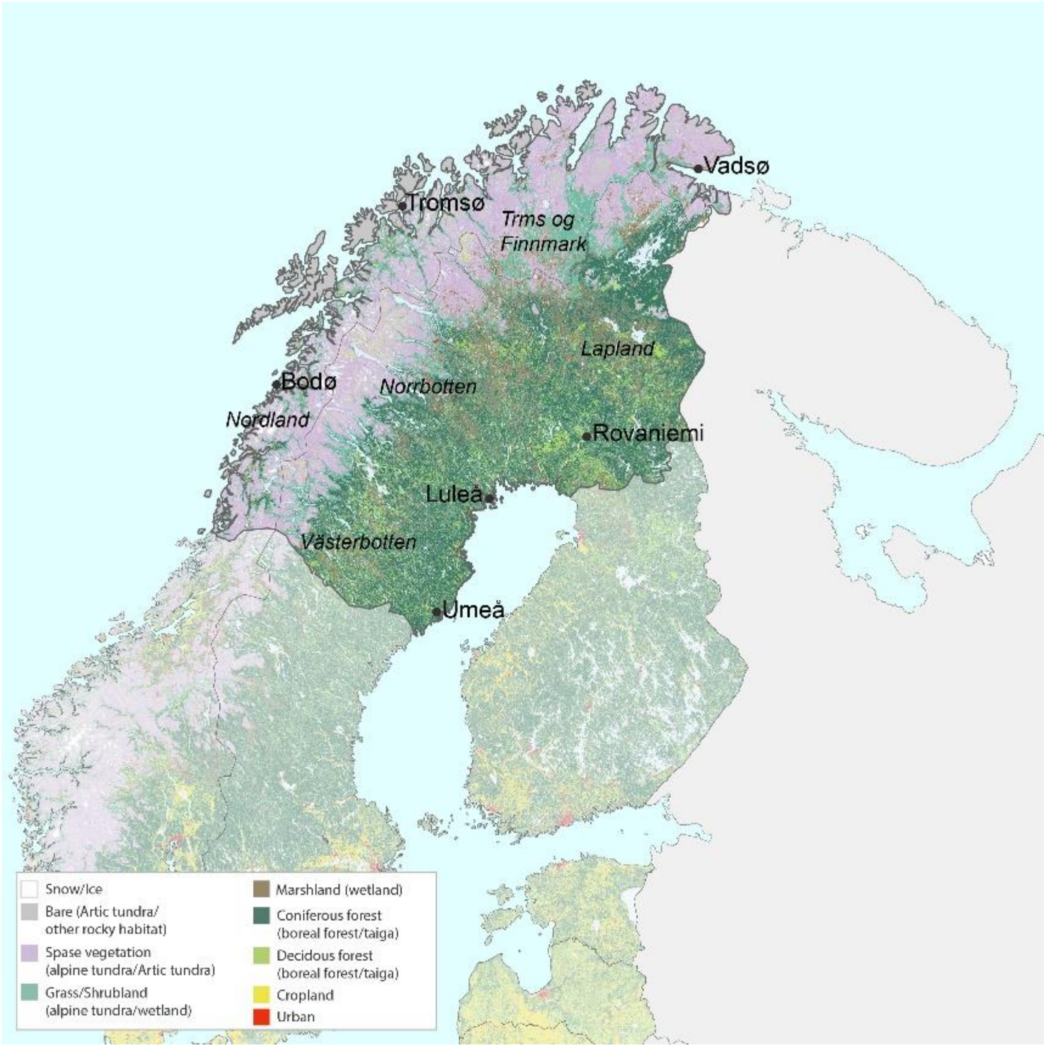

Figure 2.2. Ecozones in Arctic Fennoscandia. Reproduced from (AMAP 2017).

The region's marine ecosystems are highly productive because of the interplay of nutrients and light in the marginal ice zone. They support globally important fisheries, with the EU as a major importer (Koivurova et al. 2021; Constable et al. 2022).

Other ecosystem services include the provision of raw material for the forestry industry. Forests also provide gracing land for reindeer and moose, where reindeer herding is a cornerstone in Sámi culture. Berries, mushrooms, fish, and game are other important ecosystem services. Food provisioning is closely linked to cultural services (well-being, identity, knowledge) not only for the Sámi but for many other people in the region. Agriculture accounts for only a small part of economic activities, where the most important ecosystem service is grass for animal feed. Grassland and forage cropping support dairy farming and sheep production (Eide et al. 2017). In Norway, Nordland, Troms, and Finnmark together account for about 13% of all grass and about 6% of the national meat production (Asheim and Hegrenes 2006). There is also some cultivation of potatoes and vegetables.

Many of the landscapes of Arctic Fennoscandia are attractive for tourists and important for a growing tourism industry, where ski tourism is highly dependent on climate conditions that affect the lengths of the snow season (Finnish Ministry of Agriculture and Forestry 2014).

Regulatory ecosystem services include carbon storage and water purification (Nordic Council of Ministers et al. 2012). A scoping study to assess the economic importance of Arctic ecosystems concluded that health values of ecosystem services are often overlooked as are social and cultural attributes (CAFF 2015).

The landscapes of Arctic Fennoscandia provide energy resources, including hydropower from damming most of the large rivers during the 1900s. In recent decades, wind power has expanded and now includes large wind power parks, with plans for further expansion. The region is rich in economically valuable ores that have supported a large mining and steel industry. The region has been targeted by the European Union as important for the future supply of critical minerals for the European market and for the transition to non-fossil energy systems (European Commission 2020, see also Glomsrød et al. 2021b). Oil and gas production is important for Norway, where the northward expansion of offshore drilling has been facilitated by declining sea ice but is controversial as it is perceived as a threat to fisheries and vulnerable ecosystems and at odds with reducing the production of fossil fuels (Glomsrød et al. 2021b).

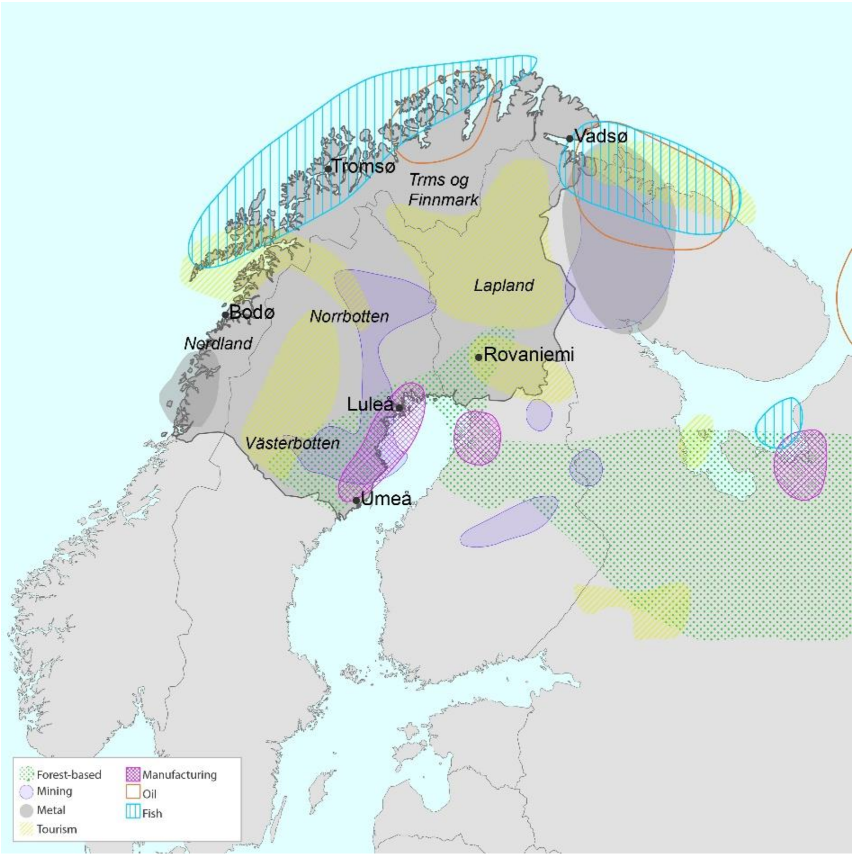

Figure 2.3. Overview of industries in the Barents area. Reproduced from AMAP (2017).

The national importance of the region's industry has led to relatively well-developed infrastructure compared to many other parts of the Arctic. The railroads, roads, ports, and airports are also important for the tourism industry and facilitate the further expansion of extractive industries.

The expansion of industrial activities has led to increasing land use conflicts among competing interests, where the extraction of resources and energy compete for land with reindeer herding, preservation of biodiversity and iconic landscapes, the demand for undisturbed recreational areas, and defence-related interests. In a ruling by the Supreme Court of Norway, wind power in a site for reindeer herding was stopped due to its negative impact on Sámi reindeer herding culture (Supreme Court of Norway 2021).

2.1.2. Population

Compared to other parts of Norway, Sweden and Finland, Arctic Fennoscandia is sparsely populated but nevertheless feature several medium-sized cities. The current demography is shaped by in-migration of early settlers as well as by people who moved north as the region was industrialized in the 20th century. The Indigenous Sámi and other early settlers are now in minority, but with relatively large share of the population in Finnmark (Heleniak 2014). The relationships between minority peoples and majority society have been shaped by a long history of interaction as well as coercive nationalization policies of integration into majority society (Eide et al. 2017). The industrial development and focus on fisheries have led to a male-dominated labour market, which is reflected in a higher proportion of men to women than the national averages (Heleniak 2014).

Since the latter part of the 20th century, mechanization of major industries has led to fewer jobs, followed by outmigration and urbanization as many young people leave for education and jobs elsewhere. Consequently, there are fewer and older people inland and in smaller communities, while some of the region's cities have benefitted, especially those that provide higher education and a more urban lifestyle. Overall, life expectancy is high in a global perspective and infant mortality low. More than a fourth of the population have completed tertiary education. Disposable incomes are more similar to the national indicators for Norway, Sweden and Finland than in some other Arctic region (Duhaime et al. 2021).

Even with attempts at diversifying the region's economy, its development and local population dynamics are tied to extractive industries with their boom-and-bust cycles. In Norway, the oil and gas industry has played an important role for some municipalities that serve as hubs for prospecting and production in the Barents Sea (Loe and Kelman 2016; van Bets et al. 2016). In Sweden and Finland, mining and related industry have shaped some settlement patterns. The expectation of increasing demand for renewable energy and metals is currently driving a new wave of demand for skilled labour to work in mines, the construction of battery factories, and with new fossil-free steel production.

Table 2.1. Selected social and economic indicator for Arctic Fennoscandia based on ECONOR 2020 (Duhaime et al. 2021).

Region	Population	Population growth 2012-2018	% females*	Life expectancy	Infant mortality per 1000 live births	Tertiary education	Disposable income USD-PPP
Finnmark	76167	0.5	49.3	79.8	5.0	28.0	24323
Troms	166499	0.8	49.1	81.7	1.8	32.9	25375
Nordland	243335	0.3	49.3	81.1	3.0	26.8	23536
Norrbotten	250497	0.1	48.8	81.1	2.9	27.8	22889
Västerbotten	270154	0.6	49.3	82.0	2.7	26.5	21717
Lapland	178522	-0.4	50.0	80.5	2.9	26.7	22314

2.1.3. Governance

Governance follows the same pattern as in the rest of the Fennoscandian countries, with a combination of central governments in the capitals further south (Oslo, Stockholm, and Helsinki respectively), regional governance structures, and municipal governments. The regional structures include the national governments' regional representation as well as regionally elected governments, with different areas of responsibility. Local governments have a relatively strong control over local development and responsibility for land-use planning (Eide et al. 2017).

Norway, Sweden, and Finland can be characterized as Nordic welfare democracies but also have their own national features based on the importance of different economic sectors. Since, the end of World War II, peace has reigned in the region and crossing borders between Finland, Sweden and Norway has not even required a passport. However, the Covid-19 pandemic made the borders very real, due to heavy restrictions on border crossings, which have affected job commuting and places that have economies based on cross-border shopping. The borders to Russia are tightly controlled.

The region is of military strategic importance due to its closeness to Russia. In recent years, it has witnessed increasing military posturing from both Russia and the West. Norway is part of NATO, while Sweden and Finland collaborate with NATO, including joint exercises, and have applied for NATO membership in May 2022.

2.2. Introduction to Bodø municipality, Nordland County, Norway

Nordland county is 500 km long and stretches from Trøndelag county in the south to Troms and Finnmark county in the north. It borders Sweden in the east and the Norwegian Sea in the west. The county is divided in five different regions: Helgeland, Salten, Ofoten, Lofoten and Vesterålen (Thorsnæs 2022).

Bodø municipality is the regional capital in Salten with a population of 52,560 (Statistisk Sentralbyrå 2021). Bodø is Nordland's largest city in terms of population and the administrative centre of Nordland county (Bodø kommune, 2018). It has a steady population growth, and it is expected that the population size will grow to 56,601 in 2030 and to 60,281 in 2040 (ibid). About 90% of the population lives in densely populated areas while 2.3% live on farms.

Bodø municipality covers 4,827 km^2 (including territorial waters). The land area is about 1,395 km^2 including islands and the mainland. Land area is divided as follows: forest 40%, agriculture 2%, fresh water 6%, city and built-up area 1%, industry areas 0.10%, and open/uninhabited land 46% (Bodø kommune, 2018).

Bodø is a coastal municipality with an 802 km long coastal line (ibid). As described by Bodø municipality, "[T]he nature is varied from coastal areas to high mountain peaks" (ibid, p.14). The municipality has two national parks and 18 other protected areas with a range of other conservation values. One such area is Saltstraumen, which is the world's strongest tidal current.

Bodø municipality has won the nomination to be the European cultural capital in 2024 (Bodø 2024 2021). The municipality has heavily invested in cultural activities the past few years resulting in a significant growth of the cultural sector.

2.3. Climate risks

2.3.1. Expected climatic changes in Arctic Fennoscandia

The Arctic climate is changing rapidly with the increase in annual mean surface temperatures three times higher than the global average between 1971 and 2019. Impacts are apparent with sea ice loss and melting glaciers, while long-lasting spells of extreme cold have almost disappeared. The changing climate has fundamental implications for ecosystems, with consequences for carbon cycling and biodiversity. Climate models project that annual mean surface temperatures in the Arctic may rise to 3.3-10^{o}C by 2100, depending on future emissions. Most projections point to a mostly ice-free Arctic in September (the month of the sea-ice minimum) before 2050 (for reviews, see AMAP 2021a; Constable et al. 2022; Meredith et al. In press).

Within the circumpolar Arctic, there are large regional variations. In Arctic Fennoscandia, temperature increases are projected to be larger in the north-eastern part with 5-5.5°C by 2100 (RCP4.5) and smallest along the Norwegian west coast with 2.5-3.5°C, as illustrated by the climate scenario tool provided by the Swedish Meteorological and Hydrological Institute (SMHI 2021). The warming is most pronounced in wintertime. At the end of the century, most of Arctic Fennoscandia may no longer feature a subarctic climate and typical environments may only be present in smaller areas at high altitude (Bednar-Friedl et al. 2022, p. figure 13.7). By 2040, most of the region is likely to experience temperature increases of 1.5-2.5°C.

Precipitation will increase, especially along the Norwegian west coast, and more is expected to fall as rain in seasons when snowfall has been the normal. Especially problematic is wintertime rain on top of snow, which can create a layer of ice that grazing animals have difficulties getting through (locked pastures) (Risvoll and Hovelsrud 2016). Another concern is that the intensity of precipitation is expected to increase (Benestad et al. 2017).

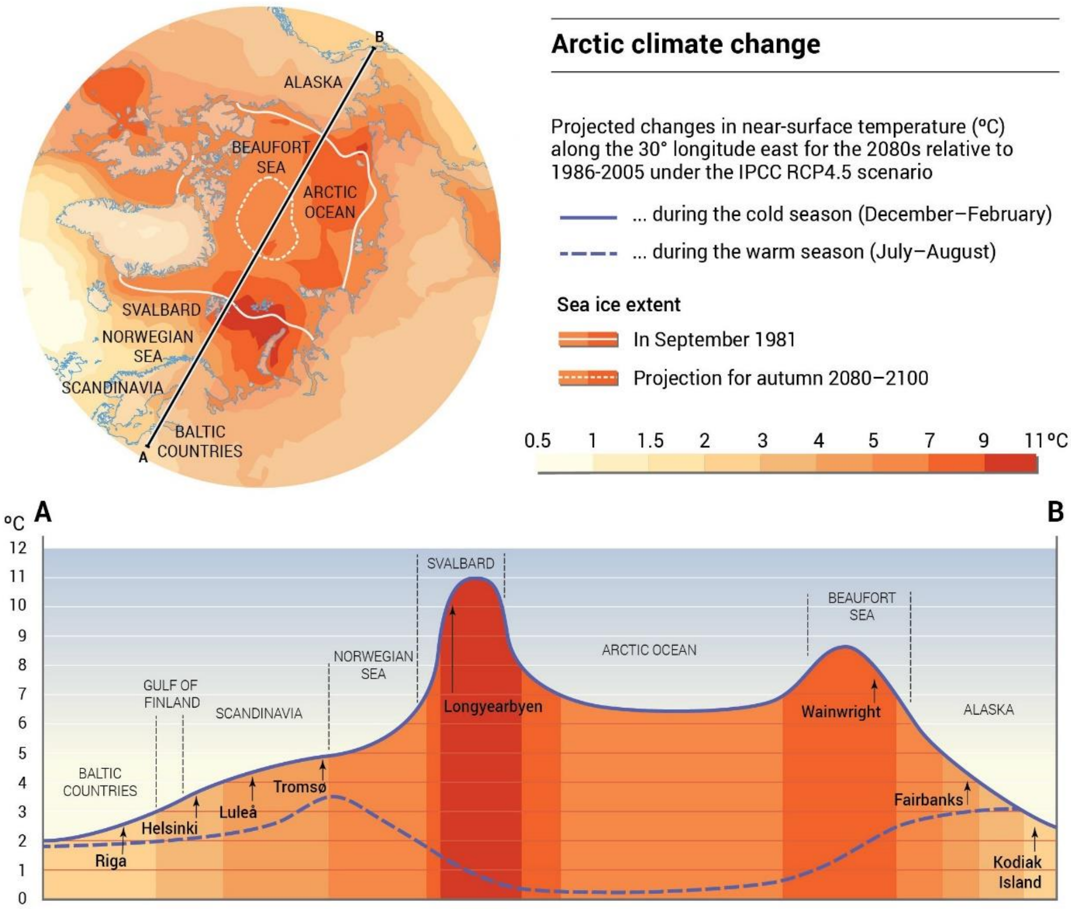

Figure 2.4. Projected changes in Arctic sea-surface temperatures. Reproduced from https://www.grida.no/resources/13335. Cartographers: Philippe Rekacewicz and Nieves Lopez Izquierdo.

2.3.2. Weather-related hazards – regionally and locally

Many weather-related hazards in Arctic Fennoscandia are connected to low-pressure systems accompanied by strong winds, high waves, and heavy precipitation (as rain or snow). The consequences include difficult traffic conditions as well as threats to physical infrastructure, including risks for power outages, which has prompted demands on upgrading the distributions network (Finnish Ministry of Agriculture and Forestry 2014). Heavy precipitation also creates conditions that increase the likelihood of avalanches and rockslides (Benestad et al. 2017) and increase the risk for the breaching of dams that are used in mining operations to store polluted water (Finnish Ministry of Agriculture and Forestry 2014).

Changes in the frequency and intensity of low-pressure systems are difficult to predict, but a slight increase in the frequency of deep cyclones over the Barents Sea is consistent with a northward shift and increase in storm activity in the Arctic in recent decades (Benestad et al. 2017). A special type of extreme low-pressure systems (polar lows) with sudden hurricane force wind occurs in the Norwegian and Barents Sea, predominantly in the cold season, and pose a threat to shipping, fishing vessels, coastal infrastructure, and offshore activities.

With many rivers and large seasonal variation in runoff, flooding is relatively common. It becomes a hazard when snowmelt and heavy rainfall coincide and/or when the breakup of ice in rivers lead to ice dams. The likelihood of precipitation causing flooding is exacerbated when the ground is frozen or when artificial surfaces hinder water from penetrating the ground.

In summers, longer warm and dry periods are expected, including conditions where summer thunderstorms can start forest fires. Climate change is expected to increase not only the length of the fire season but also the number of lightning events. The risks can be further compounded by pest damage to the forest creating a high fuel load (AMAP 2021b). Forest fires can pose a direct hazard to people and infrastructure but also significant economic losses for forest owners. They are an important source of black carbon to the Arctic atmosphere (AMAP 2021b).

2.3.3. Other climate-related changes of societal significance

A warmer climate will have long-term effects of ecosystems and human activities. For example, the snow season will become substantially shorter. Over the past 30-40 years, the length of the snow season has declined by 2-5 days per decade, mostly because of earlier snowmelt (Benestad et al. 2017). Declining snow cover may accelerate the extinction of vascular plants, mosses, and lichen (Constable et al. 2022). It also affects the hydrological cycle and hydropower, where the flow is likely to become more even over the year. It furthermore leads to a shorter season for winter tourism.

The warming leads to a longer growing season, with an additional 10-30 days, with the most impact along the North Atlantic and Barents Sea coast. This will affect both natural ecosystems and the potential for horticulture and agriculture in a region where temperatures and frost-free days have been limiting factors. For natural ecosystem, warming will lead to a northward shift of the forest at the expense of tundra biomes, but changes in specific places will also depend on precipitation and soil moisture.

In a circumpolar perspective, warming permafrost is a major concern for the integrity of infrastructure, hydrology, and emissions of greenhouse gases that have previously been held captive in the ground. Arctic Fennoscandia features some areas of discontinuous permafrost that are very sensitive to changes in climate, with consequences for hydrology and biodiversity.

Figure 2.5. Warming permafrost affects carbon storage and hydrology. At Stordalsmyren, the discontinuous permafrost is monitored by researchers at the nearby Abisko Research Station. Photo: A. Nilsson

A warmer climate creates more favourable conditions for animals that have previously been limited by cold winters. These include insect pests that affect forestry (such as bark beetles) and animals that carry disease agents, such as tick-borne encephalitis, Lyme disease, and tularaemia.

The expected increase in warm days during the summer may not appear as an imminent concern in a region where many people welcome the warmth. However, prolonged warm periods create challenges to maintain reasonable indoor temperatures in hospitals and facilities for elderly care, with increasing needs for air conditioning.

The marine environment is responding to the changing climate and declining sea ice with changes in timing of the spring bloom, altered food web dynamics, and the appearance of more southern species, including invasive species. Sea birds that rely on the marine food web are especially sensitive to the timing of the spring bloom and many marine mammals are sensitive to changes in the sea ice. Ocean acidification is an additional concern. Cascading and interacting effects of climate change impacts may affect access to and productivity of future fisheries (Constable et al. 2022).

2.3.4. Exposures to climate change and related hazards

2.3.4.1. A range of activities that depend on weather conditions

Arctic Fennoscandia features a variety of economic activities that are exposed to climate and weather-related hazards, including those that directly dependent on ecosystem services, such as herding, fisheries and forestry, as well as nationally important extractive industries and energy production. The region's infrastructure is relatively well developed, but also highly exposed to weather-related hazards. Table 2.2 summarizes some of the direct and indirect impacts on of climate change and provides examples of implications related to adaptation. In several sectors, adaptation actions are already underway as reactions to observed changes, but awareness and capacity varies (Hovelsrud and Amundsen 2017).

Table 2.2. Examples of potential impacts of climate change on different activities in Arctic Fennoscandia. The examples as primarily based on the Arctic Council assessment Adaptation Actions in a Changing Arctic. Perspectives from the Barents Area (Hovelsrud and Amundsen 2017; Turunen et al. 2017). See also Table CCP6.6 in IPCC WGII (Constable et al. 2022).

ACTIVITY	DIRECT IMPACTS	INDIRECT IMPACTS	IMPLICATIONS FOR ADAPTATION
ACTIVITIES THAT DEPEND ON ECOSYSTEM SERVICES			
Herding, hunting and gathering	Decreasing snow cover and changing snow quality Increasing frequency of rain-on-snow events	Changing vegetation (less herbs more brush) Lack of access to adequate forage	Reindeer herding becomes more challenging, with impacts of Sámi traditional livelihoods
Agriculture	Longer growing season Wetter conditions		Increasing potential for local agriculture and horticulture. Need for drainage
Forestry	Longer growing season Less severe winters but with potential increase of high winds Shorter season of frozen ground Warmer and drier summers	Potential for higher productivity Increased risk for storm damage and insect pests Greater risk for damaged ground during harvesting Increased risk for forest fires	New demands on forest management New demands on preparedness and response in relation to storm damage and fires
Coastal fisheries	Warmer water Ocean acidification	"Atlantification" of the marine ecosystem as southern species move further north	New demands on fisheries management
Marine aquaculture	Warmer water Extreme temperatures Storms	Potential for parasites shifting range and increased risk for harmful algal blooms	
Freshwater fisheries	Changing ice season and warmer water	Changing water quality	
Tourism	Shorter snow season	Arctic tourism may have a competitive advantage compared to ski areas further south but may nevertheless need to adjust to a shorter season	Need to rethink business model to include more summer tourism
ACTIVITIES THAT DEPEND ON ABIOTIC SERVICES			
Hydrocarbon extraction	Declining sea ice Changing risk for icing	Changing conditions for shipping and offshore hydrocarbon activities	More offshore extraction and related shipping require more attention to pollution control and to search and rescue capacity

Hydropower	Shorter snow season Changes in the amounts and seasonality of precipitation		Potential for more even flow in hydropower dams Need for attention to dam safety
Wind power	Changing in weather patterns that affect winds		
Mining	Changing precipitation patterns		Need to reassess water management and dam safety New demand on climate proofing in environmental impact assessment
ACTIVITIES THAT DEPEND ON TECHNICAL SERVICES AND INFRASTRUCTURES			
Shipping	Declining sea ice Extreme winds	Longer shipping season	Increased need for preparedness and response to meet growing activities and extreme weather events
Road, railroads, and airports, energy supply	Increased risk for extreme precipitation events Warming permafrost	Increased risk for flooding, avalanches, and landslides. Increased risk for heavy snow loads	Need for risk assessments, preparedness and response to flooding, avalanches, and erosion events. Need for upgrading energy transmission infrastructure
Water and sanitation infrastructure	Extreme precipitation/overflow	Disease-causing agents	Need for re-dimensioning
Housing	Long warm spells more likely Changes in extreme winter conditions		Increasing need for cooling of buildings, especially in health and elderly care Need to assess structural integrity demands in relation to snow load
CROSSCUTTING CONCERNS			
Human health	More warm days Longer warm season More days with icy conditions	Risk for heat stress Increased risk for animal and water-borne pathogens Increased risk for slippery conditions causing falls and fractures	

A context of multiple drivers of change

The impacts of climate in Arctic Fennoscandia takes place in a context of multiple drivers of change and often constitute one of multiple pressures on ecosystems and activities (Finnish Ministry of Agriculture and Forestry 2014; Expertrådet för klimatanpassning 2022; Österlin et al. 2022). The drivers of change range from external factors, such as global demand for resources, to regional processes of change, such as shifts in the demographic structure. Many drivers of change are influenced by decisions that are taken elsewhere, in corporate board room or in political assemblies at national, EU, and international levels.

In participatory scenario exercises, local and regional actors have highlighted drivers of change that they consider relevant for shaping the local future in the Nordic Arctic (Nilsson et al. 2017a, b; Nilsson and Sarkki 2023). In addition to the impacts of climate change, common themes include expectations of market demand (natural resources and energy but also tourism), politics and power relations (especially local decision-making power and the lack thereof), demographic trends (especially out-migration), and technology (especially in relation to connectivity and remote operations). Less prominent in the local discussions but important in shaping the region's history and increasingly relevant at present due to conflicts between Russia and the west are geopolitical interests and related security concerns (Nilsson et al. 2019). The region's role in energy production combined with the transition away from fossil fuels is likely to become an important driver of change in the region (Nilsson et al. 2021). It takes place in a situation of increasing land-use conflicts and social tensions (Koivurova et al. 2015; Bay-Larsen et al. 2018; Beland Lindahl et al. 2018; Zachrisson and Beland Lindahl 2019), along with calls for more holistic impact assessment processes (Karvinen and Rantakallio 2019; Nilsson et al. 2021). Conflicts in relation to environmental protection are also becoming more common, for example in relation to water management and protection of biodiversity, including Natura 2000 sites. Reindeer herding requires extensive land for grazing but increasingly finds earlier grazing grounds disturbed by other activities in ways that also challenges adaptation to changing grazing conditions (Turunen et al. 2017; Fohringer et al. 2021; Österlin et al. 2022). An example is the situation facing the Sámi community Leavas whose reindeer migrate in the vicinity of the mining town Kiruna in inland Norrbotten and where more than a third of traditional grazing land has disappeared (Fohringer et al. 2021).

Figure 2.6. Adaptation to climate change takes place in a context of multiple pressures on the landscape, including the expansion of wind power. Photo: A. Nilsson

2.3.5. Climate-related risks in Bodø municipality

Expected climate-related changes in Bodø municipality include higher temperatures, sea level rise, more frequent extreme weather, and an increase in precipitation (Bodø Kommune 2018). Bodø municipality's Risk and vulnerability analysis outlines the following expected changes towards 2100 (ibid, p.14):

- A sea-level rise of 63 cm for Bodø/Skjerstad
- Return of storm surges:
    - 20 year – 276 cm
    - 200 year – 398 cm
    - 1000 year – 312 cm
- Change in yearly precipitation: 15-25% increase. The increase is highest in the winter (24%) and least in the summer (8%).
- Change in annual temperature: 2.0°-3.0°C increase.

Extreme weather is a part of life in Nordland. It is common to get warnings of storms and heavy precipitation. With climate change, more frequent extreme weather is expected, with more frequent strong winds due to the warmer weather in the Norwegian Sea, although wind-intensity is not expected to change. Bodø municipality's climate risk analysis expects "strong storms with up to full storm in the gusts, with a maximum of up to 45 meters per second in the centre of Bodø. The risks connected to strong winds vary with wind direction, wind strength, location, and a number of other local conditions. Combinations of strong winds and heavy precipitation are the largest the challenges for the municipality. Strong wind from southwest can squeeze water from the Norwegian Sea into the Vestfjord and generate storm surge in Bodø harbour" (Bodø Kommune 2018, p. 15). Another climate risk is storm surges (an increase in water levels including waves and flooding towards land in addition to the usual tide changes) that can coincide with tidal fluctuations and cause extensive flooding (ibid).

With increased precipitation, there is an increase in the frequency of landslides. A shorter winter season, increased precipitation, and an upward movement of the snow and treeline is a recipe for more frequent avalanches (ibid).

Most of the registered landslides in Bodø happen around the Misværfjord causing damages to buildings and human life. The road network that pass along the foot of mountains could also be at risk (Statens vegvesen, 2019). Moreover, potential landslide towards Skjerstadfjorden could create a tsunami with significant consequences for Bodø (ibid). If Bodø starts to attract more tourists in the skiing season, accidents in connection with avalanches may increase (ibid).

Quick clay is another source of risk , where quick clay landslides along watercourses could trigger landslides, especially in seasons with high precipitation and water levels (Statens Vegvesen 2019).

Figure 2.7. Icy sidewalk in Bodø a few days after a winter storm. Photo: A. Nilsson

2.4. Adaptive capacity

The literature on adaptive capacity includes a range of suggested determinants and indicators but without consensus on methods for assessments (Siders 2019). The IPCC defines adaptive capacity as "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences." Working Group II has developed an analytical framework focusing on opportunities and constraints on adaptation. Opportunities are factors that make it easier to plan and implement adaptation actions, which expand adaptation options, or that provide ancillary co-benefits. Constraints are factors that make it harder to plan and implement adaptation actions (Klein et al. 2014).

In the literature on resilience in the Arctic, Kofinas et al. (2013) highlight the importance of natural capital, social capital, human capital, infrastructure, financial capital, knowledge assets and cultural capital for both adaptive and transformative capacity, a notion that was further elaborated in the 2016 Arctic Resilience Report (Nilsson et al. 2016). Other conceptual framings in the Arctic literature relate to vulnerability (Hovelsrud and Smit 2010), resilience (Arctic Council et al. 2016), and adaptation options (Hovelsrud and Amundsen 2017).

2.4.1. Regional assessment of adaptation opportunities and constraints

Using the IPCC framework and drawing on insights from literature, the following summary highlights important adaptation opportunities and constraints in Arctic Fennoscandia.

2.4.1.1. Adaptation opportunities

Awareness raising

A regional initiative to raise awareness and involve a broad group of stakeholders in adaptation was the Arctic Council assessment Adaptation Actions for a Changing Arctic that was finalized with an in-depth scientific report in 2017 (AMAP 2017). Also relevant is the Arctic Resilience Report (Arctic Council et al. 2016), which was followed up in the Arctic Council's Arctic Resilience Action Framework (Arctic Council 2017). Climate change has also been in focus for the Barents regional cooperation, specifically in its Action Plan on Climate Change, updated in October 2021 (The Barents Euro-Arctic Council 2021).

As in other parts of the Arctic, Arctic Fennoscandia features a general trend of increasing stakeholder participation research, especially in relation to Sámi reindeer herding. An example is collaboration between natural scientist and Sámi in mapping the local impact of climate change in locations that are critical for the reindeer (Rosqvist et al. 2021).

Capacity building

There is extensive research on climate change and adaptation in Arctic Fennoscandia (for review, see AMAP 2017) as well as sector-specific projects, e.g., focusing of forestry management (Keskitalo et al. 2016). Business-as-usual attitudes nevertheless dominate management practices (Andersson and Keskitalo 2018). Among coastal fishers in northern Norway, "facing whatever comes" is a common attitude and discrepancy between scientific understanding of climate change and perceptions based on experience may prevent the activation of adaptive capacity (Bay-Larsen and Hovelsrud 2017). For ocean fisheries, where fish stocks change their range in response to climate change, lack of knowledge is not necessarily the key concern but rather if management regimes and quota systems would allow for catching the new species (Tiller and Richards 2018). These examples suggest that data and research may not be the limiting factor but rather the social capital that would allow those most likely to be affected to actively engage with adaptation rather than carrying on as usual.

There is also a growing trend of Indigenous-led research and research with strong Indigenous participation, partly related to reindeer herding but also addressing the broader context of change in the region and its implications for adaptation. An example is a review of adaptation actions by Degteva et al. (2017). For reindeer herding, the activities of the International Centre for Reindeer Husbandry support reindeer herders across the circumpolar north and provides a network for exchanging knowledge that has historically been mainly local knowledge.

Tools

The tools for predicting future climate change at scales relevant for local and regional stakeholders have improved greatly, as have the interfaces for communicating the results of climate modelling. An example are web-based tools for reviewing likely changes in winter and summer temperatures, temperature extremes, zero crossing, days with extreme precipitation (SMHI 2021; Climateguide.fi). The weather services provide warning systems, for example for flooding and extreme warm weather.

National and regional agencies and organizations provide some support and guidance documents for municipalities. An example is the guidance to risk and vulnerability analysis available through the Nordland County website together with projections for changes in temperatures, precipitation, and future levels for storm surges in Nordland (County Governor of Nordland). In Sweden, the website "Klimatanpassningsportalen" serves as gateway to a multitude of resources as well as opportunities for networking (Klimatanpassning.se) and in Finland Climateguide.fi serves the same purpose. However, the Swedish Expert Council for Climate Adaptation has identified a need for further coordinated support from national agencies to the county level and from the county level to municipalities in providing and interpreting available information, motivated by an assessment that lack of adaptation action is still often connected to insufficient knowledge about methods and tools (Expertrådet för klimatanpassning 2022).

Policy

Arctic Fennoscandia is covered by Norwegian, Swedish, or Finnish national governance frameworks for spatial planning, which includes adaptation planning, for details, see Section 2.4. The coastal areas of northern Norway are furthermore covered by a plan for integrated ecosystem-based management for Lofoten and the Barents Sea, with the latest update in 2021 (Norwegian Ministry of Climate and Environment 2015). Several other policy areas are also relevant for adaptation, including sector-specific policies for management of natural resources, environmental policies, and policies related to Indigenous peoples' land rights. Whether current policies represent opportunities or constraints to adaptation varies, but in Sweden, the need to strengthened adaptation goals and incentives has been identified as a priority (Expertrådet för klimatanpassning 2022).

Learning

Experience and opportunities for learning vary depending on the capacity of individual municipalities. However, opportunities for learning have been available through collaboration and partnerships with research institutes and universities. Some examples are the Norwegian Research Centre on Sustainable Climate Change Adaptation (NORADAPT) and projects such as "Barriers for climate adaptation and local and regional levels," and "Unpacking Climate Impact Chains. A new generation of climate change risk assessments."

Innovation

The capacity for technical innovation is generally high in the Arctic Fennoscandia with northern universities often focusing specifically on Arctic conditions. The region is currently seeing an expansion of industrial activities along with a need for improved transport and energy infrastructure, which may benefit other sectors of society as well. In relation to reindeer herding, new infrastructures and the expansion of new industries can be a constraint rather than an opportunity, but there are also examples of innovative use of new technologies, for example the use of GPS collars in combination with traditional knowledge to better understand the behaviour and grazing preferences of reindeer (Kuoljok 2020).

2.4.1.2. Adaptation constraints

Physical and biological constraints

Cold and long winters have always constrained the plants and animals that can thrive the north and thus the activities that depend on them. Many Arctic species are long-lived with slow reproductive rates, which makes genetic adaptation to new conditions slow. The major response of wild species is therefore likely to be relocation as they spread to new areas, but success will also depend on the pace of climate change. Moreover, nutrient availability, soil quality, and soil moisture may limit relocation. The presence of the northern coast is a physical constraint for the northward shift of terrestrial biomes (Callaghan 2005).

Ice is a physical constrains for some activities but can also offer access to places and transport routes. The expected decline in ice will change both the presence and the nature of this physical constraint, for people, other animals, and plants, including ice-specialized species, such as ice algae and some seal species. For marine mammals, fish, and seabirds, the timing and locations of ice breakup-associated algae blooms affects food supply at a critical time of the year, where feeding opportunities will change as the ice-edge shifts northward (Barber et al. 2017).

The expansion of industrial activities, both inland and along the coasts, may create physical constrains for adaptation for animals and plants as well as for activities based on ecosystem services if the natural ecosystems are disturbed or destroyed.

Economic and financial constraints

Arctic Fennoscandia is a comparatively rich region in a global as well as an Arctic perspective (for details, see Glomsrød et al. 2021a). However, most earnings from extractive industries leave the region. Many municipalities face economic constraints due to high costs caused by large distances, which often combine with declining tax base as the population ages and declines. As highlighted in a stakeholder workshop, funding for adaptation activities is often lacking.

Human capacity

Lack of education is not a general constraint for adaptation in Arctic Fennoscandia. That said, access to education differ depending on where you live, causing many young people to leave rural and inland areas and draining them of people and knowledge that would be vital for adaptation.

Traditional Indigenous knowledge is important for Sámi activities and its importance increasingly highlighted. However, experiential knowledge from earlier generations is not always adequate for addressing situations caused by completely new weather patterns and climate conditions (Ministry of the Environment and Statistics Finland 2017).

Governance/Institutions/Policy

Arctic Fennoscandia is integrated in countries with well-functioning democratic institutions, but decision-making processes are nevertheless challenged by conflicting priorities and regional-national tensions from a history where narratives of the north have been guided by national rather than local interests (Sörlin 1988; Bravo and Sörlin 2002). Furthermore, there is lack of trust is legal processes related to environmental impact assessment for new industrial activities (Nilsson et al. 2021). While adaptation is an institutionalized policy goal in all three countries, a report from the Swedish Climate Adaptation Expert Council highlight that current incentive structures are inadequate and that there is a need for more coordination and clarity regarding responsibilities (Expertrådet för klimatanpassning 2022).

Information/Awareness/Technology

The region features world-leading expertise in relation to its major industries and access to relevant technologies or potential for developing new technical solutions is generally not a constraint for adaptation. Compared to many other parts of the Arctic, infrastructure is well developed but distances are large and not all people are equally well connected, especially in relation to internet infrastructure and collective transport options.

Social/Cultural constraints

A constraint to addressing adaptation challenges are social tensions related to cultural backgrounds, rights of the Indigenous Sámi people, and conflicts over land and resource rights. As in many other parts of the Arctic, the loss of Indigenous languages is an important concern (Degteva et al. 2017).

2.4.1.3. Sector-based assessment of adaptive capacity

The sector-based summary in this section builds on information in the following reports Adaptation Action for a Changing Arctic. Perspectives from the Barents Area (AMAP 2017), Första rapporten från Nationella expertrådet för klimatanpassning (Expertrådet för klimatanpassning 2022), Finland's National Climate Change Adaptation Plan 2022 (Finnish Ministry of Agriculture and Forestry 2014), and various other sources.

Activities that depend on abiotic services

The region's engineering-based industries (energy, mining, and steel industry) generally have access to high financial capital and technical knowhow, but adaptive capacity may be partly constrained by lack of awareness about the potential impacts of climate change, as indicated by a lack of attention to climate change in impacts assessment. These industries are often supported by strong institutions and organizations. Their financial capacity can vary over time and depend on global markets.

Activities that depend on ecosystem services

Forestry and fisheries are sectors supported by a strong institutional base for knowledge and learning, but where path dependencies in norms, practices and policies can act as constraints. For large actors, financial capital is not a major adaptation constraint, while the financial situation for small businesses can be more precarious and limit the capacity to invest. Activities that depend on ecosystem services are highly exposed to impacts of climate change, including risks for ecological tipping points that may affect economic viability of some businesses. They also face pressures from competing interests. For example, there is a highly charged discussion in Sweden about forestry practices and the relative importance of using the forests as carbon sinks and protection of biodiversity or as a source of building material and biofuels.

In the tourism industry, businesses are small and have relatively weak institutional backing. However, the structure of the sector makes it nimble in the face of change, for example expanding summer tourism when winter activities are negatively impacted by as climate change.

Reindeer herding is highly exposed to climate change impacts and to pressures on land use from other activities at the same time as practitioners often lack financial capital. Furthermore, the institutional frameworks with lack of or weak land rights can constrain adaptation. Increasing international collaboration and recognition of Indigenous rights is likely to play an important role for future development. Small-scale fisheries face similar constraints regarding financial capital and regulatory frameworks that can hinder adaptation.

Activities that depend on technical services

Mobility and communication depend on a range of actors with different responsibilities, where northern regions are not always prioritized in allocation of financial capital, unless the development is linked to industrial needs. The situation varies between different countries depending on policy decisions. It also varies within the region, where people and activities along the coasts are generally better connected to technical infrastructures than people living inland.

Constraints related to municipal infrastructures, such as water, sewage, and public buildings vary depending on financial capacity (the tax base), and where human capacity and the capacity for learning and awareness raising can also be affected by the population size and structure. These challenges are often greater in small municipalities, where the responsibility for local climate-sensitive infrastructure may become heavy in relation to the available resources.

2.4.2. Adaptive capacity in Bodø municipality

Adaptation opportunities for Bodø municipality include an increasing awareness about the need to adapt and the fact that it engages in research projects to increase its internal capacity. Practical work to map the need for specific adaptation measures have started, including attention to drainage systems that play a key role in managing runoff, where current infrastructure is inadequate already in the present climate. Bodø will also be able to take advantage of growing network activity among municipalities in Nordland County and national initiatives to improve capacity. Despite these opportunities, participants in PROVIDE's stakeholder workshop in Bodø pointed to several limitation in adaptive capacity, including lack of awareness and lack of funding for adaptation measures.

2.5. Adaptation governance

Governance and policies related by climate adaptation in the Arctic Fennoscandia were recently reviewed in the report *Adaptation to Climate Change in The Baltic Sea and Arctic Regions. Governance and Policy Tools across Counties* (Berninger et al. 2021) and in an analysis of Adaptation options in the report *Adaptation Action for a Changing Arctic. Perspectives from the Barents Area* (Hovelsrud and Amundsen 2017). Unless otherwise indicated the following summary builds on these reports.

2.5.1. Norway

At the national level, climate adaptation in Norway is governed by the National adaptation strategy: Climate change adaptation in Norway (Norwegian Ministry of Climate and Environment 2013) and by the Climate Change Act, which includes annual reporting requirements related to adaptation. The principle is that responsibility is placed with the actor that is usually responsible for the task or function that is sensitive to impacts from climate change, ranging from individuals and businesses to sectorial organizations and authorities.

At the national level, three institutions account for a significant amount of knowledge production and dissemination regarding climate and expected changes: Norsk Klimaservicesenter (KSS), the Norwegian Water Resources and Energy Directorate (NVE), and the Norwegian Mapping Authority (Kartverket) (Miljødirektoratet 2019). Moreover, the Norwegian Environment Agency, the Norwegian Directorate for Civil Protection (DSB), and NVE have special responsibilities for cross-sectoral facilitation of knowledge and practice on climate change adaptation while the Norwegian Environment Agency has a coordinating role at the national level (ibid).

The county governor is responsible for local and regional follow-up of the government's policy and coordinates prevention and preparedness at the regional level. The county governor gives guidance and supervises county councils and municipalities. County councils have responsibility for regional planning, for giving planning-guidance to municipalities, and for ensuring that planning contributes to achieving political goals (ibid).

At the local level, major responsibilities fall on the municipalities within their overall responsibilities for societal development, infrastructure, and spatial planning. The legal framework for planning is the Planning and Building Act, which requires municipalities to take climate considerations in their planning, and the Central Governance Planning guidelines that describe how adaptation should be included. Klimatilpasning.no is a website with tools, case studies and information on adaptation aimed at municipalities (Miljødirektoratet).

Responsibility for adaptation within specific sector rests with sectoral agencies where three agencies have developed their own adaptation strategies, including the Norwegian Environment Agency, the Directorate of Fisheries, and the Norwegian Water Resources and Energy Directorate (NVE). In 2018, an updated assessment of consequences of climate change was presented (CICERO and Vestlandsforsking 2018).

In addition to the formal governance, adaptation is supported by several forums and networks, including the natural hazards forum ('Naturfareforum') aimed to strengthen the collaboration between national, regional, and local actors with a focus towards reducing vulnerabilities to natural hazards (Miljødirektoratet 2019). Furthermore, the network 'I front: Kommunenettverk for klimatilpasning' aims to be an arena for knowledge and competence development on adaptation to climate change and to further the work done by municipalities in the area (Miljødirektoratet 2020). The network is coordinated by the Norwegian Environment Agency and includes 13 city-municipalities from all counties in the country (Bodø is one of the 13 municipalities).

2.5.2. Sweden

Sweden adopted its current National Climate Adaptation Strategy in 2018 (Swedish Ministry of Environment and Energy 2018). Responsibility for implementation is shared across several government agencies, where the National Board of Housing Building and Planning has a coordinating role for physical planning. At the regional level, responsibility of adaptation falls on the County Administrative Boards, which must have their own adaptation plans and have responsibility to follow up on adaptation at the municipal level. The municipalities have responsibilities under the Planning and Building Act but no obligation to develop specific adaptation action plans. The County Administrative Boards and the sectoral agencies are supported by The Swedish Meteorological and Hydrological Institute (SMHI). The National Adaptation Strategy is to be updated every five years based on review by a national expert council for adaptation. Its first review, released February 2022, concluded that organization of adaptation is not sufficient, and that stronger incentives and sharp governance tools are needed, with focus on implementation of adaptations measures (Expertrådet för klimatanpassning 2022). The report provides a detailed description of relevant actors and calls for coordination across administrative and geographic boundaries.

In addition to the formal governance framework, there is a network of 28 national agencies and 21 county administrative boards that aims to strengthen society's adaptive capacity. Information relevant for adaptation is accessible through the Swedish Climate Change Adaptation Portal (klimatanpassning.se), while climate services are available through SMHI (2021).

2.5.3. Finland

Finland was one of the first countries on the world to adopt a policy to guide climate change adaptation. In accordance with the Climate Change Act, Finland must adopt a national adaptation plan every ten years (Ministry of the Environment and Statistics Finland 2017). The current plan – National Climate Change Adaptation Plan 2022 – was adopted in 2014 (Finnish Ministry of Agriculture and Forestry 2014). In addition, there are several sectoral plans or programs, e.g., related to environmental administration, agriculture and forestry, transport and communication, and defence. Responsibility for coordination across government ministries rests with the Ministry of Agriculture and

Forestry. There is also a Monitoring Group on Climate Change Adaptation (Ministry of the Environment and Statistics Finland 2017). While the government is responsible for securing vital societal functions and for promotion of adaptation in cooperation with municipalities, businesses, citizens and organizations, the responsibility for adaptation action rests primarily with practitioners. At the regional and local levels, adaptation can be included in regional and municipal climate strategies, and even if these are mainly focused on mitigation, many municipalities have included adaptation. The national land-use guidelines that were adopted in 2008 include objectives related to adaptation, such as restrictions on building in flood-prone areas. Municipalities have responsibility for planning in relation to flood risk in urban areas while the government's decree on flood risk management regulates management of river basins (Ministry of the Environment and Statistics Finland 2017). The web portal ilmasto-opas.fi (climateguide.fi) includes a section on adaptation, and good practices from municipalities sorted by sector.

2.5.4. International

2.5.4.1. Barents regional cooperation

The northernmost counties of Norway, Sweden and Finland are part of the Barents Regional Council, which also includes neighbouring regions of Russia. The region is also in focus for the intergovernmental cooperation in the Barents Euro-Arctic Council (BEAC). The cooperation in the Barents Euro-Arctic Region was launched in 1993 with an overall objective to support sustainable development. BAEC has recently updated its action plan on climate change with the aim of supporting knowledge sharing across the different working groups (The Barents Euro-Arctic Council 2021). However, the Barents regional cooperation is currently suspended due to Russia's war in Ukraine.

2.5.4.2. Circumpolar cooperation

Norway, Sweden, and Finland are members of the circumpolar political collaboration in the Arctic Council, together with Canada, Kingdom of Denmark (Denmark / Greenland / Faroe Island), Iceland, United States and Russia. The Arctic Council also includes the Sámi Council and five other Indigenous Peoples' organizations as Permanent Participants. The Arctic Council has addressed climate related concerns through several scientific assessments, including recurring assessments of the impacts of climate change. It has also carried out three regional assessments focusing on climate adaptation, including a report on adaptation action in the Barents area (AMAP 2017). All Arctic Council activities were suspended in March 2022 due to due to Russia's war in Ukraine. A decision to start some activities but to continue to exclude Russia was taken in June 2022.

2.5.4.3. European Union

Sweden and Finland are members of the European Union and Norway collaborates closely with the EU on many issues via partnership agreements and membership in the European Economic Area cooperation. The EU's adaptation strategy adopted in February 2021 (European Commission 2021) is thus highly relevant for Arctic Fennoscandia, as are all other EU regulations that affect climate change and/or adaptive capacity (see also Tables 3.7 and 3.8 in Chapter 3).

2.6. Spatial structural and strategic profile of the Bodø municipality

The city of Bodø is a compact port town with a grid structure centre and most facilities concentrated near the port. Its current structure developed following bombings during the Second World War. In the second half of the 20th century, rapid suburbanization caused the built-up area to increase, especially along the coast. This peripheralization ended in the 21st century with a policy that favours densification in the centre. At the same time, a plan emerged for the redevelopment of the current military airport as a new and sustainable urban district.

This urbanized area of Bodø is located on the more fertile and permeable soil within Bodø municipality, which is located along the coastal zone (see Section 2.2). The higher areas are rockier, wilder and for large parts protected as nature reserves. The ecological value here is high and the scenic quality makes Bodø a unique place. However, a lot of space claims converge in the coastal zone; buildings take up the largest part, but this is also one of the only places suitable for agriculture and where run-off (rain and snow melt) water can infiltrate. The remaining agricultural activities have been protected from further urbanization since 2000 but are too limited to provide food for the city. Bodø's water system consists of many small streams descending from the mountains in the north towards the coast. Because of space limitation in the urbanized area, many streams have been diverted underground.

At the municipal level, by far the largest part of the area is nature, with only 2.5% is built environment. Within the built areas, the proportion of public green space is limited to a number of fairly small park areas. The centre itself is heavily paved, while the surrounding areas have a suburban morphology with low building density and large private gardens. The city has good, multi-modal accessibility and all the necessary amenities, which are spread throughout the centre and beyond.

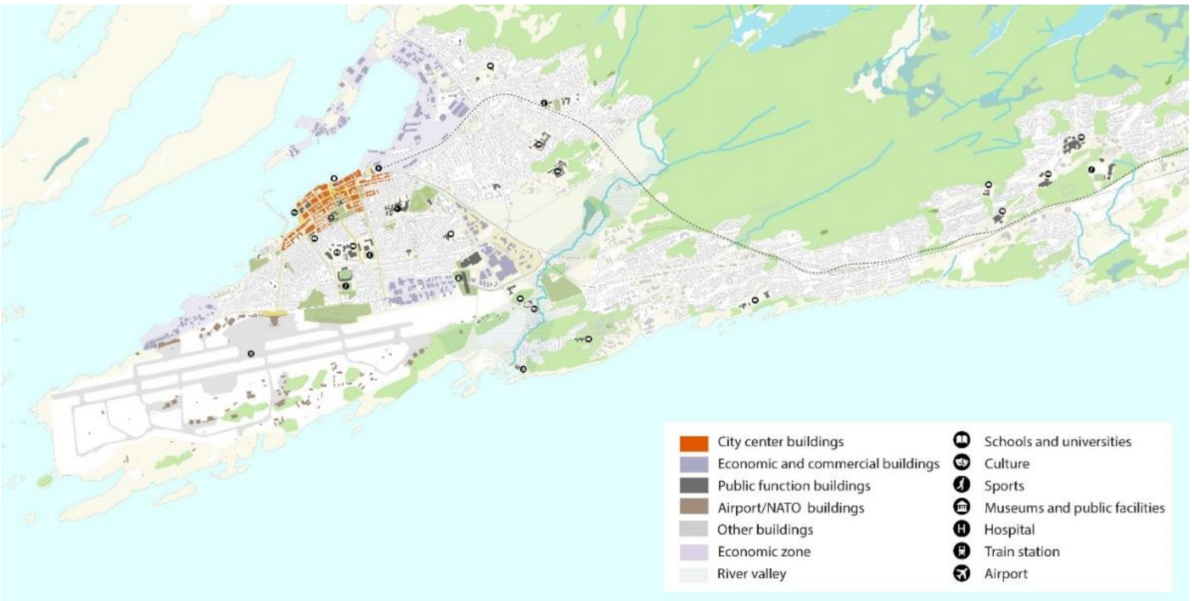

Figure 2.8 Spatial structure map of the urban area of Bodø, image by BUUR/PoS 2022.

For the urban area of Bodø, sea level rise and increasing fluvial and pluvial flooding are two major climate risks. The urban structure in the coastal zone makes Bodø vulnerable to impacts of climate change, partly due to the proximity of most buildings and functions to the coast but also because the strong urbanization of the area makes natural water management difficult. The coastline and its storm and potential flooding with rising sea level should be further investigated. Much of Bodø's coastline consists of rock formations interrupted by small beaches, estuaries, and wetlands, which appears to be a resilient system. The urbanized coastline is well protected by (port) infrastructure. However, in both cases it is not certain that this protection will hold up to increasingly extreme weather events along the coast. With such development, the spatial structure of Bodø becomes very vulnerable.

Nature based adaptation strategies for fluvial and pluvial floods start from the green-blue structure of a city. In the urban area of Bodø, this has been heavily encroached upon by buildings and only one green-blue corridor remains. The rest of the city has a green character, but this greenery is very fragmented, and the watercourses have been moved underground. Moreover, most of the green space is private gardens and is spatially complex in relation to creating continuous green-blue structures. However, this will be necessary to solve challenges around water buffering and water infiltration. For further details on the structural and strategic profile of Bodø, see Chapter 8.

Figure 2.9 Spatial analysis of the public and private green spaces of Bodø city, image by BUUR/PoS 2022.

2.7. Insights from stakeholder engagement workshop

2.7.1. Workshop purpose and setting

The first PROVIDE stakeholder engagement meeting in the Iconic City of Bodø took place on 9th March 2022. The program included presentations from the PROVIDE team, Bodø municipality, Nordland County Council, County governor, along with interactive exercises and group discussions to map local knowledge and gather feedback. Invitation had been sent to representatives from the business sector, civil society, public agencies, and politicians. Twelve people attended the workshop, which was facilitated by three members of the PROVIDE team.

2.7.2. Observations of climate ongoing adaptation efforts

After a few introductory words, the participants were invited to share a personal experience of how climate change is affecting their lives. Several people expressed a sense of worry for the impacts of climate change, and some noted a sense of loss that the "winter is disappearing." There were comments about having the most important job working with climate change issues. Some stated that they experienced that weather systems have shifted and changed unpredictably, and one participant described how a particular type of fish he used to catch has now almost disappeared.

Presentations from the municipality and the county illustrated how impacts and adaptation efforts are already underway. One example is a plan to handle surface water runoff, where Marit Elveos from Bodø Municipality described how the natural creeks have been led through pipes and the system now often overstrained, sometimes leading to overflow of untreated sewage as well as the flushing of litter to the sea. Furthermore, urbanisation has reduced the natural absorption capacity of the ground and there is a need to increase green areas in the city to better handle surface runoff, which benefits well-being in the city. Bodø has not yet experienced extreme precipitation, so, the effects and damages of truly extreme rainfalls are unknown. Elevos highlighted that adaptation measures require resources and that while there is money to do evaluations there is not enough funding to act on the results of the evaluations.

Figure 2.10. Bodø municipality collaborates with a local school to map current flooding risks and consequences. Photo: Bodin Videregående skole.

Nordland County Council is responsible for ensuring that municipalities follow state planning guidelines and has also initiated collaborations and networks across regional and municipal boundaries. see Section 2.3.7. Charlotte Alexander Lassen from Nordland County Council also described several knowledge-building initiatives, including a new statistics bank for climate and environment data hosted at the County Council's website (www.nfk.no) and a strategy document that guides planning processes in municipalities. They also plan to develop a regional Risk and Vulnerability Analysis (ROS) for Nordland County that will include climate change impacts.

The municipal and regional plan-strategy includes consideration of expected climate changes and will also shed light on vulnerability related to ecological sustainability, including attention to destruction of ecosystems, species extinction, natural hazards, threats to livelihoods, and conflicts. The new regional plan-program represent s new policy area for the county and includes new concepts such as carbon-rich areas and areal-budgeting, where the council will develop regional plans and plans for water management.

2.7.3. Future risks and potential thresholds

A joint mapping of future vulnerabilities and risks at the local level generated a long list of issues, ranging from physical hazards and ecosystem changes to economic issues and cultural well-being. They included impacts on ecosystem-depended livelihoods, such as the impacts of warmer seawater on aquaculture, impacts on reindeer herding from locked pastures due to ice, and the northward shift of fish species. Other issues were threats to infrastructure and life due to flooding, landslides, and avalanches. Infrastructure near the coast, including new developments, will also be exposed sea-level rise and more powerful westerly storms. Severe weather was also a concern in relation to conditions for fishing. Another set of concerns related to health and identity, including the loss of snow and wintertime leisure activities and the loss of reindeer. Furthermore, some participants pointed to economic challenges such as adjustment crises in industry and lack of funding. Finally, one person noted that many people don't care.

In another exercise, the participants were asked to highlight potential thresholds for adaptation. While it generated some of the same concerns of loss of ecosystems, changing landscapes, and the loss of the winter, it also included attention to the risk that it would not be possible to keep pace with the changes, e.g., when the lag in renovation of pipes cannot keep up any longer, when it becomes too expensive to prevent damages, when opportunities for innovation are lost, and when we accept losses. The examples thus pointed to a need for attention to how thresholds can relate to and interplay across social, economic, and climate-related factors.

2.7.4. Digital tools for adaptation planning

The notion of environmental dashboards is familiar to Bodø municipality, which is engaged together with a private company in a project aimed at developing digital solutions by compiling environmental data from several sources and making them easily available. They also supplement existing data sources with new sensors and new real-time data. The data includes energy use, waste disposal, traffic, air quality, and the weather, among others.

After a presentation of the PROVIDE dashboard, participants expressed an interest in its further development and need for such solutions, but it was also clear that they were not aware of digital tools that are already available to get information about further climate change under different scenarios. The on-site evaluation of the workshop highlighted a need for analysis and for visualizations to increase insights and understanding and as a base for planning.

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3. Iberian Mediterranean and Lisbon Metropolitan Area

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3.1. Introduction to Iberian Mediterranean

3.1.1. Physical and geographic characteristics

The Iberian Mediterranean Iconic Region is located in the southwest of the Mediterranean region and includes most of the Iberian Peninsula (Portugal and Spain). The Iberian Peninsula is limited by the Pyrenees in the northeast, by the Atlantic Ocean in the western, and southwestern coasts, and by the Mediterranean Sea in the southern and eastern shores. The Iberian Peninsula has several distinct orography and climate types with the Mediterranean climate covering, by far, the largest area, see Figure 3.1.

Mediterranean climates are temperate climates with temperatures in the coldest month averaging between 0 °C and 18 °C and with temperatures in the warmest month greater than or equal to 10 °C (Köppen–Geiger climate classification system (Barceló and Nunes 2011). Mediterranean climates in the Iberian region can be further subdivided in Hot-summer Mediterranean climate (Csa) and Warm-summer Mediterranean climate (Csb). Here, average temperatures in the warmest month are above (below) 22 °C in the Csa (Csb) climate and at least four months have average temperatures above 10 °C (Barceló and Nunes 2011). These are areas were precipitation in the driest summer month of summer is less than 30 mm and represent less than one-third of the wettest winter month. To serve as context, the Csa classification is the type of climate covering most of the European Mediterranean coastal regions.

For the purposes of PROVIDE, the Iberian Mediterranean Iconic Region is broadly defined as the area covering the southern half of Portugal, and the south, central and eastern areas of Spain, including the Balearic Islands. These are areas that have a distinct hot-summer Mediterranean climate (Csa) or are transition areas that may include already semi-arid and arid climates and environments (see Figure 3.2 for a territorial definition by NUTS-2).

The Iberian Mediterranean is characterised by its mountainous nature, embodied by an inland plateau, the Meseta, at more than 600 metres above mean sea level. The mountain systems are usually arranged from west to east. The influence of topography on the climate is clear as it establishes an obstacle to the access of humid air masses from the Atlantic (Cabos et al. 2020)

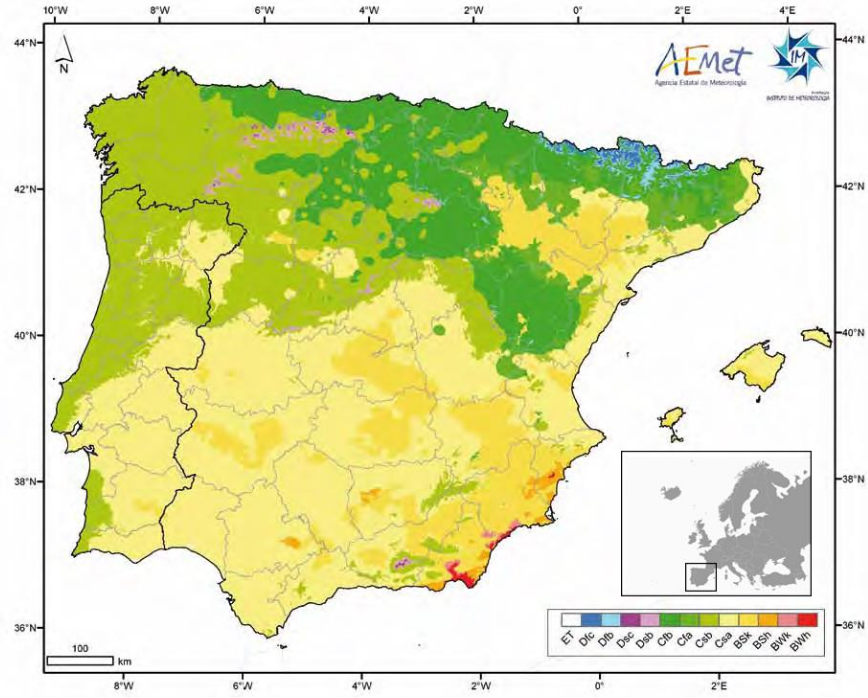

Figure 3.1. Köppen-Geiger climate classification in the Iberian Peninsula (Reproduced from the Iberian Climate Atlas, 2011); Csa and Csb are Mediterranean climates.

The territorial definition of the Iberian Mediterranean Iconic Region by NUTS-2 includes the following regions: PORTUGAL: Alentejo, Algarve, Área Metropolitana de Lisboa; SPAIN: Andalucía, Castilla-la Mancha, Cataluña, Comunidad de Madrid, Comunitat Valenciana, Extremadura, Iles Balears, Región de Murcia (Figure 3.2).

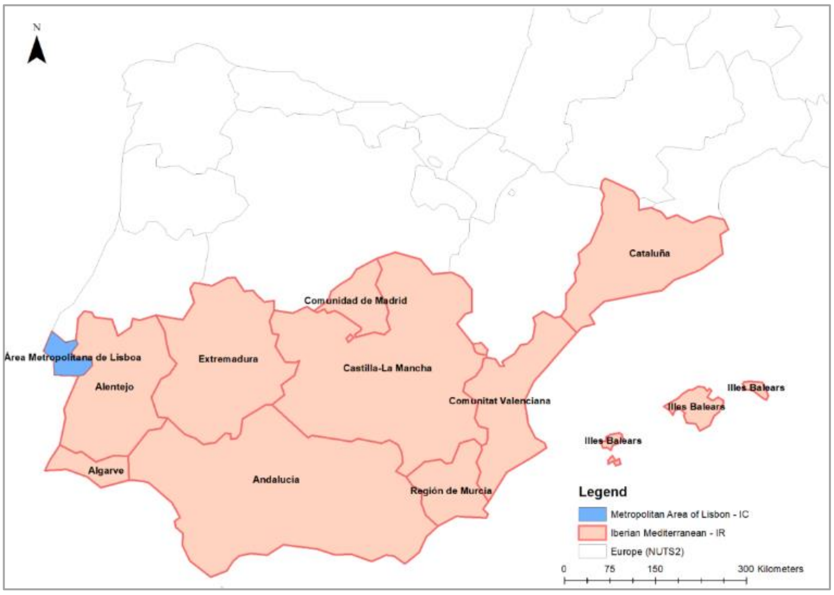

Figure 3.2. NUTS-2 territorial areas of the IR base on Mediterranean type of climate considered in the Köppen classification.

The rivers regime and hydrographic network of the Iberian Mediterranean are strongly influenced by the topography and rainfall, either through surface runoff or through underground contributions. The region’s diverse morphological and geological characteristics support different hydrological profiles. The major river basins in the Iberian Mediterranean are the Tagus, Guadiana, Guadalquivir, and the final section of the

Ebro river (Figure 3.3). The shared transnational rivers in the region (Tagus and Guadiana) are jointly managed by Portugal and Spain under the 1994 Spanish-Portuguese Albufeira Convention[2] (Council of the European Union - General Secretariat 2008; Bukowski 2011).

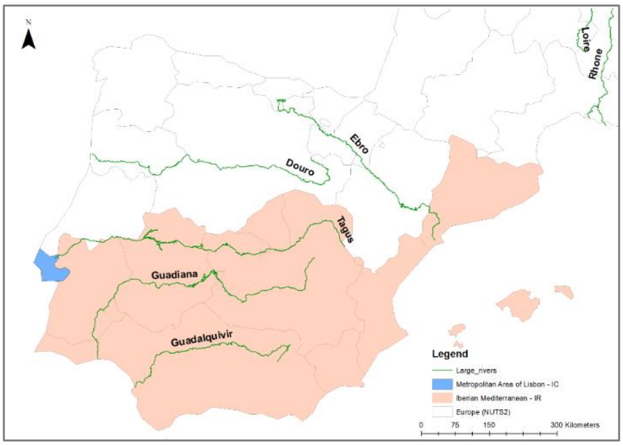

Figure 3.3. Major rivers in the Iberian Peninsula and the Iberian Mediterranean region.

The biogeographical regions in the Iberian Mediterranean are diverse and associated with a wide range of biodiversity hotspots, landscapes, ecosystem services, and natural resources. Natura 2000 sites are important hotspots for nature conservation in the region (defined by Annex I of the Habitats Directive[3]) helping to monitor conservation effectiveness and if the decline of certain habitat types is being halted (Figure 3.4).

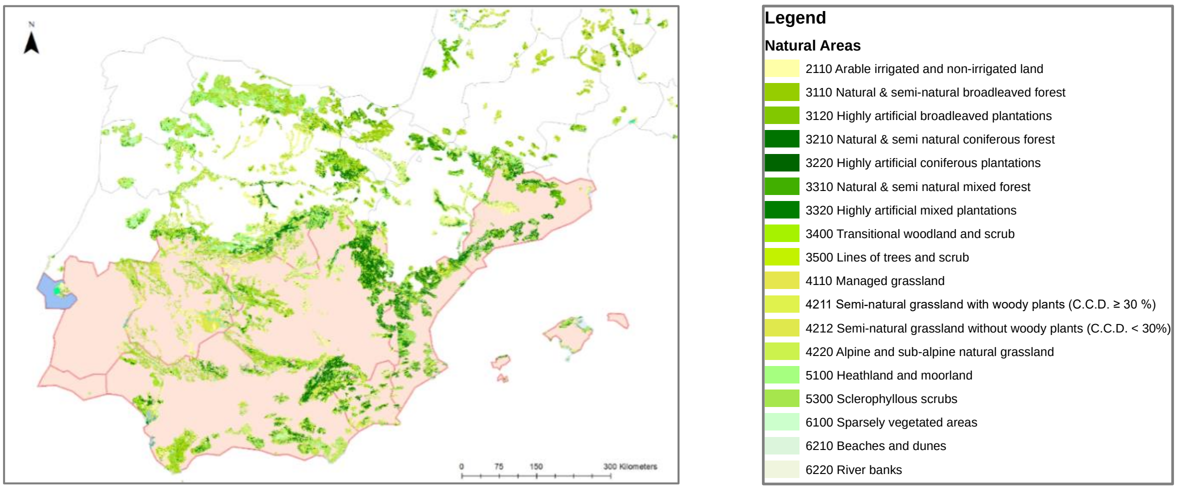

Figure 3.4. Land Cover / Land Use (LC/LU) and natural areas covering selection of Natura 2000 sites in the Iberia Peninsula and Iberian Mediterranean (Reproduced from N2K product, Copernicus, 2022)

The Atlantic Ocean and the Mediterranean Sea have a clear influence on the region's climate, which shifts gradually from the Atlantic coastline to the interior resulting in marked differences in precipitation and average annual temperature ranges (Barceló and Nunes 2011). The Mediterranean influence increases gradually from the north to south and from west to east, and during the summer, with high temperatures and low rainfall.

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[2] http://www.cadc-albufeira.eu/pt/
[3] Council Directive 92/43/EEC (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043)

The Atlantic influence increases during the winter and gradually to the west and northwest of region, promoting higher precipitation in opposition to the dry and cold winds from the Peninsula's interior (Barceló and Nunes 2011).

Recently observed climate trends in the region have been marked by a clear warming and a decrease in precipitation (both in means and extremes). Nevertheless, geographical patterns, i.e., warmer and drier inland and cooler and wetter coastal areas, have been maintained, with the noticeable exception of an increase in winter precipitation in the interior southeast of Spain (Figure 3.5 and Figure 3.6).

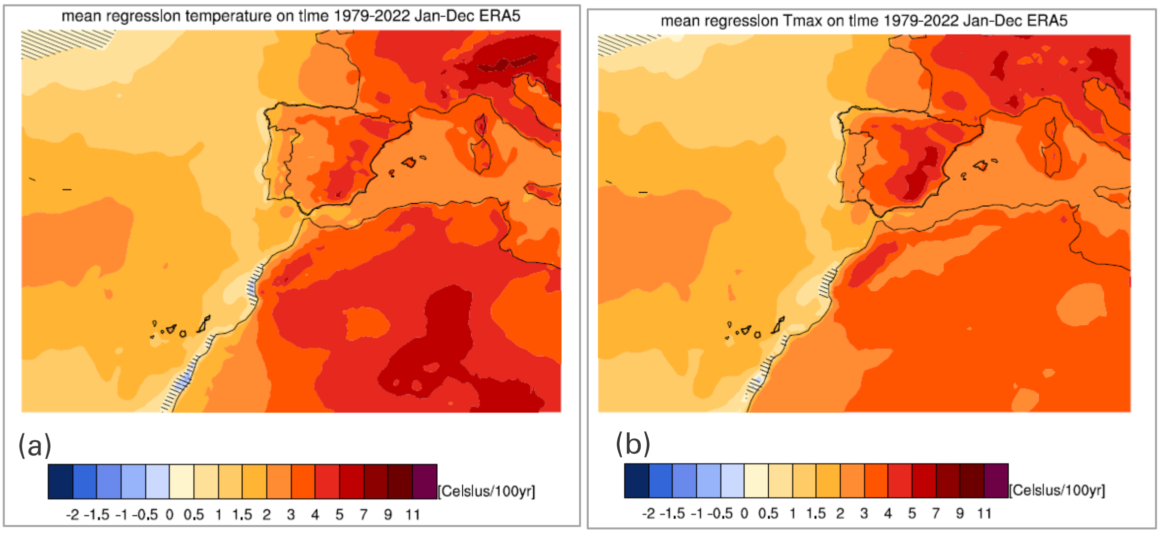


Figure 3.5. ERA5 reanalysis for the Iberian Mediterranean Region: (a) Mean regression of near-surface annual temperature 1979-2022; and (b) mean regression of maximum near-surface annual temperature 1979-2022. (Maps generated using KNMI Climate Change Atlas: http://climexp.knmi).

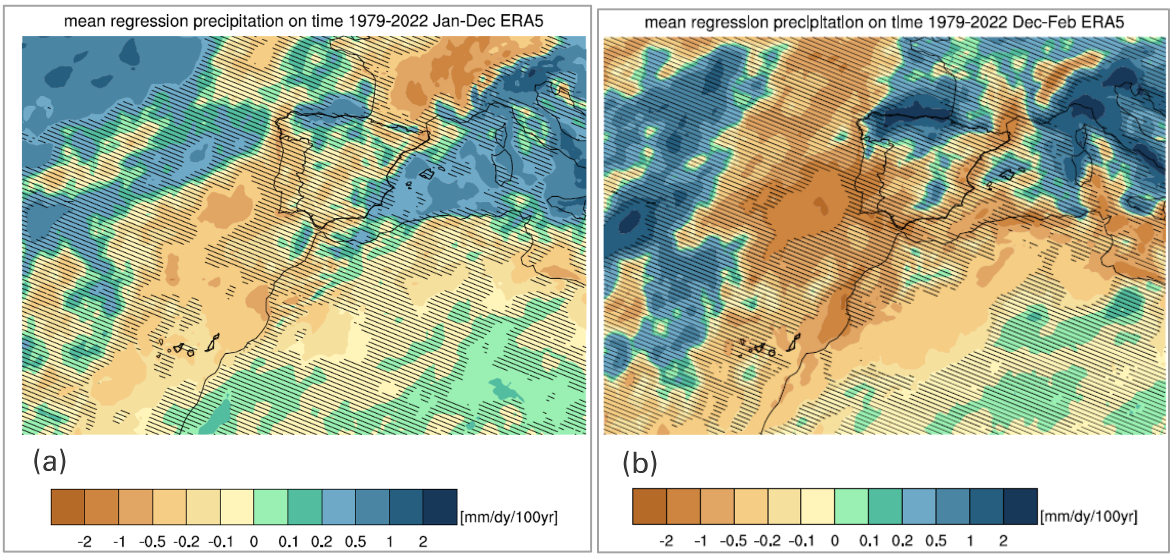


Figure 3.6. ERA5 reanalysis from January to December for Iberian Mediterranean Region: (a) Mean regression of annual precipitation 1979-2022; and (b) mean regression of winter precipitation (DJF) 1979-2022. Note: The hatching represents areas where the signal is smaller than one standard deviation of natural variability (Maps generated using KNMI Climate Change Atlas: http://climexp.knmi.nl/plot_atlas_form.py).

3.1.2. Demographics

The Iberian Mediterranean Region has a total population of about 38 million (as of January 2020)[4]. Demographic dynamics show a concentration of the population along coastlines and in metropolitan areas (Figure 3.7). Increasing desertification and ageing in the interior areas have implied a reduction in agroforestry activity and an increase in the risk of forest fires. Intense seasonal population movements associated with summer tourism increase vulnerability in areas already most sensitive to droughts.

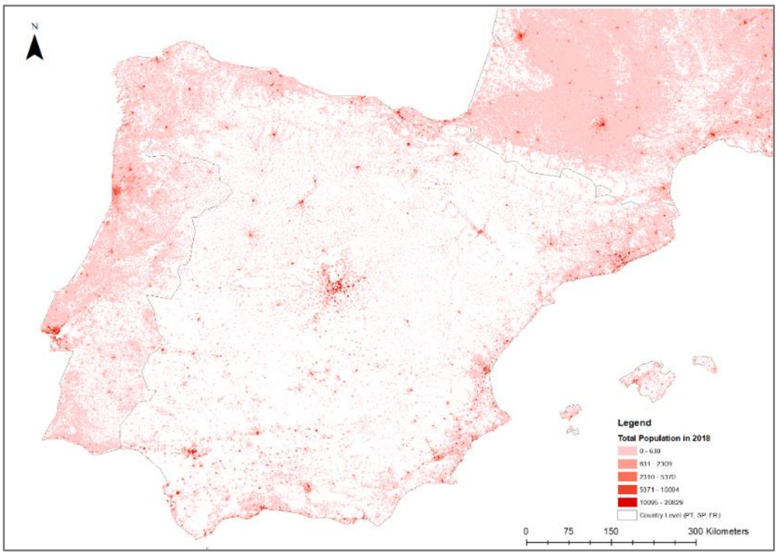


Figure 3.7. Iberian Mediterranean population in 2018, regular grid map of 1 x 1 km cells reporting the number of residents for the year 2018 for Europe (Pigaiani and Batista e Silva 2021).

The largest metropolitan areas in the region are Madrid, Barcelona, Lisbon, and Valencia, all with a population over two million.[5]

Table 3.1. Population in the major metropolitan areas. Source: Eurostat Last updated: 2021-06-14

Metropolitan Areas	Population in 2020
Madrid	6 747 068
Barcelona	5 635 100
Lisbon	2 863 272
Valencia	2 568 846

Population natural change is negative in the region, as there are currently more deaths than births each year in both Spain and Portugal. Population declining and ageing is only balanced by immigration. Significantly declining fertility rates have been registered in the region since the 1980s. Spain saw a surge in immigration during the 2000s, led by a strong economic growth, while this effect was less significant in Portugal. During the 2010s both countries, and in turn the Iberian Mediterranean, experienced a drop in population, associated with the financial crisis that led to significant emigration.

[4] https://ec.europa.eu/eurostat/web/main/data/database
[5] https://ec.europa.eu/eurostat/web/main/data/database

3.1.3. Governance

The governance structure in the Iberian Mediterranean region is mostly framed by the organizational bodies of the regional and national governments of Portugal and Spain. The regional and municipal governance structures in both countries are significantly different.

Portugal is a semi-presidential democratic republic, divided into 308 municipalities (the main elected sub-national territorial administrative unit), which in turn are subdivided into 3,092 civil parishes (the lower elected subnational administrative unit). Additionally, Portugal has two autonomous regions corresponding to the Atlantic archipelagos of the Azores (Azores Autonomous Region) and Madeira (Madeira Autonomous Region). Municipalities are responsible for enacting national law and promoting and safeguarding the interests of the population, in collaboration with the civil parishes, which includes climate action. At the regional level, the country is divided into 23 non-elected Regional Administrations (named Intermunicipal Communities, with delegated competencies from both central government and municipalities in the mainland), and the two Regional Autonomous Regions.

Spain is a constitutional monarchy, with a bicameral parliament, divided into 17 Autonomous Communities and 2 autonomous cities (Ceuta and Melilla in north Africa). These are further divided into 50 provinces (*Provincias*), which in turn are divided into 8118 municipalities (*Ayuntamientos*). The Autonomous communities are elected and have extensive legislative and executive power, with their own parliaments and regional governments.

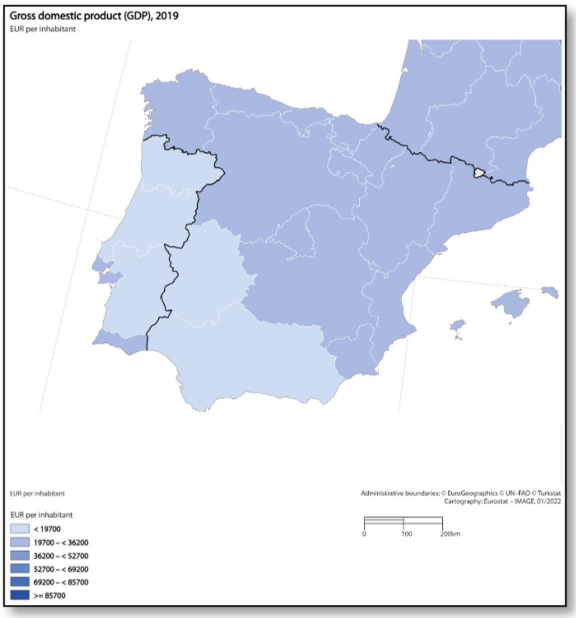
3.1.4. Economy

The regional economic structure is based on the services sector. In Portugal, 68.9% of the population works in the tertiary sector with the figure rising to 75.5% in Spain.[6]

The forestry and agricultural sectors still represent a significant part of land uses, with large potential for economic development and job creation in the region. Tourism is an economic activity of great relevance in the region, with a widespread economic dependence on this sector.

GDP per inhabitant is higher in the north of the region, in the Lisbon Metropolitan Area and in Algarve (south Portugal). In line, unemployment rates are higher in the south of Spain than anywhere else in the region, coinciding with higher desertification rates (Figure 3.8).

[6] Data for 2019, gisco-services.ec.europa.eu



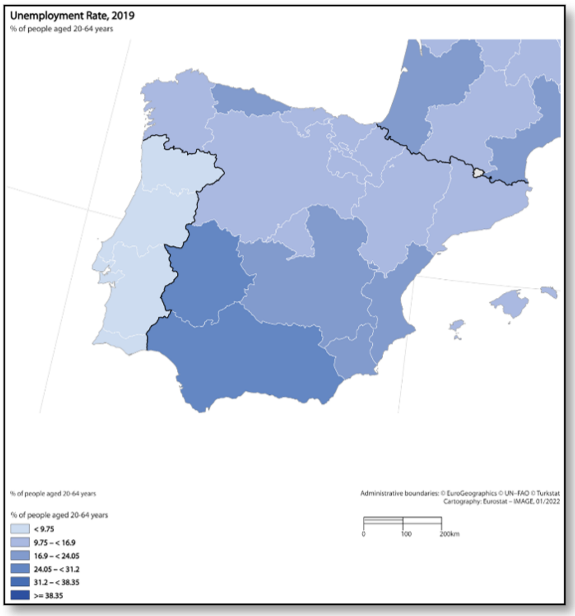


Figure 3.8. (a) Iberian Mediterranean GDP (EUR per inhabitant) by NUTS-2; (b) Iberian Mediterranean percentage of unemployed people aged 20-64 years by NUTS-2 (Maps generated from gisco-services.ec.europa.eu).

The current context is established by the global impact of SARS-CoV-2 (COVID-19) pandemic. The economic growth scenarios in the region have changed completely, compared to the outreach perspectives in 2020. The impact of the necessary measures to contain the health crisis are yet to be fully dimensioned, however, according to EUROSTAT, the changes in the first four months of 2020 represented a drop of 4% to 5% of GDP.[7] The Portuguese and Spanish economies were among the most affected in the EU, through restrictions imposed in sectors associated with tourism. The situation caused by COVID-19 led to the shutdown of the sector from the beginning of 2020. In April 2020, the flow of international visitors was reduced to zero due to the closure of borders imposed by the state of emergency.

3.2. Introduction to Lisbon Metropolitan Area

3.2.1. Physical and geographic characteristics

The Lisbon Metropolitan Area (AML) is located in south-centre of Portugal and includes 18 municipalities, with a total area of 2,892 km^2.

Located across both margins of the Tagus River estuary and to the north of the Sado River estuary (Figure 3.9) the AML has significant natural values, including relevant protected areas such as the Sado Estuary Nature Reserve, the Serra da Arrábida Natural Park, the Arrábida Marine Park, the Gruta do Zambujal Classified Site, the Tagus Estuary Nature Reserve, the Sintra-Cascais Natural Park and the Protected Landscape of the Arriba Fossil da Costa da Caparica.

[7] https://ec.europa.eu/eurostat/databrowser/view/sdg_08_10/default/line?lang=en

Figure 3.9 Lisbon Metropolitan Area and respective municipalities: south Tagus River municipalities (green), north Tagus River municipalities (purple) (Marques 2016).

The average annual air temperature in the AML is around 15/16ºC, and the average monthly values vary regularly throughout the year, with a maximum in August and a minimum in January (Figure 3.10).

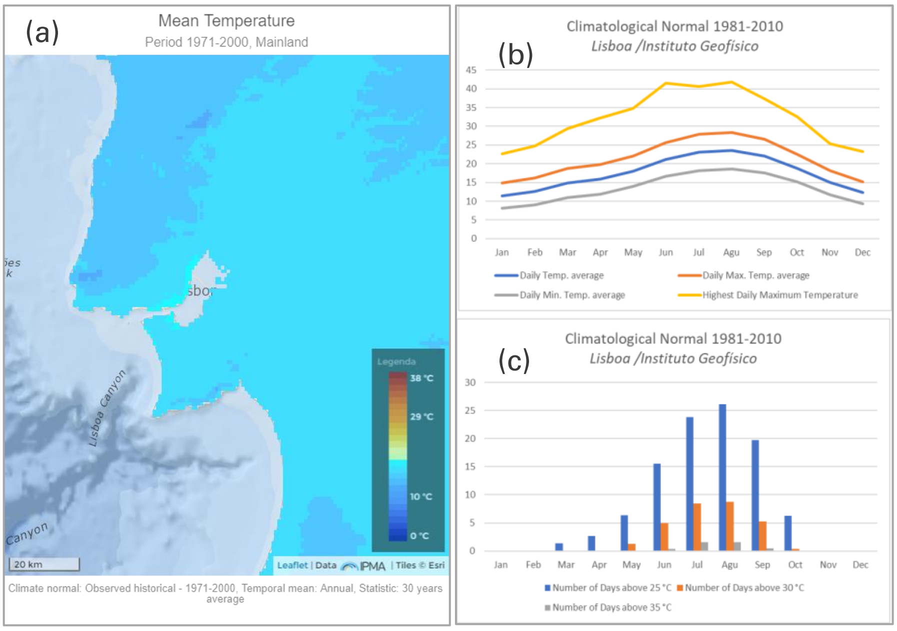


Figure 3.10. Lisbon Metropolitan Area: (a) Climate normal 1971-2000 for annual mean temperature distribution; (b) Climate normal 1971-2000 for mean temperature and (c) Climate normal 1981-2010 for number of hot days at representative weather station of Instituto Geofísico, Lisbon (IPMA 2015).

The average annual mean precipitation in the AML is around 400-600 mm, mostly concentrated between October and April. Summer precipitation is residual (Figure 3.11).

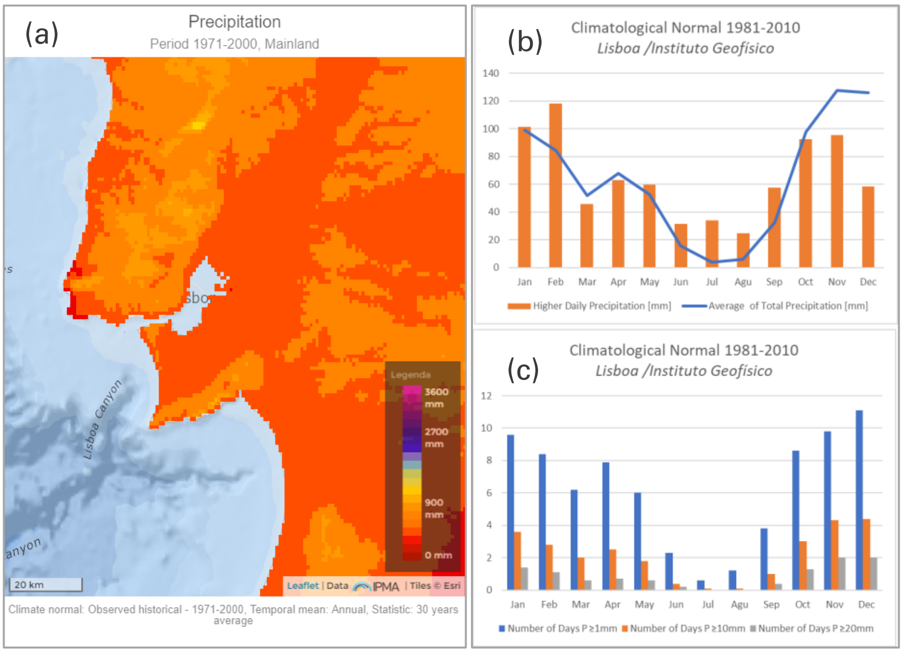


Figure 3.11. Lisbon Metropolitan Area: (a) Climate normal 1971-2000 for annual mean precipitation distribution; (b) Climate normal 1981-2010 for mean total precipitation and (c) climate normal 1981-2010 for number of precipitation days at representative weather station of Instituto Geofísico, Lisbon (IPMA 2015).

3.2.2. Demographics

The Lisbon Metropolitan Area is the third largest urban centre in Iberian Mediterranean with a population of approximately 3 million, including the Portuguese capital Lisbon and 17 other municipalities. It accounts for more than a quarter of the country's total population and over a third of its GDP. Lisbon is a typical Mediterranean coastal city, both culturally as in terms of vulnerability to extreme climate events and economic impacts such as reduced labour productivity.

In 2020 the resident population was 2,866,153, mainly located in Lisbon and Sintra municipalities (Table 3.2. Resident population, annual average (Data Sources: INE - Annual Estimates of Resident Population INE - Annual Estimates of Resident Population Source: PORDATA Last updated: 2021-06-14).Table 3.2). The AML population corresponds to 27% of the total resident population in Portugal, 26% of employment and 48% of national business production. The demographic importance of the AML results from its strong capacity to attract population.

Table 3.2. Resident population, annual average (Data Sources: INE - Annual Estimates of Resident Population INE - Annual Estimates of Resident Population Source: PORDATA Last updated: 2021-06-14).

Municipality	2001	2010	2020
Alcochete	13 191	17 329	19 860
Almada	161 294	173 634	168 852
Amadora	175 533	175 208	184 812
Barreiro	78 963	78 969	74 939
Cascais	171 997	204 767	213 775
Lisboa	563 312	549 210	509 565
Loures	198 975	204 740	214 328

Mafra	55 259	75 499	85 056
Moita	67 332	66 176	64 282
Montijo	39 682	50 593	57 853
Odivelas	134 077	143 851	162 389
Oeiras	162 347	171 786	177 602
Palmela	53 765	62 395	64 176
Seixal	150 362	157 928	167 953
Sesimbra	38 057	48 928	51 909
Setúbal	114 140	120 950	114 702
Sintra	363 575	377 301	392 145
Vila Franca de Xira	123 356	136 224	141 960
Lisbon Metropolitan Area	**2 665 212**	**2 815 483**	**2 866 153**

The capacity to attract population means that, between 1991 and 2011, the resident population in AML increased by around 12%. The demographic trends have a different expression throughout different municipalities. The municipality of Lisbon had a decrease in the number of residents (nearly -3%), on the other hand the municipalities around Lisbon registered population increases: Mafra (42%), Alcochete (35%), Sesimbra (32%) and Cascais (21%).

The population pyramid also changed over the last decade. The active population decreased from 69.7% to 66.3% between 2001 and 2011 and, for the same period, the population under 14 increased from 14.9% to 15.5%. In opposition, the elderly population (over 65) registered a considerable growth, rising from 15.4% in 2001 to 18.2% in 2011.

This evolution represents an age substitution deficit which results in an increase of elderly population proportion. In this context, the birth rate falls from 11.9‰ in 2001 to 11‰ in 2011, remaining above the national average, which was 9.2‰ in 2011. The current trend in the number of births associated with the longevity results in a demographic forcing on population ageing. This progress is particularly relevant since the elderly population is more vulnerable to extreme climate/ weather situations, such as cold or heat waves.

3.2.3. Governance

Metropolitan Areas in Portugal were created in 1991, reflecting the government objectives and needs of land-use management of the densely populated areas, and addressing the need for specific forms of territorial administration for this type of territory. Later the authority of the Metropolitan Areas was strengthened by the creation of municipal associations with responsibilities for intermunicipal planning of public transport systems, territorial strategy, regional development, and spatial planning.

In the AML, the deliberative body is Metropolitan Council that integrates all the municipal mayors. The Executive Committee, a body whose composition is indicated by the Metropolitan Council, is elected by an electoral college formed by 520 representatives of the 18 Municipal Assemblies.

3.2.4. Economy

The economic activity of the AML is relevant at the national and Iberian Mediterranean contexts. Together with Madrid and Barcelona, it represents a major economic attractor across the region, with increasing interconnectivity with its Spanish counterparts. In 2009, medium or large companies (with more than 50 employees) concentrated 50% of the staff working in the AML. The tertiary sector represented, in 2010, about 82% of national employment, which corresponded to a total of 1.2 million people.

Income distribution across the AML shows a marked concentration in the capital, Lisbon and wealthier municipalities to the West (Cascais and Oeiras) and to the East (Alcochete) (Figure 3.11). Poorer municipalities include the more urban outskirts of Sintra and Amadora, and some of the previously heavy industrialised areas on the south bank to the Tagus river.

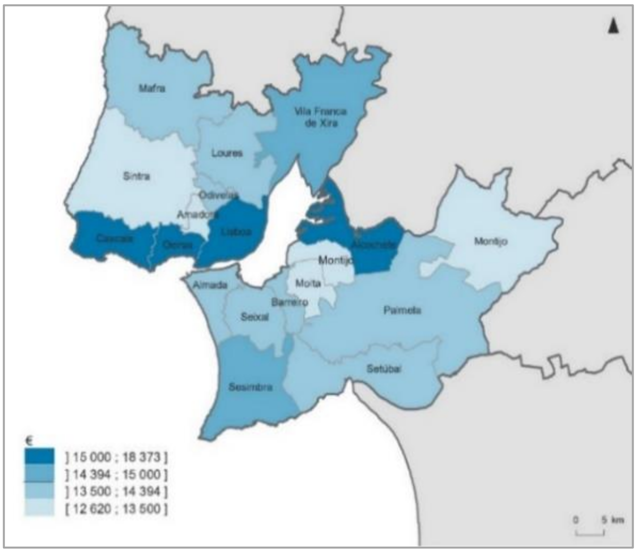


Figure 3.12. Metropolitan Area of Lisbon: (a) Median of gross income by tax person, 2019 (Source: Statistics Portugal, 2020: https://www.ine.pt/).

3.3. Climate Risks

3.3.1. Climate-related risks in the Iberian Mediterranean

3.3.1.1. Key hazards

A wide range of climate hazards are relevant for the Iberian Mediterranean and for its metropolitan areas. The risk of desertification is already intense in this region and is expected to increase in the future, under all scenarios (Figure 3.13). Current drylands (subtypes semi-arid and dry subhumid) in the Iberian Peninsula match perfectly PROVIDE's geographical definition of the Iberian Mediterranean, but these areas are expected to expand north and transition to drier types (Figure 3.13) (Cramer et al. 2020b).

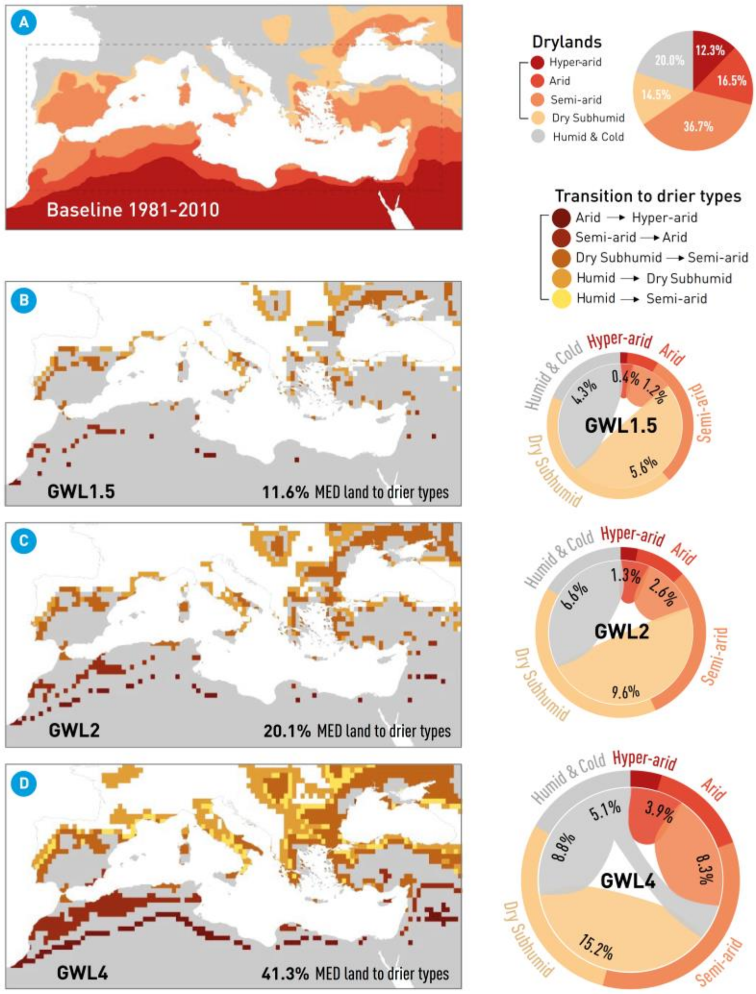


Figure 3.13. Distribution of drylands and their subtypes based on observations 1981-2010 period (A). Cover of drylands per subtype is estimated within the boundaries of the Mediterranean SREX region; (B, C, D) Distribution of projected dryland transitions for three Global Warming Levels (GWLs: +1.5°C, +2°C and +4°C above preindustrial levels), relative to the baseline period. Grey shaded areas in (B), (C) and (D) are drylands of the baseline period. Diagrams denote the extent of projected transitions in each dryland subtype (Source: Cramer et al. 2020a).

Climate risks related to extreme temperatures, droughts and water scarcity, forest fires, agriculture yield and species loss are other key hazards in this area (Seneviratne et al. 2016; Guiot and Cramer 2016). Additionally, these often occur within a combination of interacting physical processes across multiple spatial and temporal scales creating the so-called 'compound events' (Zscheischler et al. 2018), which may create additional challenges for climate adaptation and resilience.

Because of the Atlantic Ocean influence in this region, additional climate hazards related with sea level rise, storm surges and Atlantic hurricanes have to be considered. Atlantic hurricanes and storms provide an additional challenge as the wind they generate has been known to interact with catastrophic wildfires, fuelling them and creating devastating consequences[8].

[8] https://drmkc.jrc.ec.europa.eu/portals/0/Knowledge/ScienceforDRM2020/Files/supercasestudy_04.pdf

The following sections organise the key climate hazards in the Iberian Mediterranean region using the European Union (EU) Taxonomy following the Paris Agreement objectives (Dudout et al. 2021). The EU-taxonomy comprises four major hazard groups, namely those related to water, temperature, wind, and solid mass movements. This climate-related hazard classification distinguishes between acute (extreme) and chronic (slow onset) hazards, to consider both rapid and gradual changes in weather and climate within adaptation processes and to prevent maladaptation conditions.

Table 3.3 summarises key observed and projected hazards in the region as reported by Portugal and Spain in their National Adaptation Strategies (NASs) and National Adaptation Plans (NAPs) (Ministerio de Medio Ambiente; Presidência do Conselho de Ministros, Ministerio para la Transición Ecológica y el Reto Demográfico (MITECO) 2020).

Table 3.3: Climate-related observed and projected hazards as reported by the Portuguese and Spanish National Adaptation Strategies (NASs) and National Adaptation Plans (NAPs), organised according to the Eu-Taxonomy classification (source: as reported in https://climate-adapt.eea.europa.eu/).

Temperature	Wind	Water	Solid mass
Changing temperature (air, freshwater, marine water)	Changing wind patterns	Changing precipitation patterns and types (rain, hail, snow/ice)	Coastal erosion
Heat stress	Cyclone, hurricane	Precipitation and/or hydrological variability	Soil degradation
Temperature variability (PT + SP)	**Storm (including blizzards, dust and sandstorms) (PT + SP)**	Ocean Acidification	**Soil erosion (PT)**
Heat wave	Tornado	Saline intrusion	**Solifluction (SP)**
Cold wave/frost		**Sea level rise (PT)**	Avalanche
Wildfire (PT + SP)		**Water stress (PT + SP)** Water scarcity / quality deterioration	**Landslide (PT)**
		Drought	**Subsidence (SP)**
		Heavy precipitation (rain, hail, snow/ice) (PT + SP)	
		Flood (coastal, fluvial, pluvial, ground water)	

Legend:
Bold - Observed and Future climate hazards
(PT) – Report in Portugues territory
(SP) – Report in Spanish territory

Temperature variability

Increases in mean temperature and extreme heat and decreases of cold spells (Ranasinghe 2021a; Schleussner et al. 2021) are one of the most tangible climate-driven changes occurring in the region. Since 1950, mean and maximum temperatures, frequencies of hot days, and heat waves have increase and the cold-related hazards have decreased (Ranasinghe 2021a; Schleussner et al. 2021). The increasing intensity of heatwaves will cause additional mortality and extinction of vulnerable species, changing the provision of ecosystem services (Marbà and Duarte 2010).

Wildfires

Fire hazard conditions have substantially increased in Southern Europe from 1980 to 2019 (Urbieta et al. 2019; Fargeon et al. 2020; di Giuseppe et al. 2020). Wildfire events are related with multiple factors, from climate to social, but within this complex context, fire hazards have increased over the last decade and are project to increase in the future in the Iberian Mediterranean (Copernicus 2022; Bedia et al. 2018). Also in Mediterranean Basin, the frequency of heat-induced fire-weather is expected to increase by 14% at 2.5 °C of Global Warming Level, by the end of the century (Ruffault et al. 2020).

Water stress

In the Iberian Mediterranean, projected changes lead to more frequent and severe droughts, and as a consequence an increase in water scarcity (Ranasinghe 2021a). Additionally, impacts of compound events are emerging, such as recent crop failures due to heat and drought (Toreti et al. 2019).

In the Iberian Mountains, droughts can result in a significant reduction in ecosystems services like water provisioning and protection. It can also force the abandonment of pastoralism, which result in reduced water provision downstream. Ecosystems services will be significant affected and progressively limit the climate regulation capacity (Peñuelas et al. 2018; Xu et al. 2019).

Above 3°C Global Warming Level will likely lead to difficulties to adapt to water scarcity in parts of Southern Europe, due to geophysical and technological limits (Bednar-Friedl et al. 2022). The ability of trees to tolerate water stress can be exceeded with increasing duration of the dry season, leading to large-scale mortality, and changes in species dominance.

Storms (including blizzards, dust and sandstorms)

Storms are projected to increase in frequency across Europe over 2°C of warming, but there may be a potential decrease of their frequency in the Mediterranean region (Ranasinghe 2021a).

The frequency of windstorms can also rise substantially by 2100 (Forzieri et al. 2017), but there is limited evidence for windstorms and convective storms for most of the regions. With no scientific consensus about a climate-induced trend in windstorms over Europe, it is now evident that Southern Europe has the largest share of the area with an increase of 17% in wind extremes, in a scenario of 3°C of warming (Commission et al. 2020c).

Dust storms frequency has increased during recent years and projections suggest that it will continue to rise in response to climate change and anthropogenic activities (Schweitzer et al. 2018). The Sahara is the main source of dust deposition in the Iberian Mediterranean and in metropolitan areas like Lisbon, Madrid, and Barcelona (Salvador et al. 2014).

Sea level rise

Flood risks in low-lying coasts and estuaries are projected to increase due to sea level rise (SLR) combined with storm surges and heavy precipitation (Couasnon et al. 2020). For example, in a context of no adaptation the number of airports vulnerable may increase significantly between 2030 and 2080 along the Mediterranean coasts (Commission et al. 2018).

Heavy precipitation (rain, hail, snow/ice)

In recent decades, the number of floods has increased in summer (Blöschl et al. 2020) with increased economic damages, reflecting exposure of people and assets (Visser et al.

2014; Merz et al. 2021). There is no evidence that heavy precipitation is increasing in the region (observations from 1970-2019) but there is high confidence of an increase above 4°C of warming (Douville 2021; Ranasinghe 2021b).

Heavy precipitation events are expected to become more intense in a warming atmosphere, and rainfall totals during precipitation events may rise up to 7% per ºC of warming. Within this context it is expected that precipitation events (from sub-daily up to seasonal time scales) will intensify flood occurrence. However, the daily precipitation maximum (Rx1day), based on JRC data catalogue (Dosio Alessandro 2020) is projected to decrease in the region in both 1.5ºC and 3ºC warming scenarios (Gutierrez 2021).

3.3.1.2. Key components of exposure

Exposure is related with the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social, or cultural assets in places and settings that could be adversely affected. Key components of exposure considered for the Iberian Mediterranean are mainly vulnerable groups of people, related with the sociodemographic context, and the key vulnerable economic sectors present in the region and its metropolitan areas.

The key components of exposure described here are related to the above-mentioned hazards, with particular attention their interaction with urban areas, agriculture, tourism, human health, infrastructure, energy systems and coastal zones.

Heat and cities

The concentration of population in metropolitan areas represents a significant increase in exposure to urban heat islands, flash floods, landslides, and coastal-related risks.

Since the region is prone to desertification, especially inland areas, where ageing population and reducing economic activity will expose vulnerable groups of people to heat stress. In parallel, the exodus from rural areas to cities produces a significant pressure on environmental quality in cities.

Droughts in agriculture and tourism

The intense seasonal population movements related with tourism increases risks related to water stress and droughts in the region. The tourism sector is particularly exposed to increasing air temperatures considering that thermal comfort plays an important role in the attractiveness of a destination.

Climate change and decades of intensive agricultural practices and cultures make agriculture in the region prone to desertification and other potential risks (Spinoni et al. 2017). The region's spatial-temporal distribution of precipitation can lead to a reduction in water availability in certain areas and periods of the year, which can affect agricultural activity. The sector is very exposed to climate, and irrigation is fundamental to guarantee the viability of agriculture, particularly to develop spring-summer crops. Additionally, agriculture is exposed to climate change within a context of changing productivity and considerable moderate adaptation measures will be necessary (Feyen et al.; Bird et al. 2016; European Environment Agency 2019a; Moretti et al. 2019).

Combined with socio-economic development, the increase of frequency and intensity of heat and droughts will promote a reduction on water availability for irrigation leading to the potential abandonment of farmland (Holman et al., 2017).

For example, in the Lisbon Metropolitan Area, the annual precipitation reduction projected until the end of the century is between 20% and 25% (IPMA 2015), which, associated with the lack of development of some rural areas and the high risk of water erosion, will tend to significantly affect agroforestry production systems.

Health systems

Health systems could face significant pressure due to direct impacts on human health related with air quality, infectious diseases, natural disasters (floods, fires), or even as a result of extreme weather events (Austin et al. 2016a; Watts et al. 2021a). In extreme heat or heat waves context, greater morbidity and mortality from heat-associated causes is expected, like dehydration, fatigue, and heat strokes. It is expected that these will act more severely on the population with less protection capacity, such as the elderly, children, or non-acclimatized tourists. In cities and in urban areas such as the AML, the consequences of extreme heat or heat waves are generally amplified by the thermal and hygrometric factors in the field that tend to generate the urban heat island events.

Infrastructures

The exposed assets are current related with river floods and storms. However, heat and drought will become major drivers in the future. Considering the companies located in exposed locations the probability of financial default may increase to up to four times until 2050, in all sectors (Central Bank 2021). Additionally, it is projected that exposure to urban flooding will increase with urbanization (Jongman et al. 2012; Jones and O'Neill 2016; Paprotny et al. 2018; Dottori et al. 2018).

Coastal areas have already started to be affected by sea level rise and human exposure to coastal hazards is projected to increase in the next decades (Merkens et al. 2016; Reimann et al. 2018). Exposure differs between scenarios for the coastal population for the 21st century. With the exception of SSP3, the coastal population will grow faster than the inland population (Merkens et al. 2016), which will increase exposure in coastal areas.

Energy

The region's energy systems are exposed to climate change in different contexts: (1) supply dependence from renewables, considering the potential changes in electricity production associated with wind, photovoltaic and hydroelectric production; (2) distributions and storage systems disruptions due to occurrence of extreme weather events; and (3) temperature variations and the associated increase in final consumption, both for heating and cooling. All these are expected to increase under climate change scenarios (Pina et al. 2018).

Coastal zones

Sea level rise is a threat for coastal communities and infrastructures, particularly beyond 2100. Coastal areas will be affected by sea levels and this context is also a great risk for the Mediterranean cultural heritage (Marzeion and Levermann 2014; Clark et al. 2016; Reimann et al. 2018). Extreme water levels, coastal floods, and sandy coastline recession are projected to increase along the region's coastline, especially in Atlantic coastlines in (Ranasinghe 2021b). Additionally, some of the most vulnerable ecosystems in the region are also highly exposed and will be significantly impacted (Marani et al. 2007; Ranasinghe 2021a). In Portugal, the number of additional people at risk of a 100-year coastal flood is not expected to change significantly while in Spain this number is expected to increase by at least 100.000 until the end of the century, when compared with current exposure and the number of people at risk (Haasnoot et al. 2021).

3.3.2. Climate-related risks in the Lisbon Metropolitan Area

3.3.2.1. Key hazards

The key climate hazards are presented in the Lisbon Metropolitan Area Climate Change Adaptation Plan (PMAAC-AML) and are based on scenarios that include the following variables (Pina et al. 2018):

- **Temperature**: average, maximum, minimum, number hot of days, summer days, tropical nights, frost days.
- **Precipitation**: total precipitation, number of days with intense precipitation.
- **Drought**: Standard Precipitation Index (SPI).
- **Wind**: average speed.
- **Thermal comfort**: Heat waves, cold waves, bioclimatic comfort (UTCI).

The major hazards projected for the AML will be related to increasing temperatures. Warmer conditions and the increase of length of the dry season will promote wildfire conditions that will cause the loss of natural habitats in the region. Forest fire are a major cause of disturbance in Mediterranean habitats and one of the biggest causes of loss of natural habitats (Batllori et al. 2019).

Table 3.4 summarises key climate-related hazards for the AML, classified according to the EU-Taxonomy.

Table 3.4. Climate-related hazards based on AML's Climate Change Adaptation Plan, organised according to the Eu-Taxonomy classification (projections: minimum value is for 2041-2070 and RCP4.5 and maximum value is for 2071-2100, RCP8.5).

Temperature	Water
Heat stress Increase in days under conditions of thermal discomfort: 24 to 66 days/year	**Precipitation and/or hydrological variability** Decrease of 5% to 17% annual precipitation Decrease of 25% (2071-2100, RCP8.5) in spring and autumn
Temperature variability Increase in average from 1,3ºC to 3,2ºC Increase in tropical nights from 6 to 34 days/ year	**Drought** Increase in annual average SPI: from -0,23 to -0,36
Heat wave 10 to 23 days in heat wave per year	**Heavy precipitation (rain, hail, snow/ice)** Increase in days with heavy precipitation: 1 to 2 days/ year

3.3.2.2. Key components of exposure

The AML vulnerability to extreme events, combined with the strong concentration of people, infrastructure and economic activities, results in a strong exposure to climate change, whose impacts can result in risk situations for people and assets, economic, property and cultural losses and, consequently, a deterioration of the social and economic situation, which is reflected in the increase of poverty.

The forestry sector is exposed to forest fires as a result of the decrease in average annual precipitation, temperatures, and frequency of heat waves. The exposure is higher in the municipalities of Mafra, Loures, Sintra, Setúbal and Sesimbra.

The key sectors reported as heavily exposed to climate change in the Lisbon Metropolitan Area Climate Change Adaptation Plan are (Pina et al. 2018):

- Forest and agriculture
- Biodiversity
- Industry, tourism e services
- Energy
- Water resources
- Human Health

The demographic evolution in AML is relevant for climate change since an ageing population is more vulnerable to extreme weather events, such as heat waves. This particular climate context can expose the National Health Service to moments of pressure, which can limit the response of the health services. Additionally, the Adaptation Plan refers the potential degradation of air quality by high ozone levels and as result of an increase in air temperature and less precipitation (Pina et al. 2018).

AML is directly influenced by the Atlantic Ocean, which leads to a significant exposure to sea-level rise, hurricanes, storms, and high energy waves that can cause coastal erosion and flooding, as well as saline intrusion. Along the coast, buildings, communication infrastructures, port areas, coastal defence structures, water reservoirs, pluvial systems, beaches, dunes, and other ecosystems are very exposed, as it is evident from historical impacts.

3.4. Adaptation

3.4.1. Key components of adaptive capacity

Adaptive capacity is the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to the consequences of climate change. The opportunities and constraints for adaptation in the Iberian Mediterranean and in the Lisbon Metropolitan Area include links to ongoing changes in the socio-economic and environmental context, including potential social-ecological tipping points.

We considered the ability of natural and human systems, institutions, and organisms to adjust to different potential impacts of climate change, taking advantage of opportunities or being limited by constraints in responding to the consequences that arise.

Table 3.5 summarises the key opportunities and enabling conditions for adaptation in the Iberian Mediterranean region.

3.4.1.1. Regional assessment of adaptation opportunities and constraints

Table 3.5.: Opportunities and enabling conditions for adaptation in the Iberian Mediterranean region

OPPORTUNITY	REGIONAL OVERVIEW
Awareness raising	- Heat-related casualties in Southern European cities are at a low level due to the application of prevention plans, individual and household adaptation measures and growing awareness of citizens (de' Donato et al. 2015). - Limited mainstreaming of climate change is observed, particularly due to low societal pressure to change, confidence in existing health systems, and lack of awareness of links between human health and climate change (Austin et al. 2016b; Watts et al. 2021b). - Even in companies that experience consequences of extreme weather events or stakeholder pressure, the action to adapt are limited due to underestimation of exposure to risk (Pinkse and Gasbarro 2016). - There remains little research on private-sector awareness of or responses to cascading or compound risks associated with climate change (Miller and Pescaroli 2018). - Higher climate change risk perceptions observed in Spain and Portugal (Duijndam and van Beukering 2021). - In Portugal, people living in the coast were more likely to attribute local natural hazards to climate change and to take some adaptive measures (Luís et al. 2017). - Many behavioural changes such as personal and home heat protection have already been implemented in South Europe (Martinez et al. 2019a).
Capacity building	- The main instrument to improve knowledge within adaptation to climate change is the definition adaptation strategy to climate change, identifying vulnerabilities and defining measures that strengthen resilience (Ranger et al. 2013). - Action Program for Adaptation to Climate Change (P-3AC) implement adaptation measures, with concrete lines of action for direct intervention in the territory and infrastructure. - The risk associated with human heat mortality is influenced by socio-economic scenarios. The consequences are more severe under SSP3, SSP4 and SSP5 scenarios than SSP1. - Within a context of extensive water consumer, crop production in Agriculture sector (Gerveni et al. 2020)(Gerveni et al. 2020) the adaptive capacity is reduced beyond 3°C GWL (Ruiz-Ramos et al. 2018).
Tools	- The governance tools to reduce impacts related with are the establishment of networks of protected areas. The cost-effective adaptation strategy with multiple additional co-benefits should be considered (Berry et al. 2015; Roberts et al. 2017).
Policy	- The climate change actions on mitigation and adaptation remain largely sectoral. - Many behavioural changes such as personal and home heat protection have already been implemented in South Europe
Learning	- Ecosystem-based solutions require space, which trend to be unavailable in cities. Flood options to protect are effective in reducing inland flooding risk but regional variation occur considering a cost-benefit ratio (Alfieri et al. 2018; Commission et al. 2020b).
Innovation	- Adaptation across Europe and sectors are more frequently incremental than transformative actions and should promote new opportunities and associated benefits (European Environment Agency 2019b).

Table 3.6 summarises the key constrains for adaptation in the Iberian Mediterranean region.

Table 3.6: Key constrains for adaptation in the in the Iberian Mediterranean region

CONSTRAINTS	REGIONAL OVERVIEW
Physical and Biological	- Low water availability (Ranasinghe 2021a). - Dense urbanized areas and coastal population agglomerations (Merkens et al. 2016).
Economic and Financial	- There are structural and economic barriers to household adaptation due to lack of policy incentives or regulations (European Environment Agency 2017). - Building interventions alone have low to medium effectiveness independent of the region (Martinez et al. 2019b). - Most of the budget EU spending is going to mitigation (Berkhout et al. 2015; Hanger et al. 2015; Leitner et al. 2020).
Human Capacity	- Key barriers to adaptation include both external (e.g., lack of support/guidance) and internal factors (e.g., few resources, managerial perceptions (Halkos et al. 2018). - Lack of knowledge, feeling climate change is not a salient risk, and lack of social learning or collaboration, appear to be key barriers to private sector adaptation (Dincă et al. 2014; Romagosa and Pons 2017; André et al. 2017).
Governance Institutions Policy	- Decrease in hydropower potential in South Europe are expected beyond 3°GWL (Commission et al. 2020a; Spinoni et al. 2020). - There are considerable barriers to mainstreaming adaptation (Runhaar et al., 2018). - Barriers to climate services: lack of perceived usefulness, outdated statistics, mismatch needs, insufficient effective engagement lack of business models to sustain climate services over time (Räsänen et al. 2017; Cavelier et al. 2017; Bruno Soares et al. 2018; Christel et al. 2018; Oberlack and Eisenack 2018; Hewitt et al. 2020).
Knowledge Awareness Technology	- Across Europe, and particularly in relation to gradual change, non-experts continue to under-estimate climate change risks compared to experts. (Taylor et al. 2014). - Non experts have low awareness of adaptation options and confuse adaptation and mitigation (Harcourt et al. 2019). - Adaptation responses across European regions and sectors, are more often incremental than transformative options (European Environment Agency 2019c). - Under medium warming a larger portfolio of measures might be needed, while it may not be able to completely avoid water shortages at high warming (Greve et al. 2018). - At higher GWL, ecosystems are projected to experience impacts due to temperature changes (Malhi et al. 2020)and SLR combined with human pressures (Mangan et al. 2020). - Models underestimate the total costs of climate change impacts by neglecting systemic risks, tipping points (van Ginkel et al. 2020), indirect and intangible costs, and limits of adaptation (Ercin et al. 2021; Piontek et al. 2021). - There is little research on public responses to risks and to multiple and cascading risks (van Valkengoed and Steg 2019).
Social/Cultural	- Water efficiency measures in anticipation of, or response to drought are also limited (Bryan et al. 2019), while water recycle in Mediterranean and some other EU countries is increasing (Aparicio 2017).

3.4.2. Adaptation governance and key polices

In climate change adaptation, policy makers like to require detailed and precise information about the likelihood and dimension of the climate impacts (Capela Lourenço 2015). Adaptation to climate change impacts must come after focused evaluation and planning (Füssel 2007), and depend on the conditions and background of each sector and location in focus. It is recognized that integrated complementary approaches need to be developed, which can benefit from the input of stakeholders at different times, setting critical thresholds for specific climate change vulnerabilities (Adger et al. 2005).

The integration of long temporal and large spatial scales in adaptation is a challenge that needs to be integrated into the rationale of governance practices. Adaptation can be based on uncoordinated, ad hoc choices and actions of individuals and different stakeholders, or based on collective choices, coordinating numerous actions at various levels – local, regional, national, or supranational (Swart et al. 2009).

Therefore, key elements of adaptation governance and policy-making for the Iberian Mediterranean region and its metropolitan areas require an assessment across scales, from the EU to the local level. The following sections highlight the key polices, strategies and plans of relevance for the adaptation governance in this region.

3.4.2.1. EU and the Mediterranean

Tables Table 3.7

Table 3.8 summarise key EU adaptation policies, plans and strategies and other EU Policies plans and strategies with adaptation components of key relevance to the Iberian Mediterranean.

Table 3.7. Current EU adaptation policies, plans and strategies with major relevance to the Iberian Mediterranean.

Policy/Plan/ Strategy	Overview/Scope
EU Adaptation Strategy **EU Adaptation Strategy – Impact Assessment**	The new strategy sets out how the European Union can adapt to the unavoidable impacts of climate change and become climate resilient by 2050. The Strategy has four principles objectives: to make adaptation smarter, swifter and more systemic, and to step up international action on adaptation to climate change.
EU taxonomy for sustainable activities	Regulatory diploma to meet the EU's climate and energy targets for 2030. It defines a common classification system for sustainable economic activities.
The European Green Deal	It is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient, and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use.

Table 3.8. Current EU Policies plans and strategies with adaptation components of key relevance to the Iberian Mediterranean.

Policy/Plan/ Strategy	Overview/Scope
Biodiversity strategy for 2030	The EU's biodiversity strategy for 2030 is a comprehensive, ambitious, and long-term plan to protect nature and reverse the degradation of ecosystems. The strategy aims to put Europe's biodiversity on a path to recovery by 2030 and contains specific actions and commitments.
EU Common Agricultural Policy	https://www.europarl.europa.eu/factsheets/en/sheet/103/the-common-agricultural-policy-cap-and-the-treaty.
EU Farm to Fork	Within the framework of the Green Deal, the European Commission launched in May 2020 the EU Farm to Fork Strategy that aims to ensure a sustainable food value chain. Sustainable agriculture and sustainable fishery within Protected Areas can be a model to provide safe, nutritious and high-quality products.
EU Climate Law	A new legislation to complement the existing framework to tackle Climate Change by irreversibly enshrining the 2050 carbon neutrality target in the law. This legislative act is in line with the Green Deal and the Union's desire to position itself as a global climate leader.
Floods Directive	Directive to assess and manage flood risks in water courses and coast lines, aim to map the flood extent and assets and humans and planning process.
Water Framework Directive	Aims at long-term sustainable water management based on a high level of protection of the aquatic environment by achieving a good ecological status in all waterbodies. EU Member states agreed that climate-related threats and adaptation planning have to be incorporated in the River Basin Management Plans (RBMPs) elaborated under the WFD.
Marine Strategy Framework Directive	The aim of the European Union's ambitious Marine Strategy Framework Directive is to protect more effectively the marine environment across Europe.
Strategy for Financing the Transition to a Sustainable Economy	The European Commission adopted today an ambitious and comprehensive package of measures to help improve the flow of money towards financing the transition to a sustainable economy.
New EU Forest Strategy for 2030	Aims to overcome these challenges and unlock the potential of forests for our future, in full respect for the principle of subsidiarity, best available scientific evidence and Better Regulation requirements.
Land use and forestry regulation for 2021-2030	The Land Use, Land Use Change and Forestry (LULUCF) Regulation implements the agreement between EU leaders that all sectors should contribute to the EU's 2030 emission reduction target, including the land use sector.
EU4Health Programme	EU4Health is the EU's ambitious response to COVID-19. The pandemic has a major impact on patients, medical and healthcare staff, and health systems in Europe. The new EU4Health programme will go beyond crisis response to address healthcare systems' resilience.
Interreg MED Programme	Gathers 13 European countries from the Northern shore of the Mediterranean. They are working together for a sustainable growth in the region.

3.4.2.2. Iberian Mediterranean (Portugal, Spain)

Adaptation governance in the Iberian Mediterranean is incipient with the notable exception of some past efforts from both countries' Environmental Agencies[9]

Both Portugal and Spain have heavy and centralised national, regional, and autonomic regional levels of governance (see section Governance). This is also reflected on the climate action governance structures of both countries.

Tables Table 3.9Table 3.10 summarise key existing adaptation plans and other sectoral policies and plans that incorporate an adaptation dimension in the Iberian Mediterranean.

Table 3.9. Existing adaptation policies, plans and strategies in the Iberian Mediterranean.

Policy/Plan/Strategy
National Climate Change Adaptation Plan 2021-2030 - Spain
Climate Change Adaptation: 3° Working Programme (National adaptation plan)
National Adaptation to Climate Change Strategy (ENAAC 2020) - Portugal
Action Plan for Adaptation to Climate Change (P-3AC) - Portugal

Table 3.10. Key policies, plans and strategies with adaptation components in the Iberian Mediterranean.

Policy/Plan/Strategy
Adaptation Strategy for the Spanish Coast
Forest Adaptation Plan to Climate Change - Portugal
National Strategy for Preventive Civil Protection - Portugal
Southwest Europe Programme

3.4.2.3. Lisbon Metropolitan Area

Climate change is a national priority for Portugal since it is one of the European countries most vulnerable to the impacts of climate change. The Lisbon Metropolitan Area is a relevant hotspot of impacts due to its location and socioeconomic relevance.

The Lisbon Metropolitan Area is overcoming relevant transformational efforts in terms of decarbonisation and adaptation. Eight municipal strategies and one intermunicipal adaptation strategy have already been adopted, and collaboration with the cities and metropolitan officials. With regional and local stakeholders, the regional governance facilitates the overshoot planning into the rapidly growing discussion about the implementation of adaptation actions, such as those included in the Metropolitan Adaptation Strategic Plans for heatwaves (see section 3.6

Insights from stakeholder engagement meeting).

[9] LIFESHARA project: https://www.lifeshara.com/

Tables Table 3.11,Table 3.12Table 3.13 summarise key existing adaptation polices strategies and plans, other sectoral plans with that incorporate an adaptation dimensions and upcoming adaptation strategies and plans in the AML.

Table 3.11: Existing adaptation policies, plans and strategies in the Lisbon Metropolitan Area

Policy/Plan/Strategy
Climate Change Adaptation Metropolitan Plan – Lisbon Metropolitan Area[10]
Climate Change Adaptation Municipal Strategy/ Plan – Barreiro[11]
Climate Change Adaptation Municipal Strategy/ Plan – Lisbon [12]
Climate Change Adaptation Municipal Strategy/ Plan – Mafra[13]
Climate Change Adaptation Municipal Strategy/ Plan – Loures[14]
Climate Change Adaptation Municipal Strategy/ Plan – Oeiras
Climate Change Adaptation Municipal Strategy/ Plan - Odivelas
Pacto para o Desenvolvimento e Coesão Territorial da Área Metropolitana de Lisboa (PDCT-AML).[15]

Table 3.12: Other policies, plans and strategies with adaptation components in the Lisbon Metropolitan Area

Policy/Plan/Strategy
18 Municipal Master Plans (original name: Plano Director Municipal – PDM).
Municipal Plans for Forest Defence against wildfires (original name: Planos Municipais de Defesa da Floresta Contra Incêndios).
Municipal and Multi-municipal Plans for Floods Management Risk (original name: Planos de Gestão dos Riscos de Inundações (PGRI).
Hydrographic Region Management Plans (original name: Planos de Gestão de Região Hidrográfica), two plans aplei in AML: • RH5 — Tejo e Ribeiras do Oeste (Alcochete; Almada; Amadora; Barreiro; Cascais; Lisboa; Loures; Mafra; Moita; Montijo; Odivelas; Oeiras; Seixal; Sintra; Sesimbra; Setúbal; Vila Franca de Xira) • RH6 — Sado e Mira (Montijo; Palmela; Sesimbra; Setúbal)
Planos e Programas da Orla Costeira (1. Alcobaça – Mafra; Cidadela – São Julião da Barra; Sintra – Sado; Sado – Sines).
Human Heat stress in AML.

[10] https://www.lisboa.pt/fileadmin/atualidade/noticias/user_upload/plano_metropolitano_de_adaptacao_as_alteracoes_climaticas.pdf
[11] https://www.cm-barreiro.pt/cmbarreiro/uploads/writer_file/document/10297/00_EMAAC_Barreiro.pdf
[12] https://www.lisboa.pt/fileadmin/cidade_temas/ambiente/qualidade_ambiental/EMMAC/EMAAC_2017.pdf
[13] https://www.cm-mafra.pt/cmmafra/uploads/writer_file/document/1555/emmac_mafra.pdf
[14] https://www.cm-loures.pt/AreaConteudo.aspx?DisplayId=1284
[15] https://www.am-lisboa.pt/documentos/1518972446X5wlG6ed3Po44JT3.pdf

Table 3.13: Upcoming adaptation policies/plans/strategies in the Lisbon Metropolitan Area

Policy/Plan/Strategy	Lead Agency	Overview/Scope
Climate Change Adaptation Municipal Strategy/ Plan,Palmela	Palmela Municipality	The Project PLAAC - Arrábida (developed by ENA - Energia e Ambiente da Arrábida) will develop three Climate Change Adaptation Municipal Plans in Setúbal, Palmela and Sesimbra. This project intends to adapt the territory to cope to climate change by identifying vulnerabilities, reducing risks and impacts, and promoting resilience. The elaboration of the plans involves a participatory process with the key actors of the community.
Climate Change Adaptation Municipal Strategy/ Plan - Sesimbra	Sesimbra Municipality	
Climate Change Adaptation Municipal Strategy/ Plan - Setúbal	Setúbal Municipality	
Climate Change Adaptation Municipal Strategy/ Plan - Vila Franca de Xira (PMAAC-VFX)	Vila Franca de Xira Municipality	The PMAAC-VFX will be developed under the EEA-Grants financing resources. It will involve a communication planning with 4 workshops and 2 public participatory moments with citizens, companies, public institutions, and municipal bodies.
Climate action Plan – Lisbo 2030	Lisbon Municipality	Identify the current climate vulnerabilities and risks until the end of the century. Define the adaptation options to respond to future challenges – like heat waves, cold weather, intense precipitation and floods

3.5. Spatial structural and strategic profile of the Lisbon Metropolitan Area

This section summarizes an evaluation of the capacity of the spatial structure of the Lisbon Metropolitan Area to regulate heat, for details see Chapter 9. The analysis is based on an identification of the degree to which the composition and configuration of the various spatial systems that compose the territory in question correspond to the capacity to regulate heat, with focus on the existence and network of green and blue spaces (or spaces that could be green and/or blue).

The ecological structure, the system of non-built-up spaces and the space along the infrastructural networks (collectively referred to as ‘regulation systems’) were evaluated from the perspective of the size and inter-proximity of available spaces that could (or already do) perform heat stress mitigation and adaptation services. This evaluation was done according to: 1) their coherence with the conditions of the ground (landform and areas of ecological value); 2) the possibility that the surface hydrographic network and the mobility infrastructure are appropriated ‘spines’ that permeate the entire territory and organize a system of cool spaces for overall regional ventilation; 3) the transformation of spaces in close proximity to amenities and along quotidian routes between residences, work environments, amenities and public transport stops, into cool spaces (porosity); 4) the flexibility towards spatial manipulation allowed by the various land-use/land-cover classes, governance regimes and ownership patterns; and 5) the degree of correspondence between the suggested places for cooling and the current array of protection and nature conservation plans (contingency).

Figure 3.14 and Figure 3.15 represent the synthesis of the Structural Profile for the Lisbon Metropolitan Area and the Municipality of Lisbon respectively, after the evaluation of their interrelationship with the regulation systems according to the five above-mentioned spatial dimensions for heat regulation. The figures show (in shades of green) spaces that are suggested to participate in a regional and urban cooling strategy (in reference to landform, ecological value, and position along the surface hydrographic and mobility infrastructure networks), classified according to the degree of flexibility and cooling capacity (from darker to lighter green). Particular places and spaces of significance are emphasized, namely, the network of industrial and commercial units and the degrees of intensity of built-up space, due to the fact that associated heat regulation measures, as well as the overall strategy, has to consider possibilities of transformation of the economic sector and infusion of cooling devices within urbanized areas. Finally, a correlation is drawn between said spaces and their governance and ownership regimes.

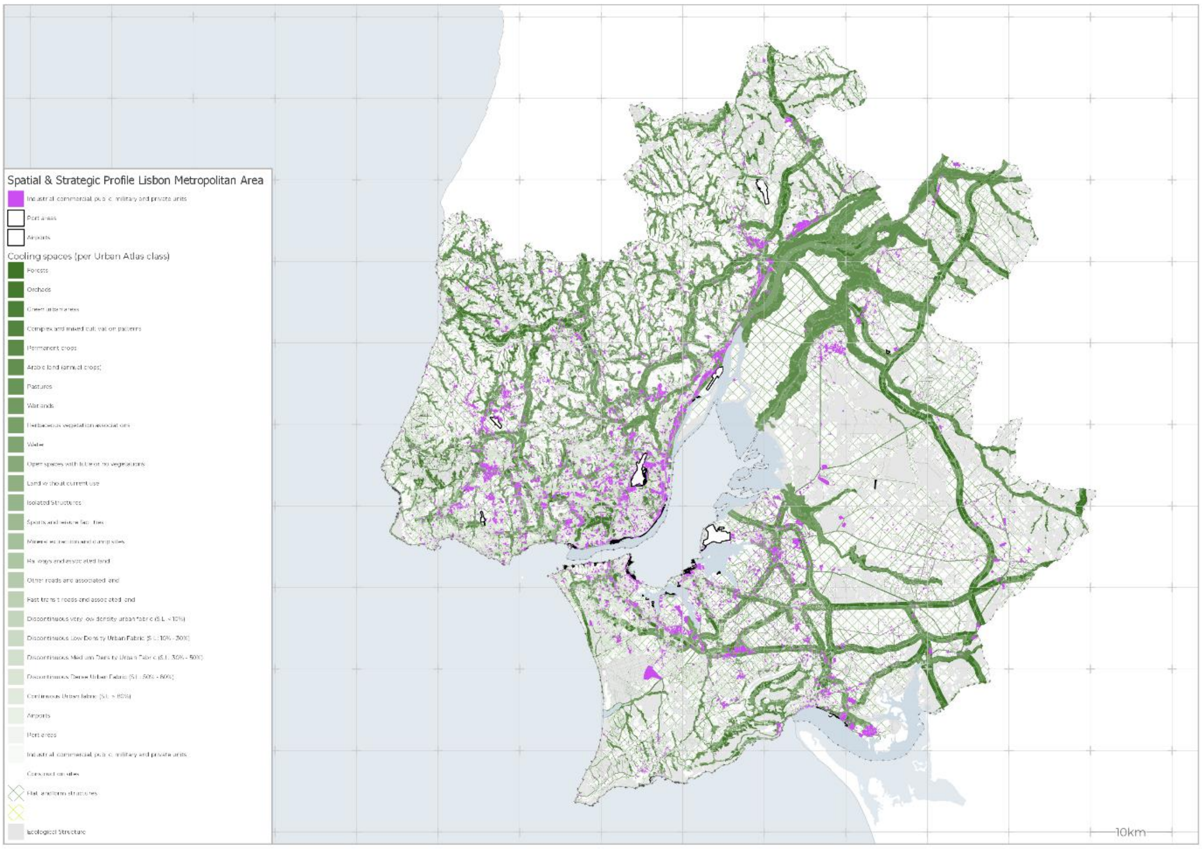


Figure 3.14 Strategic Profile for the Lisbon Metropolitan Area for heat stress regulation, image BUUR/PoS 2022.

Figure 3.15 Strategic Profile for the Municipality of Lisbon for heat stress regulation, image by BUUR/PoS 2022.

At the scale of the Lisbon Metropolitan Area what stands out is the imperative for the reorganization of the patterns of existing agricultural (cropland and pasture), land uses and land covers, as well as areas of herbaceous vegetation that rest primarily on flat landform structures (and populate the largest extent of the region), so that they incorporate higher degrees of intense vegetation. The areas where the agricultural sector is prevalent are facing a demographic reorganization and, consequently, an increase in the risk of desertification and wildfires, exacerbated by and increasing the risk of heat stress. Subsequently, the utilization of the mobility and surface hydrographic systems as carrying structures for a territory-wide cooling project is evident, thanks to their high degree of territorial penetration and their position across areas of ecological value. At the same time, the greening of the valley structures that rest primarily at the northern part of the Metropolitan Area presents itself of strategic importance (particularly due to the high presence of settlement patterns). Finally, the significance of the adaptation of the network of industrial and commercial units, transportation nodes, as well as is the infusion and retrofitting of cooling devices within the urbanized landscape (according to the degree of built-up intensity) completes the picture.

For the scale of the Municipality of Lisbon, the emphasis is on the correspondence between those spaces that participate in the everyday life of the inhabitants and visitors to the city, and the governance and ownership systems. It has already been argued that the exodus from the countryside towards the urban cores, as well as the influx of tourist populations, increase both the risk of exceeding the capacity of the region to mitigate and adapt to higher temperatures, as well the overall exposure of populations to heat stress. As such, there is a need for embedding cooling measures in close proximity to and together with places of public significance, namely, amenities, tourist spots, health service provision buildings, public transport stops, as well as general residential areas. The above is illustrated in Figure 3.15, as is their correspondence with governance and ownership patterns. While the current system of green spaces exhibits a high degree of adequacy in reference to heat regulation, the network itself needs a higher level of retrofitting along the mobility infrastructural network (that corresponds to that of the entire Lisbon Metropolitan Area). While it could be possible to be fill the gaps thanks to the existence of large non-built-up spaces, such efforts might stumble upon difficulties related to management regimes, private ownership, or inflexible uses.

3.6. Insights from stakeholder engagement meeting

3.6.1. Workshop purpose and setting

The first PROVIDE Stakeholder Engagement Meeting in the Iconic City of Lisbon Metropolitan Area (AML) was held on 4th March 2022 at the AML office, in Lisbon. Invitations to meeting were co-ordinated between the PROVIDE team and the AML, who sent out an official invite on behalf of the project to all members of the standing Metropolitan Working Group on Spatial Planning, Environment and Urbanism (Grupo de Trabalho Metropolitano Ordenamento do Território, Ambiente e Urbanismo). These included both decision-makers and technicians/planners in all the 18 municipalities that comprise the AML. The meeting took place in-person, with some participants connecting online. The meeting language was Portuguese with the exception of the online presentations by the PROVIDE team and direct questions to the presenters. There was a total of 26 participants (four online) covering 14 of the 18 AML municipalities. The meeting was supported and moderated by three members of the PROVIDE FC.ID team, who also provided notetaking. Additional AML technical local staff supported the meeting.

3.6.2. Climate risks and current adaptation efforts

After some introductory words and an opening address by the AML's Secretary Filipe Ferreira, which addressed some of the current climate-related challenges in the area, participants were introduced to PROVIDE, including the project's expected results and key concepts, such as overshoot pathways, reversal of the impact chain, limits to adaptation, critical thresholds and overshoot proofing. Participants were asked to share their perspective on how climate change is affecting their municipalities and how they are currently framing climate action across sectors and territories. There were comments and a general agreement that all the questions were valid and interesting for their work but that it was difficult to respond directly without further information on how thresholds and limits would be treated considering the current strategies already in place. The notion that impacts may be different before and after overshoot was noted by the participants as quite interesting and that it was something they had not thought about before.

A presentation from the AML illustrated the key elements of the current climate adaptation policy and practices in the region, with a particular emphasis on the Metropolitan Climate Change Adaptation Plan (PMAAC-AML). João Lopes from AML presented the climatic context of the plan, based on the definition of eight homogeneous morphoclimatic units that covered the entire region, and the local climate projections until 2100 (temperature and precipitation related variables) used to assess current and future climate vulnerabilities and risks. He noted that, in fact, it was not known if the temperature rise in the region was already above the 1.5ºC threshold set by the Paris Agreement, acknowledging that it was interesting to think about how this could frame the local adaptation context. It was noted that 14 (out of 18) municipalities already have their own

Municipal Adaptation Strategy or Plan, with the remaining four being under development, which provides a comprehensive climate action coverage in the region.

During the follow-up discussion participants from three neighbouring municipalities that are working together, explained that the application of scenarios is relevant for territorial plans at the municipal level. For example, scenarios have been already developed for agriculture and tourism, but overshooting scenarios were never considered, even if their existence is known, noting that this kind of scenarios would be difficult to introduce in this phase of the process. However, they all agreed that this is an interesting perspective, especially considering the notion of (ir)reversibility of impacts and associated consequences for adaptation (loss of beach area and was given as an example). One participant asked how to measure and communicate where we are (locally) in relation to the overshoot trajectories (globally).

3.6.3. Overshoot, opportunities and constrains to adaptation

During the meeting's several discussion moments, participants were asked to identify major opportunities and constrains to adaptation, under different climate and socio-economic change trajectories, including the newly introduced overshoot pathways.

3.6.3.1. Opportunities

Several participants noted that it would be interesting to have a clear guidance on how to integrate adaptation measures at the local level. This would promote a better integration of climate change scenarios with territorial decision-making. In this context, one participant added that the recently approved Climate Framework Law (Lei de Bases do Clima, 31st December 2021) will make it mandatory that all municipalities to produce climate action plans (mitigation and adaptation) within two years if they do not have them already. She noted that municipalities will need to connect these plans with all other existing Territorial Management Instruments (IGTs - Instrumentos de Gestão Territorial), which creates a new reality and raises questions about how municipalities will be able to incorporate all relevant variables. AML noted that the ongoing PMAAC-AML monitoring and governance mechanism can be seen as a platform to exchange knowledge. The 47 projects from 7 municipalities that were already surveyed are an example, and they expect that more are to come about soon from the municipalities that have ongoing or concluded adaptation plans.

3.6.3.2. Constrains

Participants recognized that they face difficulties in the area of adaptation and even with clear information about the importance of climate change, there are always problems in a context of strained human resources, especially among technicians in the fields of urbanism and environment. Additionally, technicians in the field must collaborate with a fixed governance structure, making implementing changes challenging. As a follow-up several participants alluded to the need to collaborate directly with communities (and not in a closed circuit) so that adaptation action is well accepted and relevant, which adds another level of complexity when using many scenarios. One participant explained that the regional governance model is not flexible and may present some problems of articulation, noting that what is important at this stage is to implement the measures and develop what is in the plans. One participant pointed out a technical limitation to address heat waves in urbanized areas, especially considering the new regulation on 'Urban trees.' This regulation will require the planting of different amounts and species of trees by municipalities over the next two years, but there are areas where it is exceedingly difficult to apply proper arborization solutions. It would be important to understand how to adapt some "grey areas" without trees in city centres by analysing what parts of the surrounding area could be used to plant trees (and if this would ameliorate the heat in those areas). One participant noted the difficulty of promoting shaded areas in historic centres because there is no available space for trees or because there is resistance from conservation services that want to protect the architectural heritage. Some municipalities do have large forest areas but not in the urban centre or where they are (really) necessary. Additionally, some tree species may be disappearing, making it important to understand which species could/should be introduced (with care not to introduce aggressive invasive species). One participant mentioned that most of the currently available scenarios are focused on municipal territories and not in the region as a whole. Several participants expressed difficulties in the definition of thresholds, especially if there is a need to define a specific value or limit (e.g., number of hot nights) or define information within specific sectors.

3.6.4. Tools and spatial planning

One participant noted that to accomplish the objective of incorporating the spatial profile with climate information, risk and exposure maps (or layers) need to be overlaid onto existing Territorial Management Instruments. In particular, Municipal Director Plans (PDMs – Planos Directores Municipais) are planning layers of interest for this work. She added that risk is being considered in most cases, but the mapping is done without data from the Territorial Management Instruments. This is done separately and then risk mapping is incorporated into the planning instruments. Participants agreed that the mapping developed by PROVIDE can be useful to calibrate the development of the Territorial Management Instruments and to validate if the use of a certain territory parcel is appropriate in terms of climate change adaptation. Exposure factors and soil data are also relevant to be added to the mapping. Participants agreed that tools like the Dashboard will be necessary in the near future, and that the work presented should be integrated (overlaid in a first approach, analysed later) with the scale of the Municipal Director Plans. They suggested that a good approach could be the overlaying of cartography about the regulatory aspects with climate change risk scenarios, which could lead to a practical application of the concepts of PROVIDE in the adaptation planning context of the AML. One participant pointed out (and was backed up by several others) that the threshold context and definition are relevant to define the level of priorities to be tackled in overshoot adaptation. Overall, participants suggested that this is relevant as a new way of presenting information to promote the establishment of priority levels, that necessarily need to take Territorial Management Instruments into account. And added that a tool like the Dashboard linking the assessment with the decision-making process will be important.

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4. The Upper Indus Basin and Islamabad

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4.1. Country outlook

Pakistan is a developing nation with a rich culture and remarkable history of resilience, growth, and evolution. It is located in the northwest of the Indian subcontinent in South Asia. Pakistan is a land of diverse ecology, varying local climates, and an abundance of natural resources. It is the world's fifth most populous country, comprised of various ethno-linguistic groups with a population growth rate of 2.4% (GoP, Brief Regarding Census-2017, 2017). One third of this population currently resides in urban areas. The country is predominantly agrarian relying heavily on its climate-sensitive natural resources. The varying topography features plains and plateaus, deserts and forests, mountains and glaciers, and rivers and lakes. The region that comprises the modern state of Pakistan was the site of several ancient cultures and oldest civilizations in the world, including the 5000-year-old urban life of Indus Valley and the 8,500-year-old Neolithic remains of Mehrgarh (Coningham & Young, 2015). The country's dynamic history also contributed to shaping its diverse culture as an eclectic blend of various regional and global influences, which is evident from its architecture, music, art, literature, and cuisine.

Table 4.1. Selected national numbers (Pakistan Economic Survey 2021).

Population in 2020	**215 million**
Population density	270 per km^2
Population falling in the age group 15 to 29 years	27%
Most significant employer	Agriculture (38.5%)
Annual percentage growth for agriculture, industry and services 2020-2021	2.77%, 3.57% and 4.43% respectively
GDP dollar term	299 billion USD
Economy FY 2021	5.37 % growth

4.1.1. Governance

Since its independence in 1947 after the partition of the British Indian Empire, Pakistan has faced its share of turmoil, conflicts, wars, and political strife. Initially Pakistan consisted of an eastern and a western section, but political stifling and economic instability further escalated the conflicts which led to the separation of eastern part in 1971, becoming what we know today as Bangladesh.

The administrative units of today's Pakistan comprise four provinces – Punjab, Sindh, Balochistan, and Khyber Pakhtunkhwa – and two autonomous territories – Azad Jammu and Kashmir and Gilgit-Baltistan, hosting a range of multilingual and multi-ethnic populations. The city of Islamabad has its own status as a 'Federal Capital Territory'.[16] Currently in place is the constitution set up in 1973 (25 amendments), which stipulates that the country is a democratic parliamentary federal republic.

There are three levels of government: national, provincial, and local. The national level governance of Pakistan is setup as a federal parliamentary republic with a bicameral legislature consisting of the National Assembly (directly elected members plus reserved representors for women and minorities) and the Senate (a permanent legislative body elected by members of the Provincial Assemblies)[17].

The President of the country is mainly a ceremonial figurehead. Under the present constitution, all powers are vested in the Parliament, the Prime Minister, and the Supreme Court, with powers and duties of other authorities defined by Acts of Parliament. Executive power is vested in the Prime Minister, elected by the national assembly and the federal cabinet, appointed by the president upon the advice of the prime minister.

Pakistan's four provinces enjoy considerable autonomy and have their own elected provincial assemblies and governments. Each has a governor, a Council of Ministers, and a provincial assembly whose members are elected by universal adult suffrage. Following the 18th amendment to the Constitution, in 2010, non-central functions were relegated to the provinces after devolution of power from the federal level to the provincial level. Local government is made up of various district, municipal and village councils. The federal government retains central functions of maintaining military relationship, conducting foreign policy, and circulation of money[18].

4.1.2. Economy

Pakistan is a lower-middle income country, with a GDP per capita of USD 1,190 in 2020 (WorldBank, GDP per capita (current US$) - Pakistan, 2020). As per the report for Fiscal Year 2020-2021 (FY20-21), Pakistan experienced a GDP growth of 5.37%, with major contributing economic sectors being services (61.7% of GDP), agriculture (19.2%), and manufacturing industry (14%) (GoP, Pakistan Economic Survey 2020-21, 2021).

Since its formation, Pakistan has struggled to achieve political and economic stability. Currently too, the situation is not much different. Weak governance capacity and slow economic growth pose serious challenges in catering to the rapidly growing population of the country, as reflected by the Human Development Index 2020 where Pakistan ranked 154th out of 189 countries (UNDP, Human Development Report 2020, 2020). Challenges like infrastructure deficit and energy shortage severely limit the development in Pakistan.

Furthermore, Pakistan has a fossil fuel driven energy sector and imports one third of its energy resources in the form of oil, gas, and coal (Malik, Qasim, Saeed, Chang, & Hesary, 2019). Resultantly, the economy is exposed to the shocks of hikes in international fuel prices. Ever increasing trade deficits and continuous capital outflows have led to a steep depreciation of Pakistani currency against the US Dollar. This rupee depreciation, along with the foreign debt repayment in turn, has stressed the liquid foreign reserves of the

[16]The Gilgit Baltistan and Azad Jammu and Kashmir are disputed territories as India also lays claim to these regions. These two regions are neither provinces nor states although in 2021 a bill was prepared to provide GB with provincial status. However, such a move is still pending. These regions are termed as Administered Areas.
[17] https://www.thenews.com.pk/print/983447-inclusive-governance
[18] https://www.countryreports.org/country/Pakistan/government.htm

State Bank of Pakistan, exposing the long-standing volatility and fragility of Pakistan's economy.

Additionally, the crises of the COVID19 global pandemic affected Pakistan's economy like it did every other economy. The overall economic growth rate in Pakistan contracted (-) 0.47% during FY2019-20.

Under such harsh circumstances, climate change exacerbates the development issues of Pakistan. Although the country contributes to less than 1% of the global GHG emissions, it is impacted disproportionately by climate change conferring huge economic and human losses. As per the long-term Global Climate Risk Index for the period 1999-2018, Pakistan ranks the 5th most vulnerable country to climate change, and 3rd in terms of economic costs (~USD 3.8 billion from 173 extreme events) (GermanWatch, 2021). It is imperative for a vulnerable and developing country like Pakistan to invest in climate resilience measures. However, due to lack of financial and institutional capacities, Pakistan has low readiness despite its high vulnerability. The Notre Dame Index Global Adaptation Index ranks Pakistan as the 32nd least ready country out of 181 countries to tackle climate change (ND-GAIN, 2019). The country needs serious efforts towards the path of sustainable development. However, the uncertainty of the changing climate makes it difficult for its struggling economy to meet the forced adaptation needs and make significant leaps in the right direction.

4.1.3. People of Pakistan

Pakistan is the world's 5th most populated country with an estimated 215 million people in 2020. Most of the Pakistani population resides along the Indus River, particularly due to concentration of agrarian activities in those regions (World Bank, Urban/Rural Population of Pakistan, 2019). The agriculture sector provides livelihood to more than half of the population (GoP, Pakistan Economic Survey 2020-21, 2021). However, there is high level of inequality between income quintiles (Haider, 2021). Some relevant numbers are also listed in Table 4.2.

Pakistani population is majorly young but lacks direction for playing an active role in nation building. The population practices a diversity of religions, cultures, and customs. Several languages are spoken in Pakistan. Even within a province, variance between languages and/or dialects is found.

Unfortunately, the health status of Pakistan's population is not optimal. Many children in Pakistan suffer from malnourishment, stunting, and wasting (UNICEF, National Nutrition Survey Pakistan, 2018). The main reasons attributed to such a drastic situation is food insecurity, disease and illness, and lack of health services. These issues are further exacerbated by the challenges of climate extreme events like floods and droughts. Moreover, sanitation and hygiene among the affected population is also compromised as a result of climatic events facilitating infectious disease transfer, such as diarrhoea, and vector-borne diseases, such as dengue and malaria.

Table 4.2. Overview of Pakistan's population (GoP, 2021) (Haider, 2021) (UNICEF, 2018) (World Bank, 2019).

Percentage population residing along River Indus	63%
Percentage population with livelihood within the agriculture sector	65-70%
Percentage population of youth (15-29 years)	59%
Percentage population experiencing multidimensional poverty	39.2%
Literacy rate of Pakistan	62.3%
Number of illiterate population in Pakistan	60%
Children under five underweight (percentage population)	28.9%
Children under five suffering from stunting (percentage population)	40.2%
Children under five suffering from wasting (percentage population)	17.7%

4.1.4. Geography and topography of Pakistan:

Pakistan holds an important geo-strategic position in South Asia, bordering Afghanistan, China, India, and Iran, and is bound in the south by the Arabian Sea. The region has been the centre of economic and military activities in the recent past. While this geo-political position has brought Pakistan opportunities to avail, it has also brought risks to evade. Pakistan was deeply affected as it was used as a route into the land-locked Afghanistan during the War on Terrorism. Simultaneously, Pakistan has benefited from sharing borders with the great economic power of the People's Republic of China. The China Pakistan Economic Corridor (CPEC) holds great potential to boost country's trading sector. Under CPEC, the Gwadar port located close to Iranian border, adds to the strategic leverage of the country. The port opens new trade routes to the otherwise land locked regions of Central Asia, boosting regional connectivity as well as growth of global trade and commerce (Rafiq, 2020).

In geographic design, Pakistan holds a unique and diverse blend of landscapes. It is the 33rd-largest country by area, spanning 881,913 square kilometres (340,509 square miles), and consists of plains, deserts, forests, plateaus, coastal areas, mountains, and glaciers (Fig. 4.1).

In the north, the Northern Highlands constitute of an array of mountainous ranges including the Karakoram, Hindukush and the Himalayan Ranges. The region is home to 7,253 glaciers as well, thus termed as the 'third pole' (Craig, 2016). It is also famous for the number of high mountain peaks, since five of the 14 mountains over 8,000 m are in this region, including the 2nd highest, K2. The region, therefore, attracts a lot of tourists' attention for extreme sports. The Balochistan Plateau consists of southern mountainous regions of Pakistan notably the Sulaiman Range.

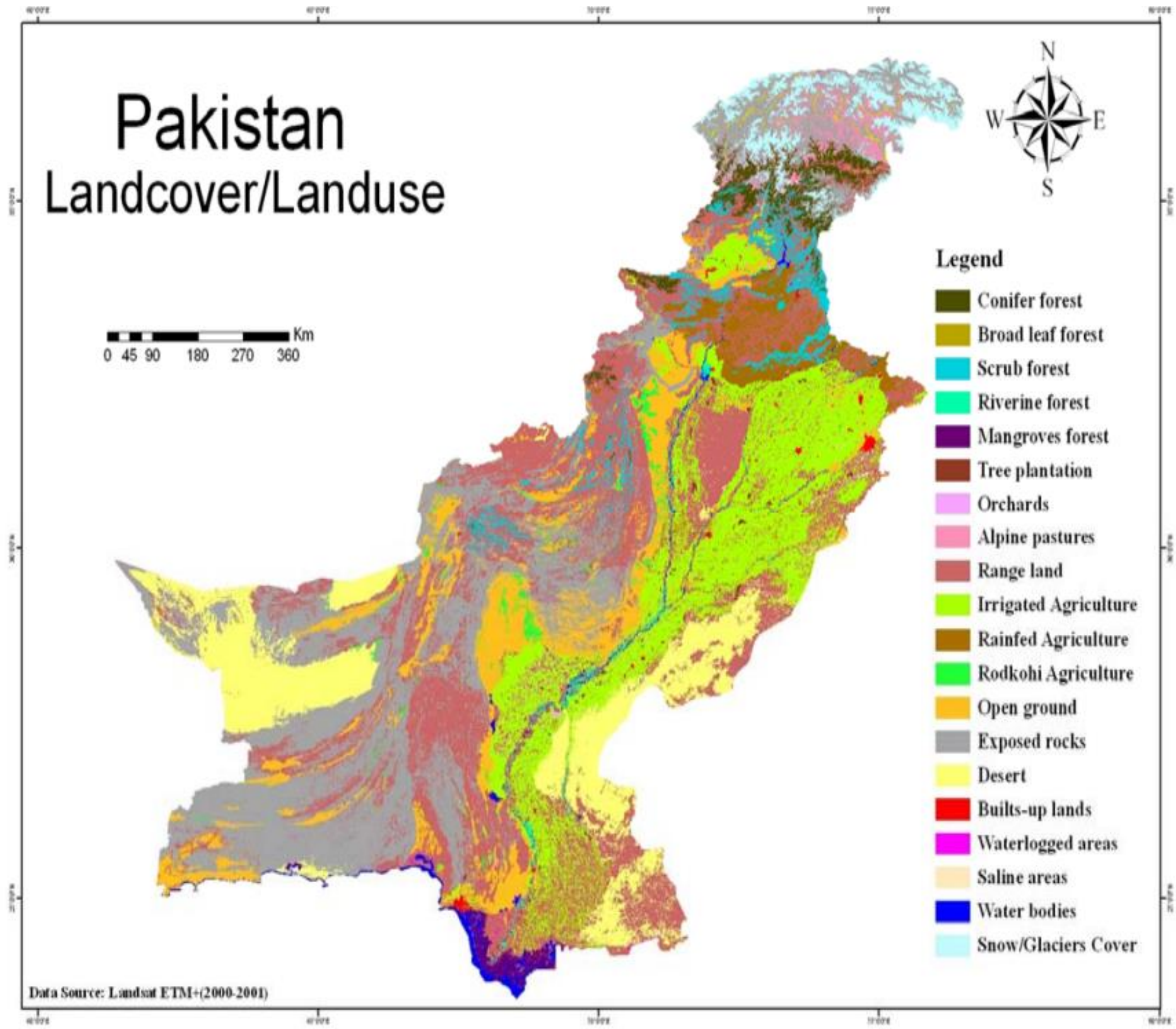

Figure 4.1. Land use of Pakistan.[19]

The Indus catchment area, spread along the entire length of Pakistan, is a vast expanse of fertile land aggressively cultivated for wheat, rice and cotton, among other crops. The plain is further divided into upper and lower Indus Plains or Basin. The upper Indus Plain drains the five tributaries Chenab, Jhelum, Sutlej, Ravi, and Beas into the Indus (Fig. 4.2). In the lower Indus Plain, the Indus River forms a single river without any tributaries. The south-eastern part of the Indus Plain constitutes of the Tharparkar desert, an extension of the Thar Desert.

[19] Note regarding this and the following maps in this chapter: The political map of Pakistan was changed in 2020 to indicate disputed region of Kashmir between India and Pakistan, final status of which will be decided in accordance with the UNSC resolutions.

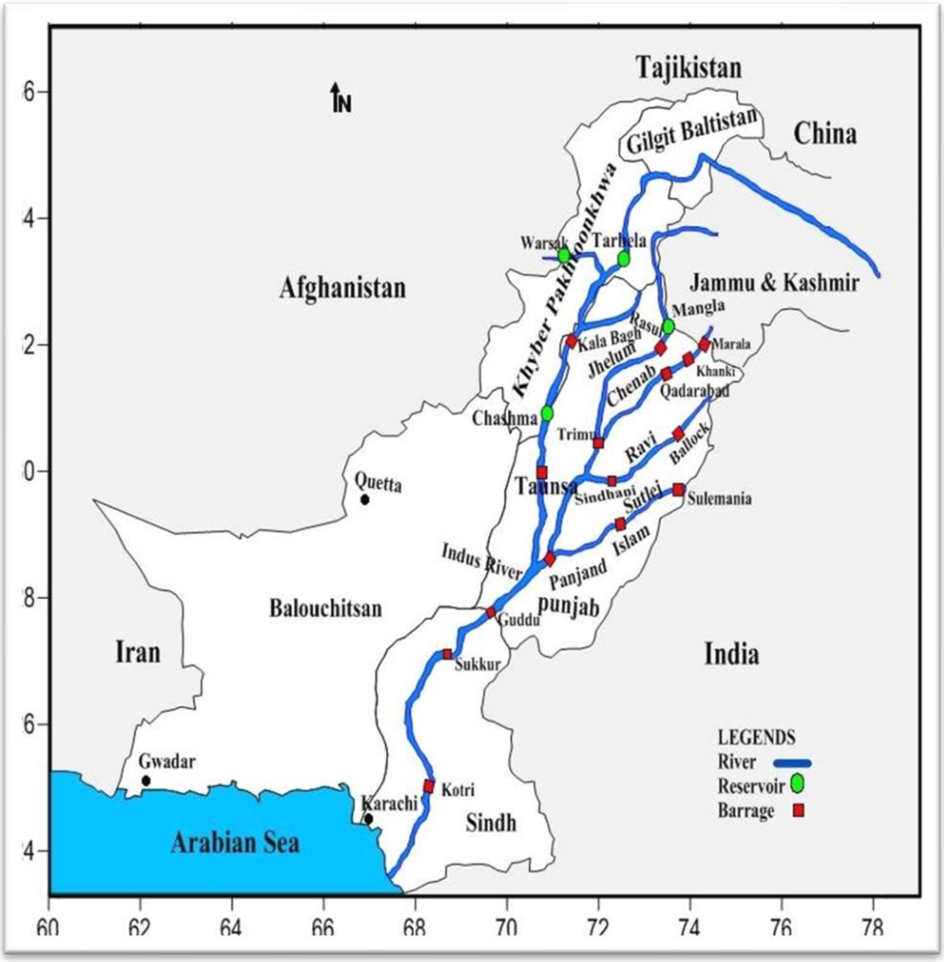

Figure 4.2. The Rivers of Pakistan.

4.2. The Indus River Basin

The Indus River, also called The Mighty Indus, is one of the longest rivers in the world. It originates on the Tibetan plateau and continues to traverse and meander through parts of China, India, whole of Pakistan with some parts also crossing the Afghan border. The end point of the river is at the port city of Karachi in the south of Pakistan where the river meets the Arabian Sea (TheThirdPole, 2021). The total length of this journey is around 3,200 km. Around 200 million inhabitants' dwell in the Indus River Basin where a significant number of livelihoods are sustained by the river basin.

The Indus Basin is an amalgam of diverse landscapes and covers a total of about 518,000 square km. It has ice capped mountains and glaciers, rocky and hilly mountain terrains, cultivable plains, rivers, forests, pastures. Owing to this diversity, various benefits are reaped from it, including water sourcing, housing, crop production, sustenance of settlements. An overview of the land and land use of the Indus Basin is shown in Figure 4.3.

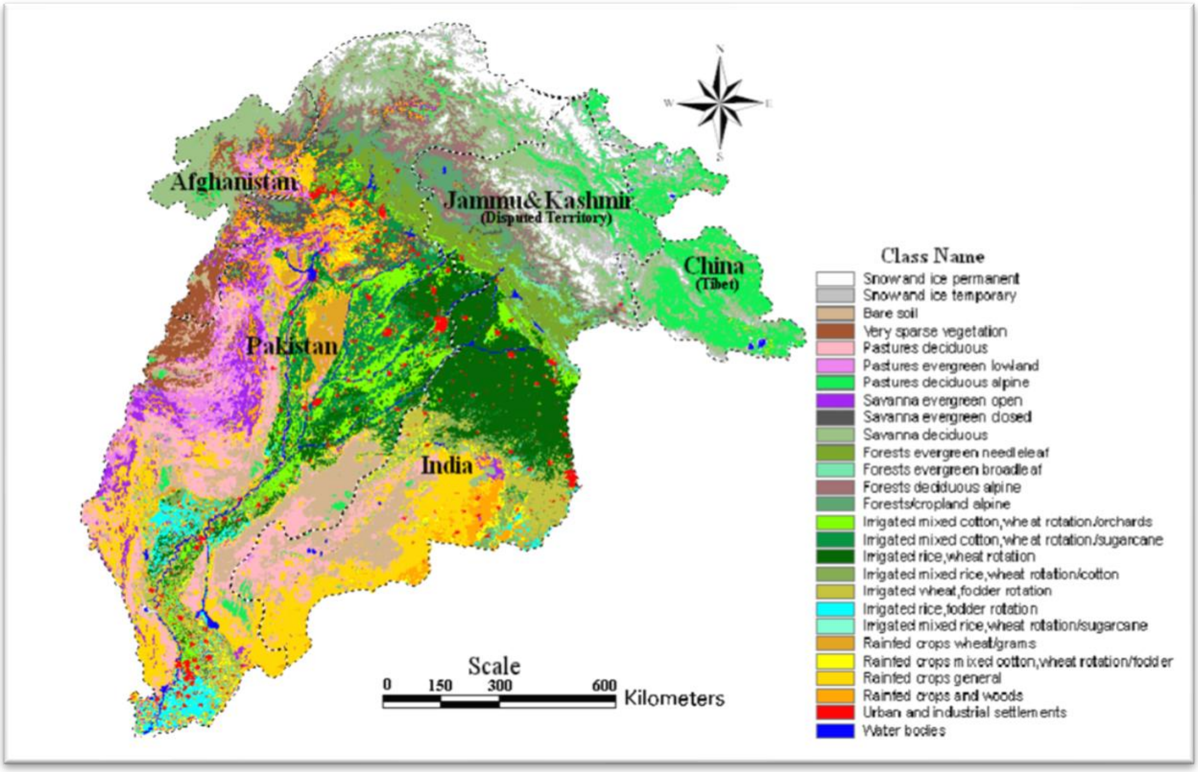

Figure 4.3. Land use and land cover map of the Indus Basin (Understanding water resources conditions in data scarce river basins using intelligent pixel information, Case: Transboundary Indus Basin, 2012).

The Indus River is rich in biodiversity and the basin is home to a plethora of wildlife. There are 25 amphibian species and 147 fish species in the Indus River Basin, signalling to the rich ecological systems it sustains. Furthermore, the rare and endangered mammal, the Indus River Dolphin also exists only in the Indus River Basin. The 7th largest mangrove forests exist in the Indus River Delta and extend to the Arabian Sea.

Most of the Indus Basin has fertile arable land, and 80% of this irrigated basin land is located in Pakistan (Kakakhel & Mohtadullah, 2015). The Indus River provides the major share of fresh-water resource in the country. Almost 90% of the irrigation water needed for agriculture is derived from the Indus River and its tributaries, fed by glacier melting and monsoon rains. It is estimated that 9% of the ~46 million tons of wheat, 15% of the ~19 million tons of rice, and 75% of cotton produced annually in the basin can be credited to glacier and snow melt. However, intensive groundwater pumping during dry seasons has introduced salinity in some areas, especially in the lower Indus Basin through the provinces of Punjab and Sindh where 55% of total irrigated land is affected by salinity (ICIMOD, The Indus Basin, 2020).

Other than food production, water from Indus River plays central role in energy generation, domestic use, industry, tourism, and fishing. Since 80% of the Indus water flow is mainly fed by glacier and snowmelt (Ahmad, 2019), lives and livelihoods of millions are extremely vulnerable to the climate change, which has hastened the pace of glacier melt under rising temperatures. As the glaciers retreat, more water flows into the river exceeding its holding capacity and resultantly, floods the nearby settlements. Climate change is persistently altering the flow of the Indus River, which in turn threatens livelihood and food security of inhabitants in the region.

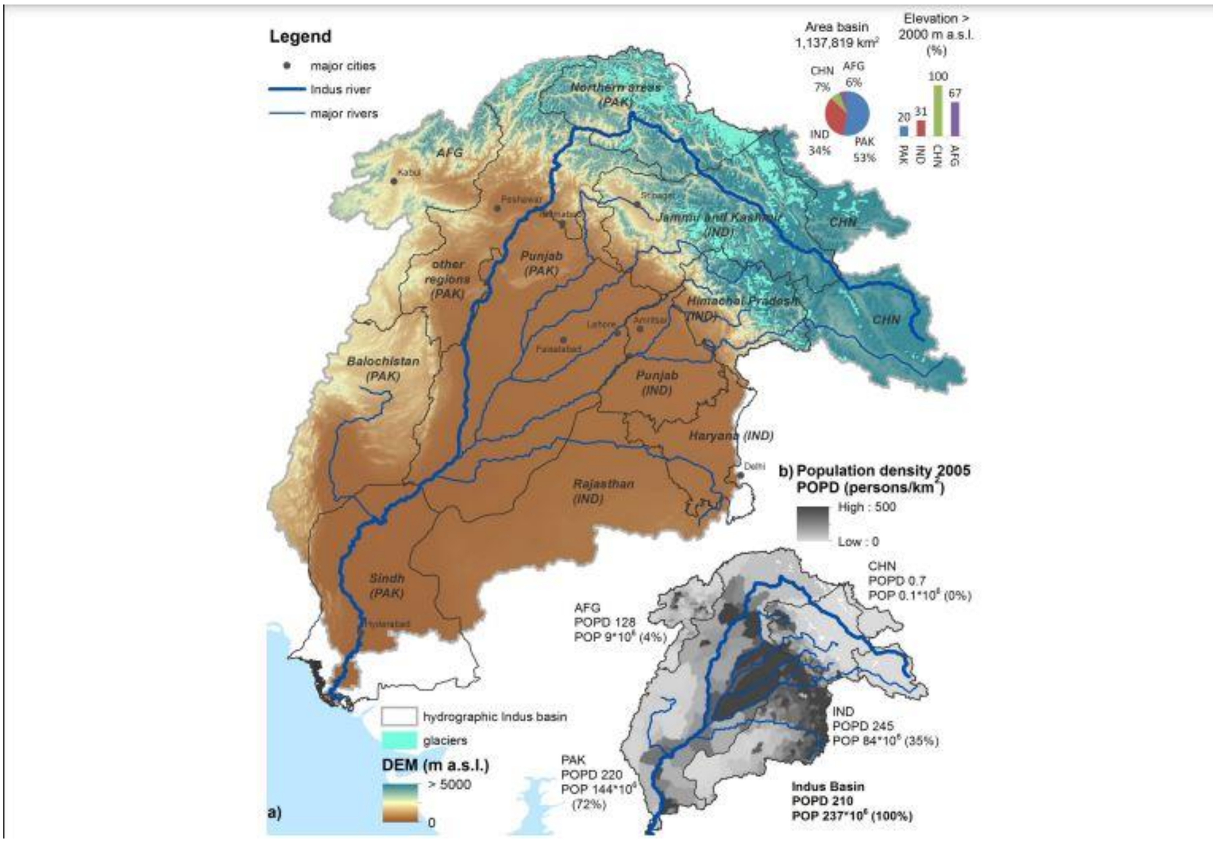

Figure 4.4. Digital Evaluation Model for the UIB, location of the Indus River, political borders, overview of area basin elevation and population density (Laghari, Vanham, & Rauch, 2012).

The river Indus and its tributaries have a trans-boundary nature and often raised conflict between the two neighbouring nations, India, and Pakistan over the share of water used. To resolve the issue, the Indus Water Treaty was signed between India and Pakistan and put in effect in 1960. The treaty essentially states that the three western rivers (Indus, Chenab, and Jhelum) were to be used by Pakistan and the three eastern rivers (Ravi, Sutlej, and Bias) were the exclusive domain of India. This treaty allowed for developing the largest contiguous irrigation network in the world with multiple water works that resulted in massive increase in agricultural output and significantly increased national economy (Mustafa & Wrathall, 2011). However, with increasing water demands for irrigation and power-generation, the tension between the Indo-Pak relations often puts the treaty under threat of violation. This indicates that the climate change in this area is not only impacting the economy, agriculture, food security, human health and ecosystem, but is also a big threat to regional peace.

4.3. Iconic Region: Upper Indus Basin (UIB)

The focus area for PROVIDE is the UIB in the northern part, where the Indus River and its tributaries originate (Fig. 4.5). In Pakistan's geographical context, UIB translates into the region starting from the Gilgit Baltistan (GB) between the mighty Himalayas and the Karakoram Range extending up to Tarbela reservoir (Fig. 4.6). After meandering through the GB, Indus River enters the Khyber Pakhtunkhwa (KPK) province making its way to Attock city in Punjab province. This is the region where first major dams and barrages are constructed on the river in Pakistan including the Tarbela dam and Ghazi Barotha dam (WAPDA, 2011). The Tarbela dam is one of the largest earth-filled dams and was constructed with the aim of providing water for irrigation but later on it was also used for producing electricity. From KPK the river passes into Punjab, Sindh, and then into the Arabian Sea (Abbasi, et al., 2017).

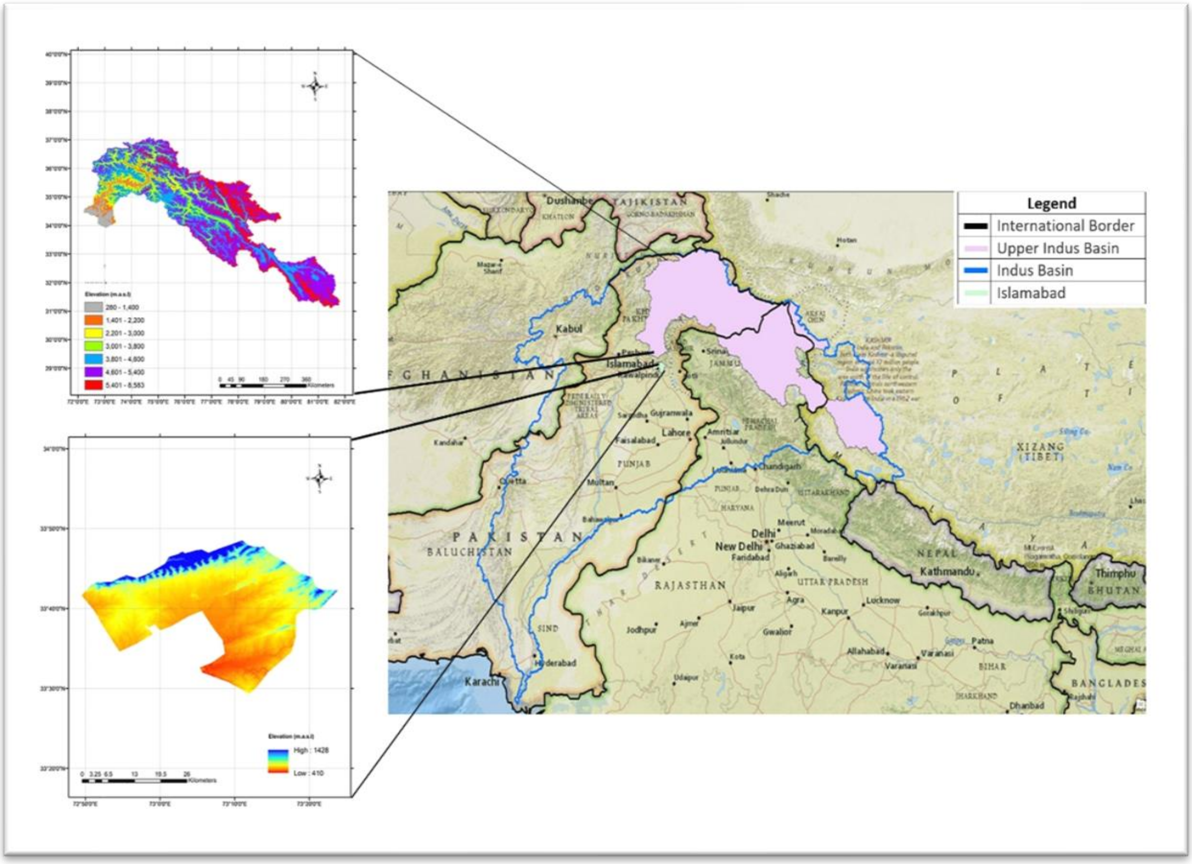

Figure 4.5. The Iconic Region Upper Indus Basin and the Iconic City Islamabad selected for the PROVIDE project (Author's own).

Gilgit Baltistan: GB, famous for its scenic beauty, is a wide and strategic region full of mountains and steep valleys. It is a meeting place of three famous mountain ranges containing some of the world's highest peaks, namely, K2, Nangaparbat and Rakaposhi and numerous beautiful lakes, such as Shandoor Lake, Sadpara Lake, Attabad Lake and Gasho Lake. Siachin, the longest glacier in the Karakoram and second longest in the world's non-polar areas, is also located here.

GB has 2% cultivable land. Agriculture is the main source of sustenance for 80% of the population by which cereal crops, fruits, vegetables, and fodders for livestock are produced. However, under climate change, water availability will face variations thus affecting the livelihood of majority population. The whole of Pakistan is vulnerable to seasonal variations in the region as the HKH glaciers and precipitation in this area are the main source of water for the country.

Khyber Pakhtunkhawa: The KPK is the northwest province of Pakistan, home to multi-ethnic and multi-lingual population of over 30 million, 80% of which resides in rural areas. KPK has suffered socioeconomically through the war on terror in the region. There are 1,130 named mountains in KPK. In the summers, the scenic beauty of the mountain and relatively cooler temperature attract numerous local tourists. The province has faced the brunt of climate change in Pakistan experiencing multiple episodes of floods, heat waves, and glacial lake outburst floods.

The people of the UIB are challenged by endemic poverty, in both rural and urban settings. They are also becoming increasingly vulnerable to the socio-ecological challenges, climate change being a major cause. The vulnerability is largely driven by poor water management practices and policies which currently focus on supplying water to different users without factoring in the financial, social, and ecological/environmental costs. UIB has become increasingly vulnerable to water stress overall, which is expected to affect dependent communities.

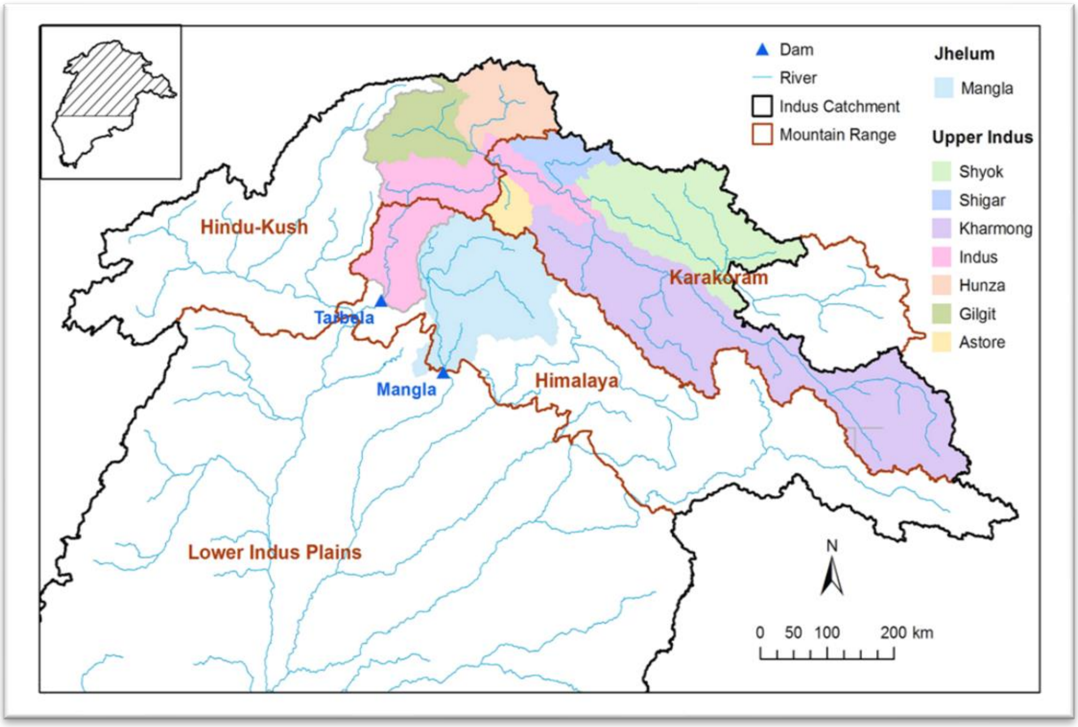

Figure 4.6. Upper Indus Basin and sub basins (Charles et al. 2018).

4.4. Iconic City: Islamabad

The Iconic City in focus for PROVIDE is the federal capital of Pakistan – Islamabad – as a case study of urban life in the region. The city of Islamabad lies at the foothills of Margallah, an extension of the Himalayas, with some features as shown in Fig. 4.7. It houses approximately 2 million people with a population density of 2,2017 person/km2, more than 50% in the urban area (Pakistan Economic Survey 2021). The percentage of educated population in the federal capital is 88% due to the above par higher education standards and universities. The city is around 100 km to the east of the Ghazi Barotha dam on the Indus River in the northwest of the country. Islamabad did not evolve like other normal cities of the country, but was a planned city designed to replace the first capital Karachi, which was turning into a congested urban area with limited space for further expansion and increasingly higher living costs.

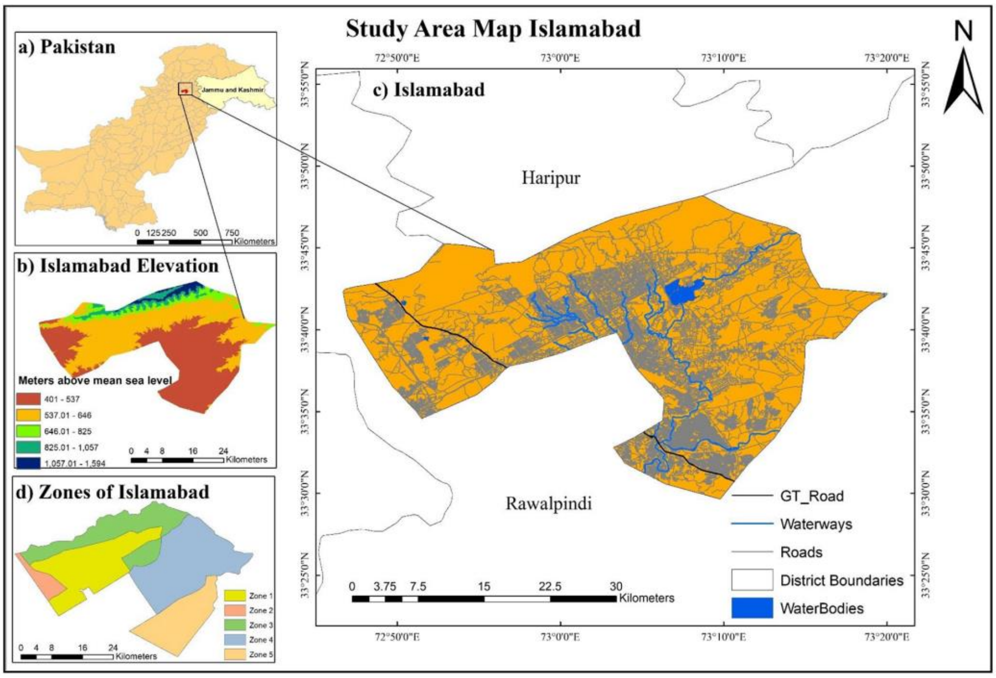

Fig. 1. Study area map. a) The administrative boundaries map of Pakistan. b) Elevation map of Islamabad. c) The map of Islamabad showing the roads, waterways, and water bodies, GT-Road within Islamabad boundary and the boundaries of the surrounding districts. d) The map of zones of Islamabad.

Figure 4.7. Location map of study area, Islamabad (The spatiotemporal dynamics of urbanisation and local climate: A case study of Islamabad, Pakistan, 2021).

A commission comprised of urban and master planners reviewed various sites and selected the current location for the city in 1959.The administrative boundary was termed as Islamabad capital territory and the Capital Development Authority (CDA) was established to plan and maintain the new capital. The master plan of the city was developed by Doxiadis Associates in 1960. Although the authority was sanctioned to conduct a review after every 20 years to access the master plan's compatibility with changing requirements and scenarios, only a few reviews have been made and without any significant modifications to the original plan.

Islamabad has faced significant **urban growth** and expansion in the past two and a half decades and has evolved into the 9th largest city of the country in terms of population. A study conducted to assess urban growth patterns in Islamabad between 1998-2018 shows that the growth patterns of Islamabad can be divided into four categories; (1) *unplanned village sprawl and leapfrog* of surrounding villages upgrading to a town, (2) *planned urban expansion* as per the master plan, (3) *fringe sprawl* characterized by conversion of various land-use types at the urban fringe to buildings and roads, and *infilling* by converting the non-urban to urban land, hence increasing building density and finally (4) *merger* of neighbouring small towns and Islamabad, now considered as the same unit as in Fig. 4.8. (Liu, din, & Jiang, 2021).

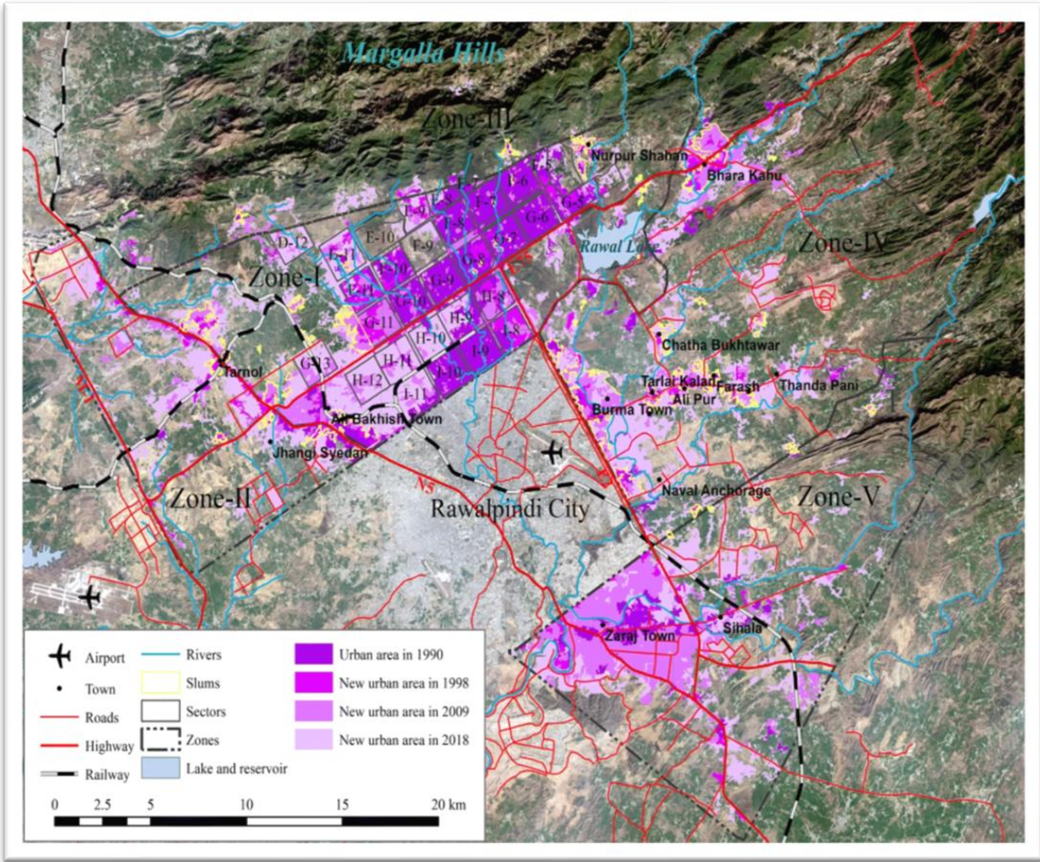

Figure 4.8. Urban growth of Islamabad between 1998 and 2018 (Liu, et al., 2021).

Another recent study provided the change in land use and land cover areas as in Table 4.2.

Table 4.2. LULC change in Islamabad during 2013-2019. (The spatiotemporal dynamics of urbanisation and local climate: A case study of Islamabad, Pakistan, 2021).

	Area (km^2)		Percentage (%)		Change
	2013	*2019*	*2013*	*2019*	
Built up area	87.66	187.11	10.36	22.12	113.46% increase
Vegetation	204.17	135.98	24.14	16.08	33.39% decrease
Bare soil	548.32	517.18	64.85	61.17	5.67% decrease
Water body	5.31	5.17	0.62	0.61	2.57% decrease
Total	845.46	845.46	100	100	

It is evident that the development and urban expansion of Islamabad has not been optimally planned and requires reforms. CDA acknowledges this fact and is of the opinion that this inertia in introducing planning and development reforms for the city has resulted in haphazard and unsustainable development. Furthermore, compromises in land use and zoning rules led to the relaxation of building height and floor area rules. As a result, unregulated and illegal encroachments have taken place in many areas throughout Islamabad (UN-HABITAT, 2014). The living conditions of the city are being affected by this rapidly changing land cover and overall rising temperatures, resulting into frequent occurrence of extreme events.

The proportion of **water supply** for the federal capital comes from the following sources: 48% from Simli Dam, 12% from Khanpur Dam, 35% from tube-wells and 5% from waterworks like Shahdara, Noorpur, Korang and Saidpur (DAWN, 2016). Peak accumulative water production from these sources varies from 62 to 84 million gallons per day (MGD), (CDA, Conduction of water from Indus River system of Tarbela Dam to Islamabad and Rawalpindi, 2017). According to Capital Development Authority, Islamabad, average demand for the city is 246 MGD and faces water shortage throughout the year. To address this shortcoming, the federal government has decided to bring in 100 MGD from Ghazi Barotha dam (roughly 100 kms from capital) to Islamabad.

Population growth in the capital has been a defining characteristic of its urban growth and has produced a 100,000-unit backlog for housing units, which is estimated to increase to 250,000 units. Compounding the issue, CDA has not been able to launch any new residential sector to house this additional population. The last such sector was launched in 1989 but since then no further development in sectors has been witnessed (Chaudhry, Ahmed, Jalil, & Hasan, 2020). Flawed land use and consistently accelerating population in the capital can only be managed if the zoning laws are reformed and regularly updated as per the needs of the area.

Mobility in the city becomes a stark issue, as is the case in unplanned and haphazard development. Roads in the capital although lavish and well-crafted are cracking under the pressure of population bust. It is being recommended to improve road infrastructure by widening existing roads and constructing new ones as required to enhance connectivity intra-city as well as inter-city. There are also concerns about the lack of mass transit lines in the capital.

The **political setup** is led by the Metropolitan Corporation of Islamabad (MCI). The MCI is headed by a Mayor. There are 23 Union Councils (UCs) of Islamabad that belong to the rural areas comprising of 133 villages, whereas the urban part of the capital comprises 27 UCs (UNICEF, Profile of Slums/Underserved Areas of Islamabad City – The Federal Capital of Pakistan, 2020). The UCs are the local tier government responsible for community development.

Other **environmental problems** include poor solid waste management polluting further the surface and ground water. The Islamabad area, on a general scale, lacks strongly developed soils which might be due to its seasonally dry climate and lack of stable surfaces (Sheikh, Pasha, Williams, Raza, & Khan, 2008). In order to promote climate resilient urban development and to help mitigate climate impacts, understanding the urbanization and the physical development of the city should be the first step.

4.5. Climate of Pakistan

Pakistan lies in the temperate zone, and experiences four distinct seasons spanning over a year. Generally, the coastal areas and lower Indus Plains are hot and dry, however the temperature becomes progressively cooler in the Northern Highlands towards UIB. This geographic diversity and climate variability makes the country vulnerable to natural hazards under climate change.

The climate of Pakistan is mainly categorized from arid to semi-arid (Chaudhry Q. Z., 2016). Diversity in the climate is also reflected in the variation of annual and seasonal temperature across the country (Fig. 4.9).

Temperature

The temperature profile of the region indicates high spatial as well as inter- and intra-annual variability. Over the 20th century, the South Asian region warmed by around 0.75°C, whereas Pakistan warmed by 0.57°C, slightly less than the regional average (WorldBank, Climate Risk Country Profile-Pakistan, 2021). Since 1961, both minimum and maximum temperatures are increased, hot days are becoming hotter while cold days are becoming warmer (IFRC, 2021). Many regions of the country regularly experience dry bulb temperatures of 38°C and above during the summer months, making it to the list of hottest places in the world.

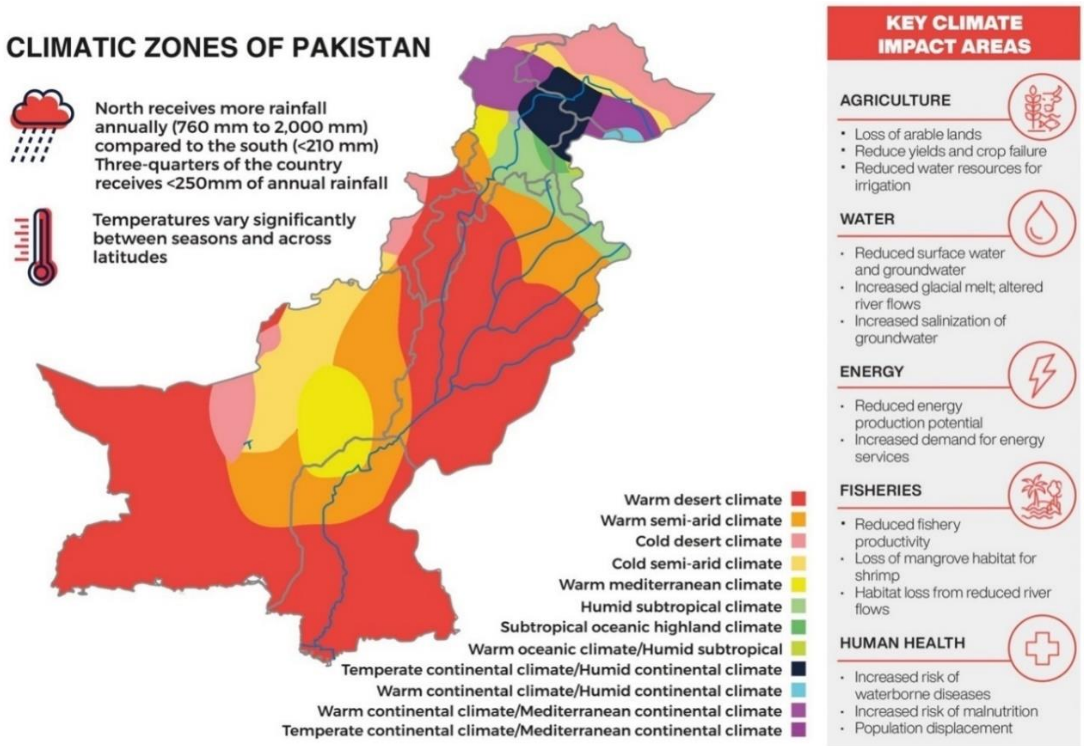

Figure 4.9. Climatic zones of Pakistan and an overview of the observed climatic impacts. Climate change impact affects energy, food production, and public health (IFRC, 2021).

UIB is among the most glaciated regions in the world outside the Polar Regions. Since 1950, regions in Asia have witnessed a retreat of glaciers and UIB is no different. Climate change is already taking a toll on the ice sheets in the region. Even the local perception highlights that there has been a change in patterns of precipitation, and temperature has risen over the decades. Over the century, the rate of increase in temperatures in the Himalaya- Karakoram- Hindu Kush (HKH) has been recorded to be at 0.10°C every decade. Studies have reported a warming trend in the high mountains and in the Himalaya, with minimum temperatures increasing faster than the maximum, and such increases are greater in the higher elevation (Ibid). Scenario based future projections have indicated that the northern regions (including the UIB) are warming at a faster rate than the rest of the country. Based on a low (medium) emission scenario RCP2.6 (RCP4.5), the temperature over the UIB is projected to increase by 1.5°C (2°C) and 1.7°C (3°C) in 2050 and 2100 respectively compared to the reference period of 1986-2006 (Climate Impact Explorer, 2022)).

Islamabad has mildly cold winters with a hot spring season. Summer is dominated by monsoon rainfall and moderate temperatures. Summer temperature is higher in dry years. Recent studies have found that the minimum (maximum) mean land surface temperature in Islamabad has soared from 21 °C (38 °C) in 1993 to 26 °C (46 °C) in 2018. Climate scenarios based on RCP2.6 (RCP4.5) project an increase of 1.4°C (1.9°C) and 1.5°C (2.9°C) by 2050 and 2100 respectively (Climate Impact Explorer, 2022). The effects of recurrent heatwaves that Pakistan experiences in summers are also severely felt in the capital city.

This rise in temperature will affect public health, water management, energy production and labour productivity in the region. In addition, several climate hazards such as floods, droughts, heatwaves and GLOFs are likely to exacerbate.

Precipitation

Due to its arid to semi-arid climate, a majority of **Pakistan** receives very little rainfall, with the exception of the Northern regions, where monsoons currents bring approximately 200 mm a month from July to September. Up until the 1960s, there was a prolonged decline in annual rainfall but afterwards, the country experienced an increasing trend both in monsoons and dry seasons except for the coastal belt (PMD, 2020).

Pakistan is also characterized by high inter-annual rainfall variability, often leading to successive patterns of floods and drought. Recent research show that El Niño plays a significant role in altering the climate variability in Pakistan, with anomalies in both temperature and flood/drought frequency and impact correlated with the El Niño cycle. For example, the 2022 record-breaking concurrent heatwave and drought conditions in March and April are attributed to the prevailing La-Nina event in the pacific (World Weather Attribution, 2022). Given **Pakistan's** topographic profile, scarcity of data, and weak performance of climate models simulating future changes in the South Asian monsoon, there exist significant uncertainty in projected precipitation patterns throughout the country (ADB, 2021).

The precipitation patterns for the **UIB** are poorly documented, due to scarcity of data and directional bias of the observed data most of which is based on low altitude valley stations and does not reflect higher altitudes of the UIB. Furthermore, several uncertainties exist regarding possible impacts of climate change on monsoon and westerly disturbance patterns and consequently precipitation trends. As a result, accuracy in future projections is compromised and uncertainties prevail regarding precipitation patterns (Rajbhandari, Shrestha, Kulkarni, Patwardhan, & Bajracharya, 2014). Based on a low (medium) emission scenario RCP2.6 (RCP4.5), the precipitation over the UIB is projected to increase by 6.8% (7.5%) and 7.7% (4.6%) in 2050 and 2100 respectively compared to the reference period of 1986-2006, with high multi-model uncertainty spanning across zero (Climate Impact Explorer, 2022).

Among all urban cities of Pakistan, the city of **Islamabad** receives the highest annual cumulative precipitation. In the summer, the monsoon moisture from the Bay of Bengal and the Arabian Sea converges in and around Islamabad resulting in rainfall. While the winter rainfall is the result of western disturbances by lesser Himalayan mountain ranges. Climate projections for Islamabad based on RCP2.6 (RCP4.5) scenario show a decrease by -1.7% (-3.5%) and -0.8% (-9%) in 2050 and 2100 respectively, once again with large multi-model uncertainty spanning across zero (Climate Impact Explorer, 2022). Even if the increase in precipitation is minimal, the late monsoon events signal towards short lived and erratic cloud bursts. The erratic precipitation patterns coupled with the urban growth will likely increase urban flooding in the city (Bashir, 2018).

4.5.1. Key climate hazards

Pakistan is one of the climate hotspots in the world. It is situated in a highly vulnerable geographical region, experiencing rapidly changing climate trends coupled with increased intensity and frequency of extreme weather events.

Due to its proximity with ocean and its monsoon climate, the country is also prone to the adverse impacts of wet-bulb temperatures which is a measure of dry bulb temperature and humidity combined. Recent research has shown that the wet-bulb temperature of 35°C, an upper limit of human survivability, was reached multiple times in the past (World Weather Attribution, 2022). A large proportion of Pakistan's population is exposed to the risk of the heatwave, as demonstrated during one of the deadliest **heatwave** of 2015, that resulted in fatalities and about 65,000 people were hospitalized with heat stroke. All these impacts are being witnessed at present level of warming which is approximately 1.2°C above pre-industrial level. Any increase of global mean temperature, even up to 1.5°C, would throw additional challenges on already struggling population. Another study done over Pakistan using CORDEX high emission scenario indicated that UIB will see highest increase of heatwaves in relative terms (Saeed, Almazroui, Islam, & Khan, 2017).

The effects of rising daily temperature are also felt in Islamabad, in the form of **Urban Heat Island (UHI)** effect. In addition to climate change taking its toll, the capital territory has lost green spaces and increased impervious surfaces over the years. Due to urbanization and climate change, a rise was recorded in minimum and maximum mean land surface temperatures in 2018, compared to 1993. As a result of this rise in temperature, in addition to the scorching heat during summer, wildfire eruption in the forest of Margallah Hills has also become a recurrent phenomenon.

Considering the huge reserves of snow and ice in the region, this increase of heatwaves will most likely increase the meltwater resulting in flooding, as well as GLOF events. The region is prone to **extreme flooding events** causing billions of dollars of economic loss to the country, besides human fatalities, making vulnerable people homeless with an added loss of livestock and crops. While plains of Indus basin also face flooding due to heavy rainfall events especially during the monsoon season, the riverine flooding generally originates from the UIB catchment. The super flood of 2010 swept across 20% of the land area, directly affecting around 20million people, claiming more than 1700 human lives and caused an economic loss of billions of dollars through damages to agriculture and livestock, housing, infrastructure and other assets[20]. This unprecedentedly massive flood also originated from northern areas of the country in UIB, and further emphasized the country's vulnerability to flooding in economic terms.

Islamabad faces several challenges posed by climatic events. **Urban flooding** is becoming common in the city particularly during heavy summer monsoon rains. Authorities report that the unprecedented rainwater received as a result of cloudbursts is unable to move through storm drains, which are blocked by illegal encroachments (Editorial, 2021). Unplanned development and accelerated population growth in Islamabad is not only

[20] https://www.finance.gov.pk/survey/chapter_11/Special%20Section_2.pdf

complicating management of climate risks but also the increasing proportion of vulnerable population.

For every 1°C increase in temperature, the snowline on mountains shrinks by about 150 m (GB-EPA, 2017). Rising temperature and glacial retreats in the glaciated UIB are producing glacial lake surges that may turn into **Glacial Lake Outburst Flood (GLOF**) events (Furian, Maussion, & Schneider, 2022). Episodes of GLOF vary in magnitude from displacing communities and claiming lives to causing damage solely to infrastructure. It is estimated that 33 out of the 3,044 glacial lakes formed in GB and KPK are hazardous and likely to result in GLOFs. The Shishper Lake formed by melting of glacier has been an active site of Lake Surge and GLOF episodes in UIB, Gilgit Baltistan. Approximately 7 million people in the UIB regions of GB and KPK are threatened by GLOF events.

In case of a global warming scenario in the range of 2-4°C, 30 to 30-50% of mountain glacier mass could melt by 2100 in the UIB. The snow melt resulting from the rise in temperature pose threats of **snow avalanches and landslides** in addition to the floods. In the Karakoram region of UIB, several areas including Shigarh and Hunza basins exhibit the risk of snow avalanches and landslide (Ashraf & Akbar, 2020).

4.5.2. Sectoral impacts of climate change

Water Resources

Pakistan ranks 3rd in the world among countries facing acute water shortage, as per a 2018 report by International Monetary Fund (IMF) and the whole country is at risk of facing complete water scarcity by 2025 (Ashraf M. , 2018). The major water resources for the country originate from the Indus River and 80% of its flow comes from glacial and snow melt. There is a lot of uncertainty regarding water availability situation for Pakistan.

Rising temperature in the region will result in glacier melt, ultimately changing seasonal profile and severely impacting water availability for Pakistan. The overall annual water availability for UIB would increase to 38% for 1.5°C warming scenario and 52% for 2°C scenario (Hasson, Saeed, Böhner, & Schleussner, 2019). The glacial melt beyond 50% would result in declining water availability and for the case of 100% loss in glacial mass, water discharge would reduce to half for UIB. The growing human and energy demand of water would further complicate adaptation measures, without improvements in water management and storage practices.

Agriculture

Pakistan's economy depends heavily on agriculture, which is one of the most vulnerable sectors to climate change. 90% of the country's food supply comes from UIB, that depend directly on water from the Indus River. The impacts of climate change would affect agriculture and livelihoods of more than 2 billion (Ali, et al., 2017).

An example is the current year 2022, when the region was hit by multiple climate extreme events like early and prolonged heatwaves, droughts, floods successively and sometimes also simultaneously, resulting into a reduced crop yield especially the seasonal wheat (by 10%)[21] and mangoes (by 60%)[22]. This indicates the severe impacts of climate change on agriculture sector though reduced yield or crop failure, thus threatening food security and

[21] https://www.cimmyt.org/blogs/wheat-versus-heat/
[22] https://climatetracker.org/mango-crops-in-pakistan-ravaged-after-record-heat-and-drought/

economy of the country. Besides that, climate change also impacts the sub-sector of livestock. Additionally, land degradation, desertification, and dryland expansion are other issues of serious concern for the agriculture sector in the region. This also calls for hasty adaptation measures by shifting to climate smart agriculture practices.

Health

Climate change directly and indirectly affects the health of the population. UIB has faced numerous small and large-scale climatic hazards. The communities living in the UIB have poor access to water, sanitation, and hygiene services and infrastructure due to developmental challenges and are prone to infectious diseases that accompany climatic hazards.

In addition to the loss of lives, the destruction of homes, properties, livelihoods, and injuries has taken a toll on the mental health of the population in the northern mountains of Pakistan (Ebrahim, 2022). Furthermore, infectious diseases spike after an episode of climatic hazard such as floods. In the UIB, majority of the health facilities are located at lower elevation. Communities living in villages on higher elevation often lack the transportation means to timely visit health facilities in the lower region, especially after a climatic disaster strikes (Baig, Rehman, & Janjua, 2021).

Another very critical factor is the correlation between food consumption patterns and temperatures. At a certain temperature threshold consumption drops, thus resulting in undernourishment. Around 20% of Pakistan's population is already under-nourished and climate change will further exacerbate the situation (ADB, 2021).

Labour Productivity

Intense heat waves and rise in daily mean temperature are directly linked to decreased labour productivity. In Pakistan, the hot spring and summer seasons affect the health and hence the productivity of labour from services industry. Pakistan is expected to lose more than 5.5% of working hours in 2030 owing to excessive heat, prompting an increased number of people to migrate (ILO, 2019).

Migration

Climate induced migration is another important issue in the context of South Asia, which is home to over a billion people. In addition to the impacts of climate change on health and lives of the population, a major reason for migration is attributed to loss of livelihood, particularly in the UIB (Salik, Shabbir, & Naeem, 2020). As variation in water flow increase and agricultural productivity is affected by rising temperature, people from the UIB migrate towards less vulnerable areas in search of sustenance and livelihood. According to a World Bank report, 17-36 million people in South Asia are estimated to be internal climate migrants by 2050, and the rate is likely to accelerate beyond 2050. If not well planned, this would poorly impact the receiving communities, created further challenges for adaptation planning.

Damage to infrastructure

Climate induced disasters damage the infrastructure at a huge scale. Landslides can block roads and hinder mobility, hence medicine, food and other amenities face delay in reaching the affected area. Flash floods and GLOFs hit infrastructure, power plants, livelihoods, and irrigation channels. Irrigation channels in the UIB are earthen channels dug by farmers to provide glacial and snowmelt water from rivers and streams to the agricultural land. These crude and lengthy irrigation channels pass through disaster-prone areas. The fluctuation in the river flow and the process of sedimentation cause riverbank erosion, hence, damages the adjacent irrigation heads, channels and croplands (Khalid, Abbas, & Khan, 2021).

Other effects include destruction of homes, healthcare units, cattle sheds, arable land, drinking water systems, sewerage systems. (GB-EPA, 2017). During recent heatwaves, a GLOF event from Shishper resulted in the collapse of a historical bridge in the UIB due to erosion of pillars (Taj, 2022). Owing to the topographical location of the UIB, the communities populating the region are highly vulnerable to such impacts of climate change.

4.6. Adaptation governance

Adaptation has been flagged as the most significant domestic challenge viz a viz climate in the country. Nevertheless, it is crucial to build resilience against climate change. Adaptation measures stem from policies and are translated to actions across all sectors of development. Unfortunately, comprehensive assessment at the regional or city level is not available, hence this section mainly reviews available information at the national level. As a highly vulnerable country, Pakistan is strengthening its institutional and policy framework for climate change. Streamlining climate resilience in development sector policies and projects is also gaining momentum in Pakistan. However, capacity limitations, lack of knowledge, and financial issues are the major obstacles hindering progress for adaptive capacity enhancement.

4.6.1. Institutional arrangements

Institutional arrangements for climate change management in Pakistan have frequently been altered over the past two decades. Responsibility for climate change management at the federal level originally rested with the Ministry of Environment but following the 18th Amendment to the Constitution by the National Assembly of Pakistan in 2010, Ministry of Environment was devolved to the provinces (Chaudhry Q. U., 2016). This shift facilitates Pakistan's provinces to tailor adaptation plans and actions for climate resilience to better suit their context-specific needs based on provincial risks and priorities (Table 9 in (Chaudhry Q. U., 2016)

A new federal Ministry of Disaster Management was established in 2011, renamed later to Ministry of Climate Change (MoCC) in 2012. This cabinet level ministry was tasked with responsibility for leading coordination of climate change actions with other key ministries and agencies, as well as serving as Pakistan's focal point to UNFCCC in dealing with all the climate relevant international negotiations and dialogues. In 2013, the MoCC was downgraded to Climate Change Division (CCD) under the Cabinet Secretariat and this decision was reversed in January 2015, when the government reinstated the MoCC (Parry, 2016).

The MoCC has been vested with the mandate to comprehensively plan disaster management along with spearheading national climate change initiatives both in climate change adaptation and mitigation. Amongst duties that include environmental assessment and monitoring, and law- and policy-making, the ministry is responsible for the development of national strategies and action-plans in order to meet international obligations.

Effectively, the 18th amendment has shifted primary responsibility to subnational governments for the development and implementation of adaptation policies. The federal MoCC still steers coordination of adaptation planning and actions. The MoCC arranges quarterly meetings with all the provinces and relevant federal level stakeholders to assess the overall progress of climate relevant initiatives. The MoCC, although not directly tasked with implementation, can provide guidance and support to the provinces for effective climate governance.

Climate resilience planning and development requires intricate coordination and communication between stakeholders. Sectors like water, agriculture, health, economics, environment. need to work in a close-knit proximity that is only possible through robust communication. However, in Pakistan institutions lack such coordination. Institutions adopt siloed approaches without much knowledge or resource sharing. There is a need for umbrella PC1 (Planning Commission of Pakistan form 1) to streamline all relevant stakeholder sectors and institutions and ensure well-articulated coordination among them if climate resilience is to be effectively developed in Pakistan.

In Pakistan, development issues consume majority of the funds and climate change issues have low priority. During the COVID19 pandemic, the government of Pakistan among other interventions announced a funding cut of 34% for the MoCC to direct funding for dealing with the emergency situation (PSDP, 2020).

4.6.2. Climate adaptation policies and programs

Pakistan recognizes the important role of subnational governments/provinces for effective response to climate change. As mentioned earlier, after the 18th constitutional amendment in 2010, the responsibility of implementing climate change policies rests with respective provinces/subnational governments. At the national level, the MoCC coupled with the National Disaster Management Authority (NDMA) are leading the efforts for developing adaptation policies and plans.

Policies

In the year 1992, **the National Conservation Strategy (NCS) of 1992**, was set to integrate environmental concerns in all sectors of development. The strategy was based on three objectives: 1) conservation of natural resources, 2) sustainable development, 3) improved efficiency in resource management and use (Hanson, Bass, Bouzaher, & Samdani, 2000).

The **National Environmental Action Plan (NEAP) 2001** was created to provide the country with a clear and progressive environmental agenda for the 21st century. The plan was divided into two major themes: addressing sustainable development concerns and perspectives from nine major sectors.

In 2005, the **National Environment Policy** was enacted with a focus on responding to environmental issues and challenges faced by Pakistan. The focus of the policy, as in the previous NCS and NEAP was around water, biodiversity, waste management, changing climate, and extreme climate events. This policy also stressed the need for sub national capacity building and plans to tackle unique challenges faced at respective levels (GoP, National Environment Policy, 2005)

The year 2012, is a hallmark for climate governance and the country’s response to climate change. After facing massive destruction post-earthquakes and floods, the country had decided to launch the **National Climate Change Policy (NCCP)** (2012). The formulation of the policy was in effect since 2008 and was published four years later in 2012. The NCCP of 2012 defined its goal as mainstreaming of the climate change phenomena in socio-economic sectors of the country to achieve climate resilient development. A similar focus on adaptation by anchoring climate change into vulnerable sectors’ programs and funding was placed by the **National Sustainable Development Strategy** of 2012 (Aslam & Pervaiz, 2012). Recently, in 2021, an updated NCCP was developed that aim to steer Pakistan towards climate resilient and low carbon development (GoP, National Climate Change Policy 2021, 2021)

Pakistan continues to receive socio-economic shocks from the impacts and the aftermath of climate extremes including floods and heatwaves. To build resilience capacity towards such disastrous events, the country devised its **National Disaster Risk Reduction Policy (NDRRP)** in 2013. Prior to this policy federal government, provinces and regions were conducting respective risk reduction plans albeit with little to no coordination and support between them. The NDRRP set forth a collective agenda with coordination as its central feature. The NDRRP further developed on the ideas proposed in the **National Disaster Risk Management Framework** (NDRMF) (2007-2012) that outlined a comprehensive national Disaster Risk Reduction (DRR) agenda. Both the framework and policy propose to have a decentralized mode of operations and strategies to assess and respond to disaster risks.

The Ministry of Planning, Development, and Special Initiatives formed a 10-year national development vision for Pakistan, in order to set a pathway for become an upper-middle income country by 2025. The **National Vision 2025** identified climate change as a growing challenge as it has severe negative implications on food security and hence the nutrition status of the population, two important determinants of national development. The document also outlined goals designed to respond to the challenges of climate change.

In Pakistan, deforestation has risen significantly in the past two decades. Population of the northern area especially uses wood as fuel for cooking and heating. In addition, activities of the timber mafia have led to a significant loss of forest cover. Between 2001 and 2021 Pakistan lost 9.75kha of tree cover, leading to increased landslides and soil erosion during rainfall or floods. Pakistan developed its first **National Forest Policy** in 2015 to curb deforestation, replant forest covers, and promote conservation through new approaches such as the REDD+. A key element of the policy requires federal and provincial governments to carry out environmental impact assessments for all new projects.

By the year 2017, it was evident beyond doubt that the country was vulnerable to significant risks emanating from climate change. The undeniable need to incorporate strategies and plans into economic development prompted the government of Pakistan to promulgate **Pakistan Climate Change Act**. The Act categorically mentions its objective to give legislative backing to international conventions on climate change, and to develop comprehensive policies of both adaptation and mitigation. More importantly, the Act also set forth the need to establish a **Climate Change Council**. It was proposed that the council under the Act would work as the execution arm of the Act. The council would coordinate, supervise, and monitor climate change strategies and plans across the country. The council was also tasked to monitor international conventions' requirements and obligations to Pakistan (Jamal, 2018).

In addition to the Council, the Climate Change Act also established **Pakistan Climate Change Fund**. The fund was developed to utilize funding to aid and support the adaptation plans and strategies in the country as well as finance research and other plans that seek to address the concerns of climate change. Similarly, the Act established the Pakistan Climate Change Authority to develop and implement policy mechanisms for adaptation plans at national and provincial levels.

Climate Adaptation Technology Action Plans & Ideas of 2017 developed by the MoCC identified the technologies for climate adaptation with special focus on water and agriculture sectors (GoP, Technology Needs Assessment For Climate Change Adaptation, 2017).

Northern areas in Pakistan have a distinct climate risk profile and with isolated communities in the valleys and mountains the risks are accentuated. Increased instances of extreme weather events, changing patterns of rainfall and increasing temperatures seriously constrain the livelihoods and economy of the region. The government of Gilgit Baltistan being cognizant of the fact and the need to devise a comprehensive adaptation mechanism, developed the Gilgit-Baltistan **Climate Change Strategy and Action Plan 2017** (Government of Gilgit Baltistan 2017). The action plan seeks to adapt to climate change via incorporating climate change into development programs and plans. The government of GB considers adaptation, climate resilient infrastructure and capacity enhancement of officials as top-most priorities.

The National Water Policy of 2018 was developed to address the emerging challenge of water insecurity in Pakistan. The policy recognizes climate change to have serious implications on the water resources of Pakistan. It aims to strengthen the water system through appropriate adaptation measures.

Similarly, as in the case of GB, the government of KP also realized and devised its own response plan to climate change for the province. As a pillar of response against climate change, the province has generated in 2018 the **Climate Change Financing Framework (CCFF).** At the core of the framework lies the idea of incorporating climate change plans and strategies into budgetary and finance allocation cycles (Pakhtunkhwa, 2018).

Cross sectoral policies in Pakistan are becoming increasingly responsive to the climate action needs of the country. The **National Agriculture and Food Security Policy** (2013) includes climate relevant elements. It aims to "flexibly adapt to climate change and be resilient enough to quickly recover from shocks and emergencies." It calls to adopt climate smart agriculture techniques.

Pakistan's **NDC** of 2021 provides an update of Pakistan's 2016 NDCs and form the basis of climate inclusive development. The contributions embody the country's aims to reduce GHG emissions and increase resilience by streamlining climate action within development sectors. The NDCs have provided substantial direction especially for the sector of energy and transportation. It also focuses on nature-based solutions to curb climatic impacts (GoP, Pakistan: Updated Nationally Determined Contributions, 2021).

Realizing the vulnerabilities, the Government of Pakistan (among other initiatives) has recently decided to roll out a **National Adaptation Plan (NAP)**. The plan is aimed at anchoring country's climate related challenges and vulnerabilities into national development and sectoral programs across different levels of governance. Pakistan's **Nationally Determined Contributions (NDC)** 2021 states that the plan would be assisted by the Global Climate Fund (GCF) via the United Nations Environment Program (UNEP) for knowledge sharing, integrating climate change adaptation into policies and legislation and to scale up government's initiatives in climate change adaptation.

Pakistan's first ever **National Climate Change Gender Action Plan** is developed 2022. The plan aims to ensure women inclusion at local and national level policy and program development. It promotes policy dialogue, capacity development, and pilot projects aimed to empower women and support their contribution in environmental conservation and climate change adaptation and mitigation. A timeline of these initiatives is provided in Table 4.4.

Issues related to formulation and implementation of climate change policies have been assessed in recent literature. Different aspects of governance such as engagements of local actors, activism of political leadership, awareness campaigns and capacity building are the notable initiatives which are taken inconsistently across different provinces of Pakistan. Differences of initiatives in the provinces are manifest in subnational climate change policy differentiation, research capacity and institutional maturity (Mumtaz & Ali, 2019). However due to lack of experience, lack of technical, institutional, and financial capacities, and socioeconomic challenges, the effective enforcement of governance policies has not yet been achieved. There exists a considerable knowledge gap between researchers and policymakers. Knowledge flow from researchers to policymakers is crucial to provide a ground assessment of realities, climate vulnerability of population, and projected risks. Without this knowledge, effective policies guiding context specific solutions cannot be developed (Ali, Khan, & Shakeel, 2019)

Table 4.3. Timeline of climate change relevant policy initiatives of Pakistan.

Policy Initiative	Year
The National Conservation Strategy (NCS)	1992
The National Environmental Action Plan (NEAP)	2001
National Environment Policy	2005
National Disaster Risk Management Framework (NDRMF)	2007
National Climate Change Policy (NCCP)	2012
National Sustainable Development Strategy	2012
Ministry of Climate Change	2012
National Disaster Risk Reduction Policy	2013
National Agriculture and Food Security Policy	2013
National Vision 2025	2014
National Forest Policy	2015
Intended Nationally Determined Contributions	
Pakistan Climate Change Act	2017
Climate Change Strategy and Action Plan (Gilgit Baltistan)	2017
Climate Change Financing Framework (CCFF) (Khyber Pakhtunkhwa)	2018
Alternate and Renewable Energy Policy	2019
National Electric Vehicle Policy	2019
Revised nationally Determined Contributions	2021

Programs and Projects

With regards to the country's capacity for adaptation, multiple programs and projects have sought to address capacity development and governance structures. It is argued that a small chunk of such programs directly seeks to implement or support any adaptation measure per se (Parry, 2016). Though still insufficient, development projects are becoming increasingly inclusive of climate resilience aspects. Other than that, several programs have been initiated to enhance adaptive capacity especially in areas that are highly vulnerable to climate change.

In addition, the government of Pakistan started a mass plantation drive throughout the country aimed to plant 10 billion trees across Pakistan by 2025. The project is called the **Ten Billion Tree Tsunami (TBTT).** The benefits of tree plantation extend to stabilization of weather, preservation of atmospheric health, reduction in greenhouse gas effects, lowering cases of erratic floods, rainfall patterns, and drought. In addition, the project generates gender inclusive livelihoods such as plant nursery raising, plantation and protection of forests. During the COVID19 pandemic the TBTT provided jobs to 85,000 daily wagers (MoCC, 2019).

In 2018, only 12% of Pakistan was classified as environmentally protected. Through the **Protected Area Initiative** in 2020, the government of Pakistan set targets to increase the protected areas such as national parks, wetlands and wildlife reserves to 15% of the country's total area by 2023. The protected areas will safeguard biodiversity, protect habitats, provide carbon storage, and build resilience against natural disasters through nature-based solutions. The initiative was highlighted under the Revised NDCs as an important adaptive intervention. In addition to the environmental benefits, the project also provides livelihood to many (UNEP, 2021).

Addressing the growing water insecurity in Pakistan and the flood risks, the government of Pakistan has planned a 30-year long project. The **Recharge Pakistan** project will develop country's resilience to climate change through cost effective eco-system-based adaptation for integrated flood management. Implementation parts include the MoCC, WWF, and the Ministry of Water Resources. Under the project interventions will aim to; increase water storage and recharge through wetlands, floodplains, and hill-torrents management; promote climate-adapted community-based natural resource management and livelihoods; and forge a change in thinking to scale up this approach (WWF, 2019). It will be implemented in selected sites, spanning over a stretch of 1,300km of the Indus, across Khyber Pakhtunkhwa, Punjab, Balochistan and Sindh.

The river Indus holds critical importance in sustaining Pakistan's development. In efforts to protect the Indus Basin ecosystem, the MoCC has launched the **Living Indus Initiative**. This initiative aims to improve and restore the natural resource of the Indus Basin through a series of 26 innovative programs. These include building back biodiversity to restore terrestrial, aquatic and bird life in the Indus Basin, integrating coastal management in the Indus Delta, development of protected areas and zero carbon protected areas, and scaling up GLOF. The initiate will focus greatly on ecosystem-based adaptation approaches.

As a developing country, most of the government spending focuses on development projects. Among these some projects have elements of climate resilience such as construction of dams can lower risks of flood and renewable energy projects will lower the country's GHG emission. However, specially focused climate relevant projects are few and have only gained importance in budget approval process recently with approval of TBTT project.

In addition to these above-mentioned project, public sector departments are set to undertake the following programs in the next five years (see Fig. 4.10). The programs include planning and policy development, risk assessments, and climate proofing initiatives.

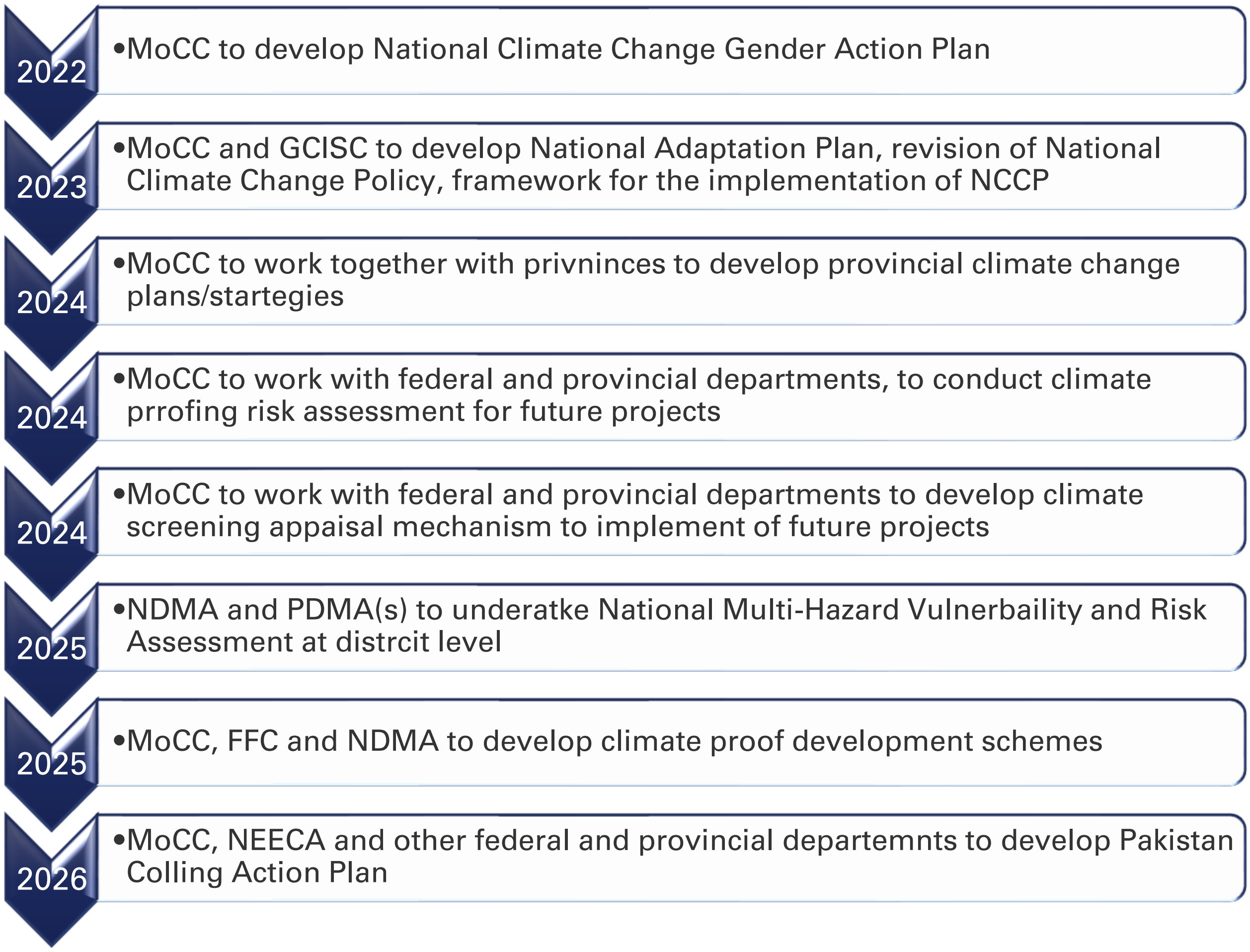

Figure 4.10. Planned climate initiatives in Pakistan, GoP 2021.

4.7. Adaptive Capacity

International policy and climate change forums have increasingly focused on adaptation as means to tackle the effects of climate change. Devising and scaling up adaptation interventions for nations has become the central point of debate globally. Generally, adaptive capacity can be summed as the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences (IPCC, 2018). The system may refer to an economic sector, a population group, an ecological system, a regional system. The systems are exposed to the risks posed by potential climatic hazards. Vulnerability assessments form the basis of interventions to enhance adaptive capacity. This way the needs of the system are directly assessed and addressed in scaling up its adaptive capacity. In addition, early warning signs can also help recognize the need of adaptive capacity enhancement in areas where potential climatic events are apparent but the readiness of the system to curb or withstand their impacts is low. Unfortunately, there is no holistic and comprehensive risk or vulnerability assessment carried out at national and provincial level in Pakistan to facilitate context specific adaptive capacity development. Capacity development projects should also consider the role of external or contextual factors that affect systems. At national level, these factors could include governance, health literacy, economic development. Such factors are reflective of a nation's development status and thus contribute to the context within which sub-national scale systems must adapt to potential risks. For example, here the country's outlook in terms of poor households is presented.

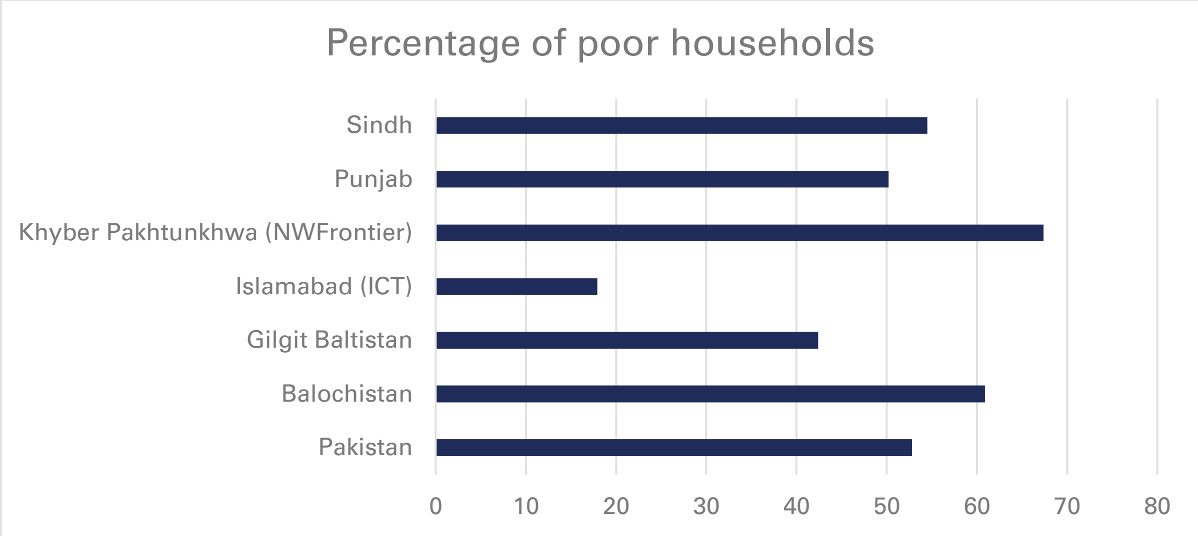

Figure 4.11. Province-wise percentage of poor households, a development indicator [Source: Global Data Lab].

Islamabad territory has the lowest percentage of poor households with only 17.9% poor households[23]. The province of Khyber Pakhtunkhwa has the highest percentage with 67% households facing poverty. This might indicate that the population of KPK is more vulnerable to climatic impacts as they have little dispensable income to spend on adaptive measures. As a result, adaptive capacity interventions in this area could focus on assisting communities in minimizing the damage to livelihoods as a result of climate change.

A plethora of factors hinder development and implementation of adaptation planning. Institutional weaknesses, lack of coordinated governance and legal instruments, and conflicting objectives among different actors can constrain adaptation. In addition, lack of knowledge base such as regarding climate vulnerability and potential risks also hinders effective and context specific adaptation planning for a system. Insufficient human and financial capital can hinder designing and implementation of adaptation interventions (Brooks & Adger, 2004).

Better definition and/or implementation of opportunities, constraints, tools, and factors can assist in planning and implementing adaptation measures. Adaptation opportunities are the sum of factors that can contribute towards the ease of reaching adaptation objectives and/or expand options of adaptation. For instance, factors such as awareness raising among vulnerable communities and acquiring additional support from relevant stakeholders in the system can assist adaptation planning and implementation. On the contrary, adaptation constraints are factors that hinder or hamper available adaptation options and/or make adaptation objectives realization extremely cumbersome. Some examples of such constraints include lack of resources, institutional shortcomings and/or lack of connectivity.

[23] https://globaldatalab.org/areadata/maps/iwipov50/

Table 4.4. Adaptation opportunities in Pakistan.

OPPORTUNITY	REGION	EXAMPLES	REFERENCES
Awareness raising	UIB	Glacial lake outburst floods have wreaked havoc in the northern parts of the country thus prompting the government and development partners to join hands in dealing with the risks. As a result, GLOF projects have been initiated to empower communities to identify and manage risks associated with GLOFs and related impacts of climate change. Moreover, at the government level there is a realization that there is a need to enhance awareness about climate change and possible adaptive options as well as coping strategies.	Scaling-up of Glacial Lake Outburst Flood (GLOF) risk reduction in Northern Pakistan.
Capacity building	UIB	Since GLOFs have become the focus of attention and response from government and development partner, the project seeks to strengthen public services to lower the risk of disasters related to GLOF and improve community preparedness and disaster response.	Scaling-up of Glacial Lake Outburst Flood (GLOF) risk reduction in Northern Pakistan
Capacity building	UIB	Agha Khan Development Network has undertaken multiple trainings for women and men as first responders in disaster-prone areas of Gilgit-Baltistan	Agha Khan Development Network
Capacity building	UIB	The changes in precipitation and the growing irregularity in the behaviour of glacial melts has greatly impacted the irrigation supply for agriculture in UIB. As an effort towards adaptive strategy, the communities under the 'Agriculture Water Resource Management' project have started utilizing energy-efficient technologies such as hydraulic ram pumps and solar pumps to lift water from the river and facilitate farming in lands that would otherwise remain barren	(ICIMOD, 2020).
Capacity Building	UIB	Support to Rural Livelihoods and Climate Change Adaptation in the Himalayas explored alternate livelihoods for vulnerable communities and facilitated technology transfer for local small and medium enterprises to operate in the UIB.	ICIMOD, 2018
Tools	UIB	The Aga Khan Agency for Habitat (AKAH) AKAH Pakistan has developed hazard and risk maps for 658 villages with over 600,000 habitants in Gilgit-Baltistan and Chitral (GBC) and 12 maps for urban settlements. Automated Weather Stations are installed at four GLOF prone stations in GB that gather surface weather data that is used by the Pakistan Metrological Department (PMD) to predict flooding events via hydrological modelling. Alerts regarding possible flooding events is then disseminated via mobile phones and media outlets amongst the vulnerable communities to evacuate the area or adopt protective measures where necessary.	The Aga Khan Agency for Habitat (AKAH) UNDP, 2020
Tools	UIB	Community Based Flood Early Warning Systems have been developed in 5 regions including Passu, Ganche, Dammas, Sherqilla, Shighar. The CBFEWS is an integrated system of tools and plans managed by and for communities, providing real-time flood warnings to reduce flood risks.	ICIMOD, 2018

Policy	UIB	The action plan seeks to adapt to climate change via incorporating climate change into development programs and plans. The government of GB considers adaptation, climate resilient infrastructure and capacity enhancement of officials as top-most priorities.	Gilgit-Baltistan Climate Change Strategy and Action Plan 2017
Policy	Pakistan	Pakistan realized post devastating floods of 2010 that a comprehensive legislative and administrative setup was required and thus NCCP of 2012 was developed which defined its goal as mainstreaming of the climate change phenomena in economic and social sectors of the country to achieve climate resilient development. In the same year Ministry of Climate Change was established. Government of Pakistan has pledged to develop its National Adaptation Plan in the coming year i.e., 2023 along with development of framework for implementation of the national climate change policy.	National Climate Change Policy Ministry of Climate Change
Learning	Pakistan	National Disaster Management Authority has over the years both expanded and learned lessons from responding to disasters. Such lessons and experiences form a larger part of understanding nationally on how best to tackle disasters and prepare for them.	NDMA 2016
Learning	UIB	Himalayan Climate Change Adaptation Programme increased understanding of uncertainties influencing climate change scenarios and water availability and demand projections for parts of major river basins, and to encouraged use of the knowledge thus created especially for the farming community. Transboundary Study of Climate Change Impact on Livelihoods of UIB Communities in Ladakh, India and Baltistan, Pakistan aided in identifying livelihood challenges and opportunities under climate change for communities residing high altitudes. The study highlighted best practices such as use of glacier fed water irrigation systems.	Mountain Research Initiative
Innovation	UIB	At least 250 small-scale engineering structures established to reduce the effects of GLOF events. Expanding climate information surveillance by installing 50 of these automated weather stations in Gilgit-Baltistan and Khyber Pakhtunkhwa.	UNDP

Table 4.5. Adaptation constraints in Pakistan.

CONSTRAINTS	REGION	EXAMPLES	REFERENCES
Economic		The province of Khyber Pakhtunkhwa has the highest percentage of poor households among all provinces of Pakistan i.e., 67% of the households. The adaptive capacity of poor households is low thus indicating that in KPK, larger population is exposed to the potential climatic risks faced by the province compared to other areas in Pakistan. Climate specific projects are on low priority and ongoing projects experienced budget cuts during the COVID19 to utilize funds for dealing with the emergency situation (see section 4.8.2 Institutional arrangements).	
Human Capacity	Pakistan	To increase human capacity of public sector to meet challenges of disaster risk reduction significant funds were utilized towards raising capacity for effective and timely disaster management.	National Action Plan 2009

Governance Institutions Policy	UIB and Islamabad	Multiple action plans and policies over the years have identified the need to embed disaster risk reduction and adaptation into development plans and programs. Similarly on paper there is cognizance of the fact that climate resilience infrastructure is the need of the hour followed by capacity enhancement of relevant public and private sector stakeholders. Ambiguity or overlap in institutional roles and responsibilities hinders climate risk identification, management, adaptation, and mitigation (see section 4.8.2 Institutional arrangements). Islamabad's master plan has faced inertia over the years resulting in haphazard development and expansion has resulted in significant increase in population and congestion (see section 4.4 Iconic City: Islamabad).	Gilgit-Baltistan Climate Change Strategy and Action Plan 2017
Knowledge Awareness Technology	UIB	Multiple policies have highlighted the need of utilizing technology for effective risk reduction and response mechanisms. The need to develop database for knowledge management and disseminate information through information and communication technology (ICT) across GB has been mentioned in the GB action plan.	Gilgit-Baltistan Climate Change Strategy and Action Plan 2017
Knowledge Awareness Technology	Islamabad	Gaps in spatial data for the city hinder vulnerability assessment and effective adaptive planning as pointed out in the PROVIDE first stakeholder meeting for UIB and Islamabad.	

4.8. Spatial structural and strategic profile of the city of Islamabad

This section summarizes an evaluation of the capacity of the spatial structure of the Islamabad, for details see Chapter 10. The city of Islamabad, planned from scratch in 1960, was deliberately built in a green landscape with a pleasant climate and plenty of water. However, the tremendously rapid urbanization is increasingly endangering these characteristics. Islamabad was planned with a grid structure, as a linear city consisting of square sectors separated by wide roads. The city is situated on a fertile plateau at the foot of the Margala Hills. This plateau is intersected by many parallel rivers and streams, which converge into the Soan River. The increasing urbanization and growth of the urban area is causing increased space to be paved over and reducing the space for nature, agriculture and water.

The original master plan consists of both urban (around the traffic infrastructure) and ecological corridors (around the rivers). The recent formal and informal growth of the city no longer respects these ecological corridors to the maximum extent. This causes an increase of the flood risk, visible in recent flood events with a lot of material and human damage. Another evolution is the decrease of available drinking and ground water. Overall, the water resources of the metropolitan area seem to be relatively vulnerable, the socio-economic factors enhancing the effects of the climate change. The visible increase in built surface is definitely one of the leading sources of increasing urban temperatures. There is a high correlation between the amount of green and the lower temperature areas, whereas the densely built areas with a dense infrastructure and high percentage of paved surfaces have higher land surface temperature (Figure 4.12).

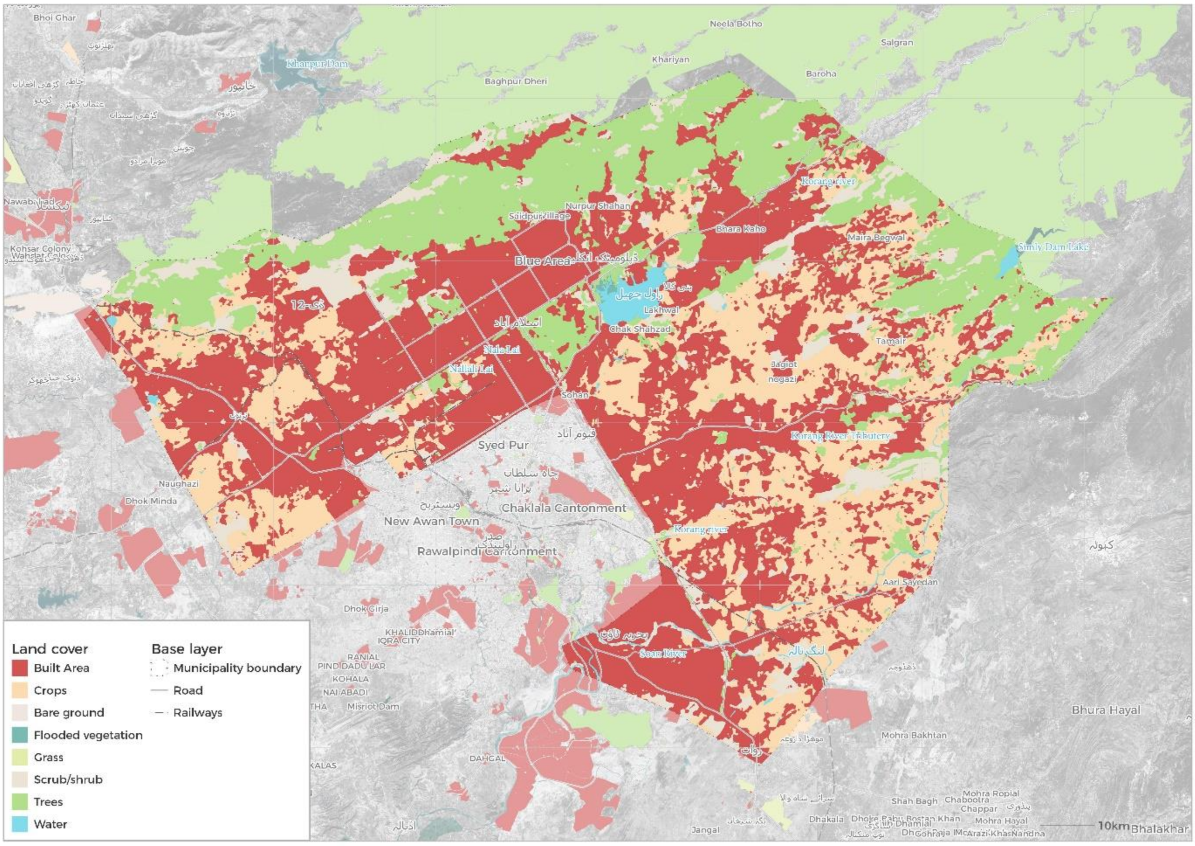

Figure 4.12 Land cover analysis of the city of Islamabad, image by BUUR/PoS 2022.

Perhaps the most defining natural feature in the Islamabad area, besides Margalla Hills, is the Nullah Lai basin with its natural ravines. This natural landscape has been fully respected when designing the layout of the new city in the 1960's. The ravines network, on top of which the formal mobility and social grids were imposed, formed a diagonal open space system equally present in all the sectors.

The robust green blue network was intended to bring nature in the close proximity of the residential areas, secure ventilation corridors and ensure ecological continuity. However, over the past 60 years many changes have occurred in the open space structure in Islamabad. Many of the watercourses have been buried (blue dotted line) and the green corridors along them have been also partly disappearing (Figure 4.13). This results into a lower infiltration and water buffering capacity in case of flooding.

Besides the already well described ravine and stream system, Islamabad benefits from one large urban park situated in sector F9 – the Fatima Jinnah Park – and one national park, the Kachnar Park. Adding to this, green buffers which can be found along motorways and primary ways contribute to the cooling and ventilation of the urban system. While comparing Islamabad and Rawalpindi urban morphology it becomes clear that districts with large amounts of vegetation and surface water are cooler than densely built areas with many sealed surfaces. Trees in Islamabad have a positive effect on the microclimate due to their shade and by the fact that the ground below them is heated less.

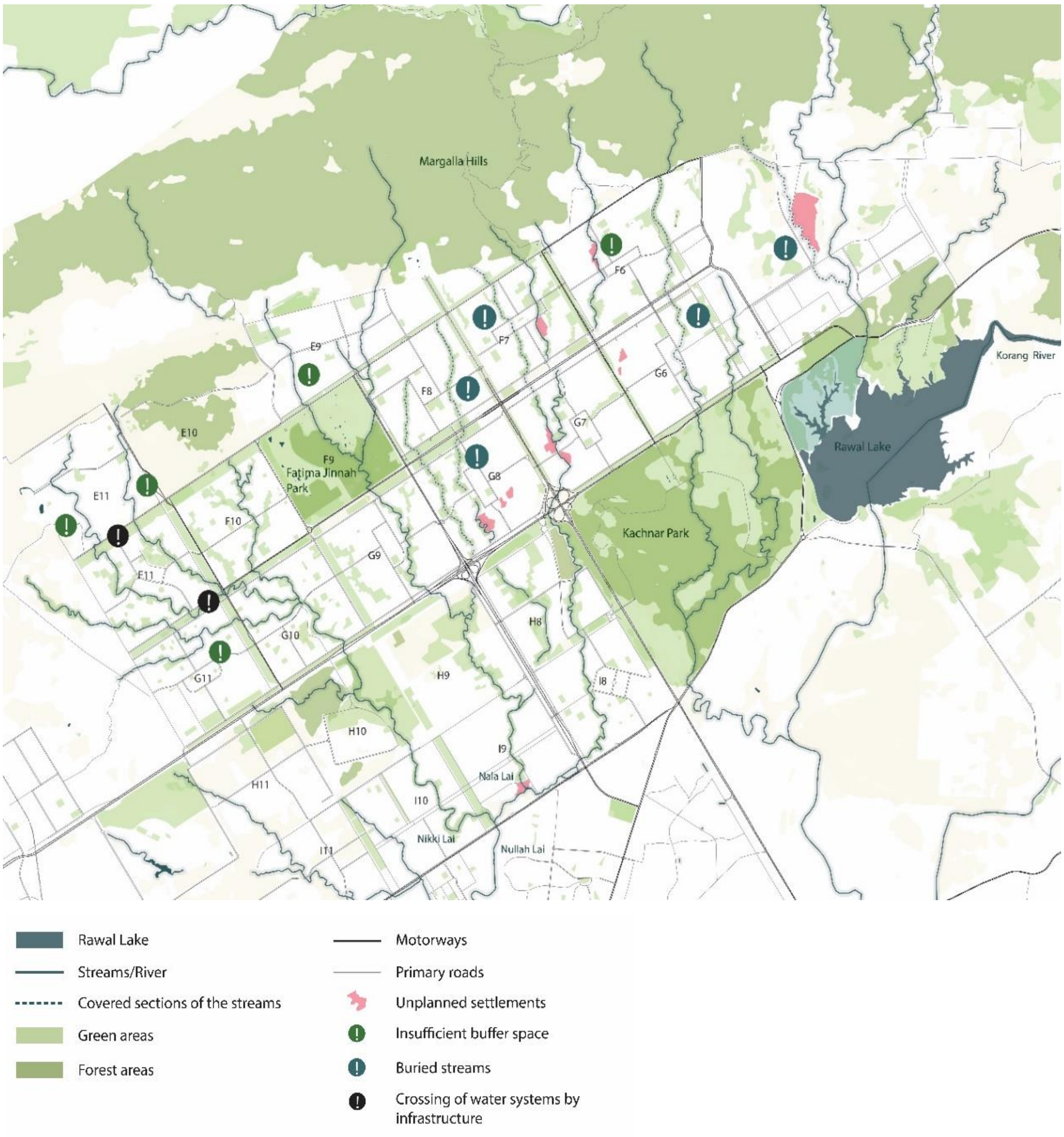

Figure 4.13 Spatial performance analysis of the green blue system of Islamabad, image by BUUR/PoS 2022.

4.9. Insights from stakeholder engagement workshop

4.9.1. Workshop purpose and setting

The first PROVIDE regional stakeholder engagement meeting for the Upper Indus Basin and Iconic City of Islamabad was held on 20 – 21 April 2022, at the Sustainable Development Policy Institute (SDPI), Pakistan. The format of the workshop included presentations, online interactive menti-surveys and brainstorming sessions on adaptation and overshoot scenarios, with a way forward on collaboration for the dashboard. The purpose of the meeting was to develop interest and enthusiasm of regional stakeholders in co-developing the regional module of the PROVIDE Climate Service Dashboard and validating PROVIDE concepts. The meeting also focused on identifying the needs and gaps in climate adaptation information/tools currently available and used by regional stakeholders and to gather input on topics relevant for specific regions such as access to local data.

4.9.2. Overview of climate impacts and ongoing adaptation efforts

The introductory remarks presented a picture of the climate change and need of adaptation by building upon the irreversible climate impacts like melting of glaciers that are main source of water supply in the UIB region. The melting glaciers will result in further catastrophic events and impacts for billions in the regions like GLOFs, floods, water scarcity, droughts, loss of agriculture and crop failure, food security, farming practices, climate induced migration, increasing populations density in urban areas, heat waves and Urban Heat Island effect, tourism, exporting cotton industry, air and water pollutions, sanitation and waste management, and everything else linked to survival of human communities. Considering the urgency of climate change, the need to act and adapt now, make effective planning, and the cooperation of all actors was stressed upon. The PROVIDE dashboard, its design and its implication were also shared with the participants. Valuable feedback was obtained. It was suggested that the innovation of the PROVIDE project is modelling overshooting scenarios, but the macro-economic side of the model should at least include what exists already and where possible, improve on it. It would be important to model taxes and subsidies because that is a key lever in adaptation strategy implementation, e.g., removing subsidies on sugarcane, introducing subsidies on climate smart agriculture and renewable energy, levying taxes on urban construction on cultivated land.

Regarding the need for more information from PROVIDE, participants pointed out cost-effective adaptation measures, how to calculate climate adaptation costs, and effective ways of communicating the consequences of climate change for the region internally, among others.

The participating stakeholders presented the ongoing adaptation relevant efforts in Pakistan. GIZ-Pakistan is developing a Climate Risk Profile for the country that would give brief overview of NDC implementation and climate risk-informed decision making. In addition, an adaptation needs assessment and an assessment for adaptation strategy, prioritization, and implementation planning is being done by GIZ. GIZ-Pakistan's involvement in strengthening the capacity of Adaptation Tracking in Pakistan via Strengthening Climate Adaptation and Resilience (SAR) project was mentioned. Climate Smart Agricultural (CSA) Investment Plans project was also mentioned that supports the development of targeted climate smart action plans, employs a value chain approach to consider both on and off farm adaptations strategies along with enabling services for greater uptake and scaling. It was emphasized that climate impact models can help to understand agro-ecological systems and consequences of climate change, and with the higher resolution can be more expressive for agricultural models.

4.9.3. Climate tools and spatial planning

Participants mentioned the climatic issues faced by the Iconic City Islamabad including recent extreme events like urban floods, flash floods, heatwaves, forest fires, air pollution. The expected rapid population growth of the city might put the already vulnerable city under more stress. Moreover, water scarcity is also prevalent in various areas.

The meeting helped form connections, recognize present issues such as lack of data, and shared several ongoing adaptation projects in Pakistan. Participants from the public sector or government organizations were very much thrilled to see the scale of proposed work on the city level, since they have no such tools or skills locally and they were of the opinion that this is going to be very useful, if the scientific results are translated into policy recommendations for the non-scientific officials working in the planning and implementation sector. They were interested to contribute and collaborate further.

The "Spatial and Strategic Structural Profile of Islamabad" in relation to Climate change impacts and adaptation was also presented showing that the spatial form and programme of a city affect vulnerability and adaptability to climate change, see Chapter 10 for details. By using examples and illustrations of the very recent climate extreme events, BUUR team showed how differently spatial forms expose different areas to the natural hazards, such as pluvial and flash floods. Gaps in data for Islamabad were highlighted. The need for detailed urban planning data/maps, advanced/high- resolution and aerial satellite imageries, and ground-level data for Islamabad was recognized.

Further, preliminary results from the 'Meter-Scale Climate Information for the city of Islamabad" was also presented depicting how the global data is converted into meter-scale urban data, and the strength of such local scale data in providing information for sectoral climate impacts indicators for health, energy, biodiversity, transport, tourism. All these modelling techniques can provide crucial information regarding the climate change projections for urban centres such as the iconic city Islamabad and help with identification of vulnerabilities and adaptive capacity development.

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5. The Bahamas

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5.1. Overview of The Bahamas

5.1.1. Physical Characteristics

The Bahamas is an archipelagic small island developing state (SIDS) comprising of over 700 low-lying islands and cays (Figure 5.1) and is part of the Caribbean. The country has a sub-tropical climate and is positioned between two major warm ocean currents which provide some seasonal variability. The rainy season is from May to October with the hurricane/tropical cyclone season extending from June to November. Rainfall generally occurs in the form of intense showers, accompanied by strong and gusty winds.

The Bahamas extends over 100,000 square miles (260,000 square kilometres) of sea, stretching over a distance of approximately 760 miles from northwest to southeast (The Commonwealth of The Bahamas 2005). The total land area is approximately 5,380 square miles (13,934 square kilometres). The country is mostly flat in elevation with the highest point being found on Cat Island at only 206 feet (63 meters). The islands are comprised of calcium carbonate, the result of coral reefs which became dry land when sea levels dropped hundreds of centuries ago.

Figure 5.1.: Map of The Bahamas

5.1.2. Economic characteristics

The Bahamas is one of the wealthier nations in the Caribbean region with a GDP per capita of US$25,194 in 2020 (The World Bank 2021). The national economy is driven by tourism and financial services (Government of The Bahamas 2016). Tourism employs about half of the labour force and contributes approximately 60% to the GDP. The financial services sector employs about 10% of the labour force and contributes approximately 15% to the GDP. These two sectors are vulnerable to external stressors and shocks and have experienced volatility in recent years due to changing financial regulations and the COVID-19 pandemic. However, the government projects an economic rebound as tourism improves which will reduce domestic unemployment and increase government revenue (Central Communications Unit 2022).

Despite the relatively high GDP, there is marked income inequality and uneven development with serious infrastructure gaps and challenges in public education and health care systems (The Government of The Bahamas 2018). Development is further challenged by the need to strengthen public institutions and increase accountability, transparency, and effectiveness in the public sector.

Like many SIDS, The Bahamas relies primarily on imports to satisfy basic goods needs, including fuel, food, medicine, and building supplies. The COVID-19 pandemic has reignited discussions on the need to diversify the economy and reduce reliance on imports, through investing in light manufacturing, technology, agriculture and fisheries, extractive industries, and renewable energy (US Department of State 2022).

5.1.3. Demographic characteristics

Approximately 29 islands of The Bahamas are inhabited. The 2010 census counted a total population of 351,461 people, with approximately 70% of the population located on the island of New Providence which hosts the capital city of Nassau (Department of Statistics 2012). Grand Bahama Island is the second most populous island, with about 15% of the population. The other islands, collectively referred to as Family Islands, have much smaller populations and are much less densely populated. The primary language of The Bahamas is English. However, there are many residents of Haitian descent and Haitian Creole is the second most used language.

The 2019 Human Development Index (HDI) for The Bahamas was 0.814, placing the country in the very high human development category and above the average of 0.766 for countries in Latin America and the Caribbean (UNDP 2020). However, there are high levels of inequality with approximately 13% of the population living in poverty, and 25% of those living in poverty being children between the ages of 5-14 years (The Government of The Bahamas 2018). While an inequality adjusted HDI is calculated for 152 countries, due to data unavailability, this statistic is not available for The Bahamas.

There has been a steady increase in informal settlements throughout the islands of the country, mostly concentrated in the islands of New Providence, Abaco, Exuma and Eleuthera (The Government of The Bahamas 2018). A 2018 survey of informal settlements on New Providence alone found 1,410 residents in 428 households. Informal settlements generally have high population densities and housing structures which are illegally constructed with non-durable hazardous material and do not meet building codes. These settlements also often lack sewage disposal systems and access to water.

5.1.4. Governance system

Since independence in 1974, The Bahamas has had a parliamentary democracy with peaceful transition of government over the past 48 years (Government of The Bahamas 2016). The Parliament consists of two chambers: an appointed Senate and an elected House of Assembly. Her Majesty the Queen, represented by the Governor General is also part of the Parliament. The Prime Minister is the elected head of government of The Bahamas. The Parliament is mandated by the Constitution to make laws for the peace, order and good government of The Bahamas and to approve the government's budget. The Parliament also maintains oversight of government financial matters.

Gender inequality is evident in government with historically low percentages of women elected to the House of Assembly. The 2021 national elections resulted in an unprecedented high of 18% of House of Assembly seats being held by women (7 out of 39 seats).

In addition to the Parliament, which address national issues, there is also an elected local government for Grand Bahama and the Family Islands (Commonwealth Local Government Forum 2020). Local government is responsible for hospitals and clinics, the supply of public potable water, the upkeep of public schools and other government buildings and general health and sanitation. Local government is not empowered to raise revenue and is funded by the national/central government. There is no local government for New Providence.

5.2. Climate risks and impacts

5.2.1. Key hazards

A range of climate hazards are relevant for The Bahamas. Hurricanes are a regular occurrence, with a hurricane affecting at least one of the many islands of the country every two years on average (Pathak et al. 2021). Projections of increased intensity of tropical cyclones due to climate change are a major hazard for the country. Climate modelling of projected changes in tropical storms suggest that rainfall associated with tropical cyclones could increase by 20-30% and that maximum wind speeds could increase by 2-11% (Community et al. 2020).

Sea level rise is another key hazard. With more than 80% of The Bahamas' land surface area being less than 1 m above sea level, along with limited land mass, sea level rise poses an existential threat for coastal communities. Sea level rise projections for the Caribbean by 2100 relative to the 1980-1999 mean span a large range, from an increase of 0.13 meters to 1.45 meters (Community et al. 2020).

Changes in precipitation are also projected for The Bahamas with longer dry seasons and shorter wet seasons. These changes may have serious implications for the water sector, as the country relies on replenishment of groundwater aquifers through precipitation as there are no rivers, streams, or other sources of surface water.

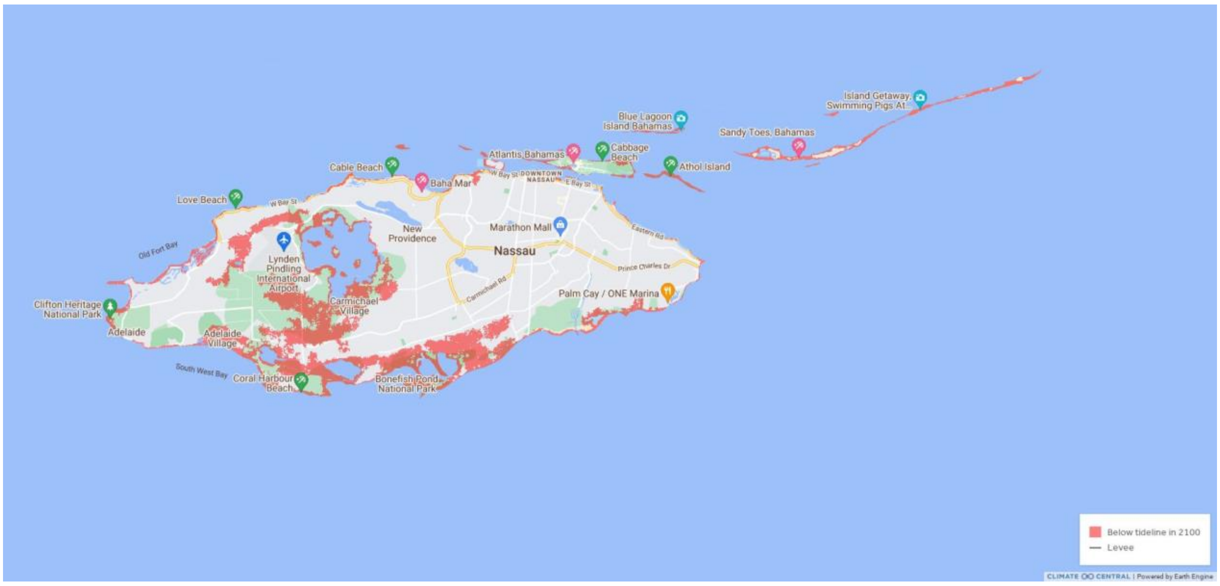

Figure 5.2. Land projected to be below tideline in 2100 with temperature increase of 2C: New Providence, The Bahamas. Source: Climate Central, 2022.

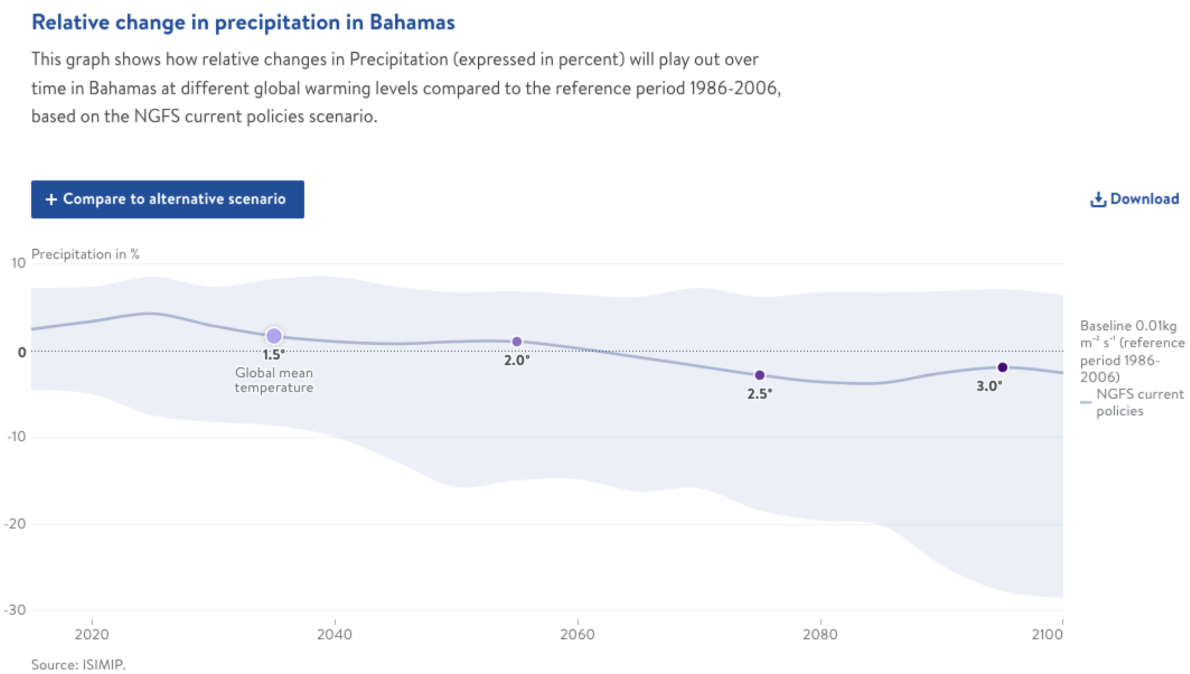

Figure 5.3. Relative changes in precipitation. Source: Climate Impact Explorer.

Ocean acidification and warming are also key hazards for The Bahamas. With 5% of the world's coral being found in The Bahamas and with the world's third longest barrier reef, ocean acidification and warming are significant hazards for coastal ecosystems which provide ecosystem services and foster biodiversity. Projections indicate that if global temperatures exceed 1.5°C of warming, approximately 99% of coral reefs will be at risk of destruction (IPCC 2018).

5.2.2. Key components of exposure

The entire nation of The Bahamas is classified as a coastal zone, due to the very flat land and small land area of the many islands (Horsley and Witten 2004). The majority of critical infrastructure – including major road networks, infrastructure, energy systems, transportation hubs, and housing – are located in close proximity to the actual coastline. These characteristics of The Bahamas mean that there is high exposure of people and assets to climate hazards.

More than 70% of the Bahamian population resides in New Providence, concentrating people and assets in a small geographic space. The island of New Providence has an area of 207km^2, with a length of 34km and width of 11km. There is limited land area available for relocation of communities or infrastructure that are located directly along the coast, thereby contributing to high exposure to climate hazards for the capital island in particular.

Migrant communities that live in informal settlements are disproportionately exposed to climate hazards as they are often located in informal housing areas that are cited in areas that are prone to flooding. For example, the majority of deaths and missing people from the 2019 Hurricane Dorian were from informal settlements located on the island of Abaco. Informal housing that did not meet building codes, along with the location of these communities in low-elevation areas, resulted in even higher exposure than the rest of the island.

5.2.3. Key components of vulnerability

The Bahamas has been consistently identified as one of the most vulnerable SIDS to climate change, due in part to limited adaptive capacity along with high exposure to increasing climate hazards (Pathak et al. 2021). There are a number of constraining factors that contribute to low adaptive capacity as detailed in Table 5.1. Limited land area constrains the feasibility of adaptation measures while economic and financial constraints make it difficult for both individuals and government actors to adapt. The lack of human personnel with climate change expertise as well as significant challenges with institutional capacities also contribute to low adaptive capacity. Low awareness of climate change risks, despite high vulnerabilities, along with the prioritization of other development challenges – such as poverty, education, and crime – are also key factors that influence vulnerability to climate change for The Bahamas.

Table 5.1. Adaptation constraints: The Bahamas.

CONSTRAINTS	OVERVIEW	SOURCES
Physical	Limited land area constrains the feasibility for some adaptation measures such as accommodation or retreat.	(Petzold et al. 2018)
Economic	Structural barriers including poverty, gender inequality and unemployment have resulted in significant inequality and exacerbated challenges faced by vulnerable groups. Reliance on tourism and financial services increases economic vulnerability to extreme climate events.	(The Government of The Bahamas 2018)
Financial	Budget constraints to fund adaptation which involves high upfront costs. No national budgeting for adaptation.	(Government of The Bahamas 2016)

Human Capacity	Lack of human personnel with climate change expertise. Capacity challenges with the National Statistical Institution (human resources and infrastructure). Institutional capacity deficiencies within environmental management agencies.	(Government of The Bahamas 2016; The Government of The Bahamas 2018)
Governance Institutions Policy	2005 National Adaptation Policy is out of date and lacks an implementation plan, resulting in limited implementation thus far. Economic development priorities may take precedence over adaptation with large scale developments, particularly in the tourism sector, taking place along the coast without considering climate risks. Lack of long-term coastal protection strategy. Lack of coordinated or organized efforts among government, NGOs and private sector in coastal protection resulting in small efforts scattered across coastlines which may result in maladaptation. Weak land use planning for New Providence with a history of mangrove deforestation and concentration of construction along the coast. Lack of enforcement of existing regulations, leading to illegal sand mining and destruction of coral reefs and mangroves. Multiple government agencies responsible for coastal protection: Ministry of Works, Ministry of Environment, Ministry of Health. Fragmented environmental legislation and management.	(Government of The Bahamas 2016; The Government of The Bahamas 2018; Petzold et al. 2018)
Information Awareness Technology	Awareness of climate change risks relatively low and focused on risks of tropical storms. Lack of reliable data on local sea-level trends. Inadequate data on the majority of SDG indicators, including SDG13. Inadequate disaggregated data by geography and gender. In general public, discussions on climate change focus more on mitigation than adaptation, e.g., banning plastic bags, need for renewable energy Short-term attention paid to climate change, particularly after an extreme hurricane or after significant international attention (e.g., Paris Agreement, COP26) with limited long-term adaptation developed and implemented.	(The Government of The Bahamas 2018; Thomas and Benjamin 2018a; Petzold et al. 2018)
Social/ Cultural	Social inequalities influence who is impacted by climate change and also affects knowledge and perceptions of climate change, with vulnerable groups having the least adaptive capacity and facing highest risks. Climate change not a significant priority in comparison to other pressing issues such as economic development, health, education, and crime.	(Petzold et al. 2018)

Despite the many constraints that limit adaptive capacity, there are some opportunities or enabling conditions that may contribute to reducing vulnerability, as detailed in Table 5.2. Climate change has gained recent and increasing attention since the impacts of the 2019 Hurricane Dorian, with more of the general public and governmental officials paying attention to climate change as risk for the country. Reports that have been developed and submitted by the government to various United Nations bodies (e.g., Sustainable Development Goals Voluntary Report, United Nations Framework Convention on Climate Change Nationally Determined Contribution), do identify that capacity constraints to address climate change as a critical issue. There has been some attention paid to the need to adapt in the draft National Development Plan and an initial Climate Change Adaptation Policy was developed in 2005, although these initiatives have yet to be implemented.

Table 5.2. Enabling conditions: The Bahamas.

Opportunities/ Enabling Condition	Overview	Sources
Awareness raising	Climate change has gained increasing attention in The Bahamas, particularly after the impacts of 2019 Hurricane Dorian. While there have been limited awareness raising efforts specifically on climate risks, there are a number of opportunities: Politically aware and engaged population on key public policy issues. Widespread newspaper readership, traditional and social media, and active radio media with multiple “all talk” radio stations discussing topical issues of the day. Public broadcasting company with nation-wide television and radio coverage. Government information services agency with a website that has information on government policies and programs.	(The Government of The Bahamas 2018)
Capacity building	National Development Plan identifies vulnerable groups where specific attention should be paid including persons living in poverty, persons living with disabilities, Family Island residents, the elderly, at-risk youth, youth falling behind academically, unemployed persons, migrants, children with obesity, single parents, women, and men with criminal records. National Development Plan details clear actions, outputs, and outcomes to improve capacity building for adaptation. Caribbean Community Climate Change Centre (5Cs) has hosted training for government officials on using the CCORAL climate change risk management tool.	(Government of The Bahamas 2016)
Tools	Emerging and Sustainable Nassau Project prepared a study on natural hazards and risks for New Providence (inland flooding, coastal flooding, and salinization of fresh-water table) and a proposed urban land use plan.	
Policy	2005 National Adaptation Policy contains adaptation policy directives for multiple sectors. Climate change entrenched in one of the four pillars of the National Development Plan. National Development Plan aligned with Sustainable Development Goals, including Goal 13 on Climate Action. National Development Plan details clear actions, outputs and outcomes to improve adaptation policy.	(Government of The Bahamas 2016)
Learning	Series of strong hurricanes affecting the country has increased contemporary experience with disaster risks.	

5.2.4. Observed impacts

There is a lack of systematic assessment of climate-related impacts in The Bahamas, with the majority of impacts that are assessed being those associated with the most extreme of events (Thomas and Benjamin 2018b). Recent hurricanes have caused catastrophic damage, injustices, and loss of lives and livelihoods on islands throughout the country. Most recently, Hurricane Dorian in September of 2019 hit the second and third most populous islands of the country, Grand Bahama, and Abaco, causing damages of approximately US$3.4 billion, over a quarter of The Bahamas' GDP (IDB 2020). Prior to this, Hurricanes Maria, and Irma (2017), Hurricane Matthew (2016) and Hurricane Joaquin (2015) affected other islands causing damages of over US$1.1billion.

In addition to these economic damages, hurricanes have also caused non-economic losses to ecosystems and communities. While there is no systematic assessment of ecosystem losses post-hurricane, a study on coral reefs after Hurricane Dorian found that 25-30% of reefs suffered severe damage, including major structural damage, high levels of debris, heavy siltation, and widespread bleaching (Dahlgren and Sherman 2020). Non-economic losses associated with displacement due to hurricanes in The Bahamas include lack of access to health care, poor living, and health conditions such as lack of running water and electricity, loss of sense of place, and loss of connection to community (Thomas and Benjamin 2019).

Assessment of impacts from slow onset events is scarce and anecdotal. However, significant coastal erosion is already identified as an issue for New Providence, where there is evidence of undercutting, exposed beach, and exposed vegetation (Petzold et al. 2018).

5.2.5. Projected risks

The risk of relative change in annual expected damages from tropical cyclones increases significantly with warming. With 3°C of warming, damages are near to 40% higher compared to current levels -which already pose significant economic challenges.

Changes to the ocean, including higher sea surface temperatures and rising ocean acidity, are projected to lead to further bleaching of coral reefs and erosion of coastal areas, putting terrestrial and marine biodiversity at risk and also threatening coastal areas with higher incoming waves and more extensive storm surges (The Government of The Bahamas 2018).

As a result of several hazards, including changes to precipitation patterns and sea level rise, The Bahamas is expected to face significant risks to water security. Freshwater resources are already finite and inadequate, requiring seawater reverse osmosis which currently supplies more than 50% of The Bahamas' potable water supply (The Government of The Bahamas 2018). Declining freshwater availability and drought are significant risks with particularly high risks for the southernmost islands where reverse osmosis technologies are less feasible due to small economies of scale (Community et al. 2020). Sea level rise is projected to increase the risk of increasing contamination of freshwater through affecting the islands' groundwater lenses. Increasingly intense extreme weather events may also damage wastewater treatment and collection systems and flood septic tanks, also increasing the risk of contaminating groundwater.

Tourism, the main economic sector for The Bahamas, is also projected to be at high risk. Most tourism properties currently lie in a storm surge zone and the extent of properties within the zone increases as sea levels rise (Pathak et al. 2021). While sea level rise alone poses a threat, the main risks are projected from sea level rise in combination with tropical cyclones. With 1 m of sea level rise, a Category 1 hurricane is projected to impact 34% of the tourism infrastructure on New Providence. A Category 3 hurricane will affect 69% of infrastructure and a Category 5 storm will affect 83% of tourism infrastructure. Additionally, properties are also at risk of coastal erosion with over 60% of infrastructure being located within 100 meters of the coastline. Given the economic importance of tourism for The Bahamas, and for New Providence in particular, the risks of climate change have far-reaching implications for economic development.

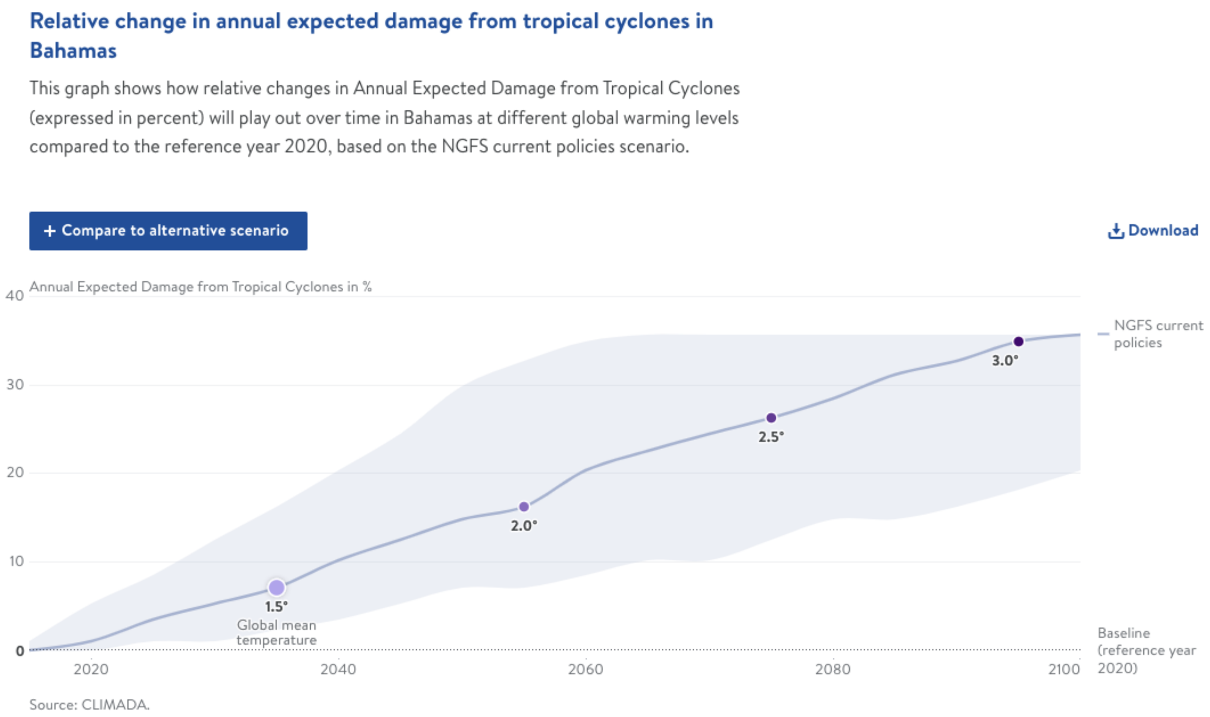

Figure 5.4. Relative change in annual expected damages from tropical cyclones, Source: Climate Impact Explorer

5.3. Adaptation policies, plans and strategies

To date, the most comprehensive adaptation policy is the National Policy for Adaptation to Climate Change which was developed in 2005. The policy establishes objectives for adaptation and key actions that are needed to address climate change for different sectors (Government of The Bahamas 2005). The policy doesn't link adaptation options identified to particular global warming scenarios. Risks of climate change that are identified are largely qualitative.

The policy identifies the government as the major facilitator of the implementation of the policy directives and provides a framework for advancing capacities to effectively adapt to climate change. However, there has been little adoption of the actions outlined in the policy. For example, while the policy advises against particular actions that would increase vulnerability to climate change, these actions continue to take place, such as continuing developing in low-elevation areas that are already susceptible to flooding (Thomas et al. 2015).

There has also been limited development of any sectoral adaptation policies or plans which are a key recommendation of the report. However, there have been some recent developments, which are detailed in Table 5.3. Most notably, The Bahamas recently gained funding approval from the Green Climate Fund to develop a National Adaptation Plan, which has the potential to significantly advance adaptation for the country. The process is expected to begin in mid-2022.

Table 5.3. Upcoming adaptation policies/plans/strategies.

Policy/Plan/Strategy	Lead Agency	Status/Expected Completion
Agriculture Adaptation Plan	Ministry of Agriculture	Late 2022
Health National Adaptation Plan	Ministry of Health	2023
Technology Needs Assessment	Ministry of Environment/ Department of Environmental Protection and Planning	Late 2022
Third National Communication	Ministry of Environment/ Department of Environmental Protection and Planning	Late 2022
National Adaptation Plan	Ministry of Environment	Expected to begin in mid-2022

While there are few dedicated adaptation policies or plans, there are a number of related policies and plans that refer to the need to adaptation. The draft National Development Plan: Vision 2040, was developed in 2016 and identifies the need for adaptation to climate change (Government of The Bahamas 2016). Goal 11 of the plan focuses on the natural environment and includes climate change adaptation as a key strategy. The plan identifies the need to increase research and development in climate change adaptation and to have an 80% increase in islands of The Bahamas that have climate change adaptation plans by 2025. However, the plan disproportionately focuses on mitigation with a goal of a 70% increase in homes using alternative energy sources in 2025, increasing the number of partnerships with green technology firms to build capacities in green technology, increasing green foreign direct investment flows by 2025 and increasing by 50% the share of renewable energy in total energy consumption. Regardless of these goals, the plan is still in draft form and has not been formally accepted or enacted by the government.

There are also some island-specific plans that refer to adaptation, although these also have not been formally accepted or enacted by the government and it is not clear whether these are being used to guide planning or development. The Sustainable Nassau Plan was developed in 2018 and identifies the need for and specific activities to support sustainable urban growth in Nassau (Inter-American Development Bank 2018). Adaptation actions identified as needed for Nassau include mangrove replanting, beach and coral reef restoration, replanting of native plants, removal of invasive species, and encouragement of low impact development techniques such as roof gardens and porous pavement. The plan also recommends the design and implementation of a coastal management plan, identifying natural barriers to protect infrastructure from storm surges and regulations against development in low-lying and floodable areas.

5.4. Implemented adaptation projects and programs

There have been some ad hoc adaptation projects that have been implemented in The Bahamas by a range of actors. NGOs have been the ones that have largely led these efforts. The Nature Conservancy is currently implementing a nature-based community adaptation project, focused on developing community-based adaptation plans. The Bahamas National Trust is similarly working with fisheries communities on some of the islands, focusing on developing specific adaptation plans for these groups. As noted in the IPCC Working Group II report, most adaptation action is focused on planning rather than implementation.

In addition to the few projects that focus specifically on adaptation, there have also been infrastructural projects that have focused on reducing coastal erosion, without an explicit link to climate change. In New Providence, man-made coastal protection schemes such as groynes, sea walls, dikes and beach nourishment have been implemented in a piecemeal fashion, largely concentrated along the northern coast (Petzold et al. 2018). The private sector and individuals have also implemented ad hoc adaptation measures, largely in response to coastal erosion (Petzold et al. 2018).

5.5. Adaptation governance and key adaptation actors

The Department of Environmental Planning and Protection (DEPP) within the Ministry of the Environment and Natural Resources currently serves as the national climate change office.[24] DEPP is responsible not only for climate change but also for the prevention or control of pollution, the regulation of activities and the administration, conservation and sustainable use of the environment and for connected purposes. DEPP also manages multilateral environmental agreement, including The Bahamas' participation in the UNFCCC and the Paris Agreement. With so many different responsibilities and limited staff, DEPP has identified capacity challenges as key factor affecting progress in climate change adaptation.

A three-person climate change unit has also been established within the Office of the Prime Minister, responsible for implementation of the government's multi-agency priorities related to climate change, including a recently introduced carbon credits bill.

DEPP has also established a National Climate Change Committee (NCCC), comprised of representatives from a range of government agencies, NGOs, academia, and the private sector. Members of the NCCC are detailed in Table 4.

Table 5.4. Members of The Bahamas' National Climate Change Committee.

Agency	Category
Bahamas Agricultural Health and Food Safety Authority	government
Bahamas Chamber of Commerce and Employees Confederation	NGO
Bahamas Maritime Authority	government
Bahamas Power and Light	Quasi-government
Bahamas Protected Areas Fund	
Bahamas Reef Environment Educational Foundation (BREEF)	NGO
Department of Agriculture	government
Department of Environmental Planning and Protection	government
Department of Gender and Family Affairs	government
Department of Marine Resources	government

[24] https://www.depp.gov.bs/

Department of Statistics	government
Disaster Management Unit (Social Services)	government
Forestry Unit	government
Meteorology Department	government
Ministry of Environment and Natural Resources	government
Ministry of Public Works	government
Ministry of Tourism	government
Ministry of Transport and Local Government	government
National Emergency Management Agency	government
Port Department	government
Sustainable Development Unit at Office of the Prime Minister	government
The Nature Conservancy	NGO
University of The Bahamas	academia

5.6. Spatial structural and strategic profile of the city of Nassau

This section summarizes an evaluation of the capacity of the spatial structure of the island New Providence and the city of Nassau, for details see Chapter 11. The urbanized area of New Providence is located on the eastern half of New Providence, along the coastal zone. Nassau city is a low-rise sprawl. The city only really urbanized in the 18th century with a stretch of some 15 blocks along the coast, where the harbour and colonial buildings are. The town's fabric was made up of English-style masonry houses aligned to the property line, placed on large plots of land. Nassau's modern growth began just over 200 years ago as the population grew along with the built-up areas. After the Second World War, the Nassau airport reverted to civilian use and developed as the largest airport in The Bahamas and the largest international gateway into the country. Population levels exploded in New Providence at that time as the tourist economy began to develop, and the city extends to the east coast of the island. The wealthier residents continued to spread east and west during the 21st century. Today, the urbanized area covers more than one-third of the island. Land use on New Providence is directly related to the primacy of the city of Nassau as the major Bahamian urban area. The mobility network on the island is challenged by a lack of room to expand and a lack of public transport network. As such, there are no cross-island public transport routes to allow users to travel directly from one side to another. The current mobility and transport system in New Providence does not appear to be supporting the island's economic, social, or environmental well-being.

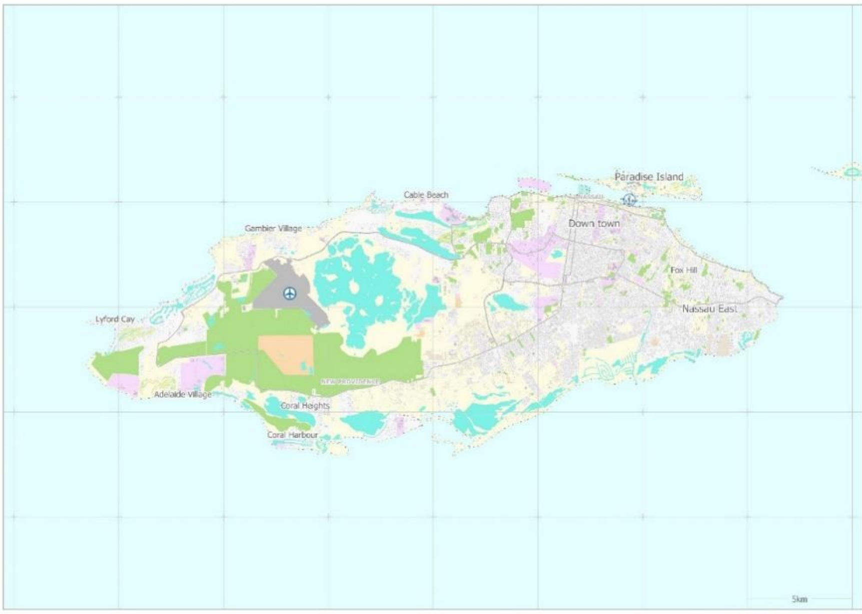

Figure 5.5. Base map of New Providence, image by BUUR/PoS 2022

New Providence is an island of low altitude mainly composed of sand, coral, lakes, and ponds. The ecological value here is high and the scenic quality makes New Providence a unique place. Almost a quarter of the island is occupied by nature elements (inland water, forest, and national parks). Wetlands on the island not only provide habitats for a wide variety of wildlife species but also play an important role in water management. However, uncontrolled urbanization and a lack of long-term urban planning and urban management vision on the island lead to a very severe water resource situation in New Providence. Surface water features may be polluted by industrial and urban runoff. The only source of freshwater in the country is rainfall. Thus, inland wetlands fulfil an important function as water catchments, influencing the condition of the island's freshwater lens. During the rainy season, inland wetlands can collect and store water away from homes and roads. Nevertheless, a lot of building was and is still built along these shallow basins. Consequently, the ecosystem's ability to prevent flooding is diminished. Due to low relief and large urban areas, the New Providence is often inundated.

For New Providence, hurricanes and other tropical storms that cause extensive flood and wind damage are two major climate risks. The urban structure in the coastal zone makes New Providence more vulnerable here. This is due to the proximity of most buildings and functions to the coast, but also to the strong urbanization of the area that makes natural water management difficult. The coastline and its storm and flood security under a rising sea level should be further investigated. Much of the New Providence coastline consists of long, flat coral formations interrupted by small beaches, estuaries, and wetlands – this appears to be a resilient system. The urbanized coastline is also well protected by port and marina infrastructure. However, in both cases, it is not certain that this protection will hold up to increasingly extreme weather events along the coast, and in that case, the spatial structure of the island is very vulnerable. The adaptation strategies are structured around restructuring coral reefs and underwater plants, beach restoration mangrove protection, and infrastructure adjustments.

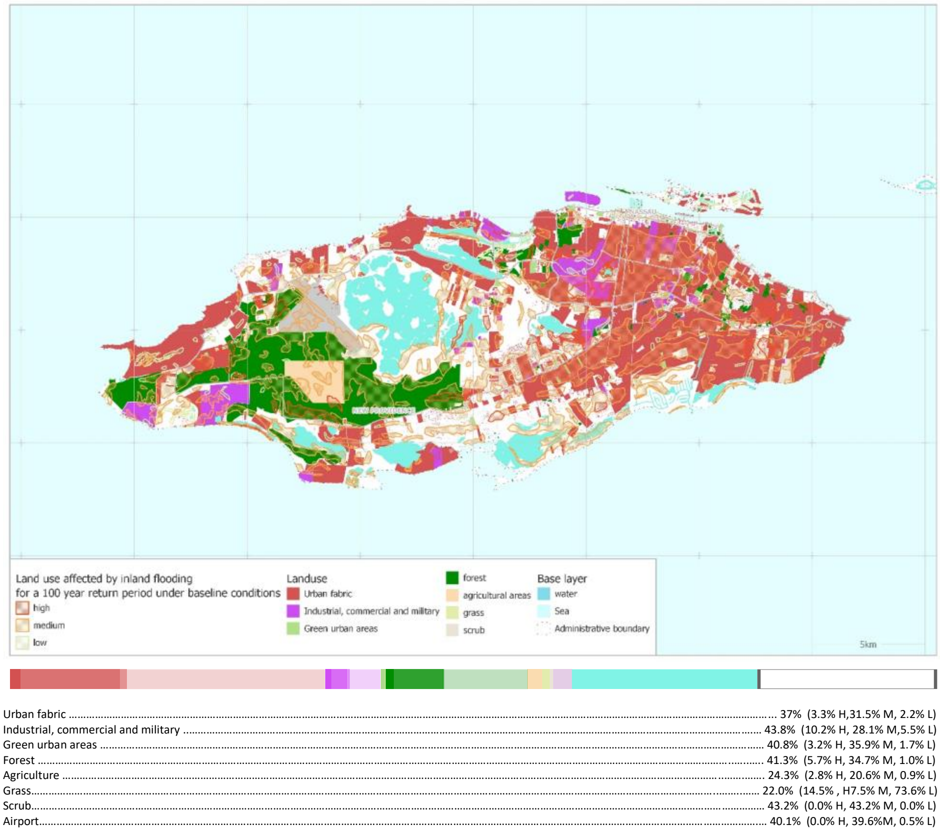

Figure 5.6. Land use affected by inland flooding (BUURpos, 2022)

5.7. Insights from stakeholder engagement meeting

5.7.1. Workshop purpose and setting

The first PROVIDE Stakeholder Engagement Meeting in the Iconic City of Nassau was held on April 22, 2022, in a virtual setting. Invitations to the meeting were coordinated by the PROVIDE team who sent out official invitations on behalf of the project to all members of the National Climate Change Committee (NCCC) and to other individuals that were identified by NCCC members as relevant to adaptation planning for the country. These included representatives from government agencies, NGOs, the private sector, and academia. The meeting language was English. There was a total of 12 participants. The meeting was supported and moderated by the PROVIDE team.

5.7.2. Overshoot and limits to adaptation

Participants were introduced to the PROVIDE project and to key concepts used in the project, including overshoot and limits to adaptation. Participants were asked to share their views on the relevance of PROVIDE for The Bahamas and familiarity or questions about key concepts. Participants expressed support for the project and that there is a need to focus on adaptation. However, there was very limited familiarity with concepts of overshoot or limits to adaptation. There were some questions about the effects of changes to the ocean affecting the ability of coastal and marine ecosystems to provide critical ecosystem services, such as protection from coastal erosion and flooding. This was the most direct engagement with the limits to adaptation concept among the group. It was noted by participants that capacity building in this area would be welcomed.

5.7.3. Adaptation in the Bahamian context: tools, constraints, opportunities

After a presentation highlighting the current state of national adaptation that was gleaned from a review of the literature, participants were invited to provide their inputs on the current state of adaptation as well as constraints and opportunities. Participants expressed that the most pressing constraint is lack of capacity. While there are efforts being made within various agencies to consider climate change in ongoing responsibilities, there is a lack of trained personnel that is experienced and knowledgeable about the particular aspects of climate change that are relevant for each of the various sectors. The lack of progress with implementing the National Adaptation Policy as well as the lack of a national adaptation plan were also identified as key constraints for adaptation. In terms of opportunities, The Bahamas will soon embark on developing a national adaptation plan and participants did express that output from PROVIDE could help to inform that process. Other participants asked about how PROVIDE relates to other adaptation planning tools that have been introduced to the country, such as the CCORAL tool which provides guidelines for risk management and adaptation planning. It was determined that outputs from PROVIDE could complement these other tools by providing information on different levels of risk that will need to be adapted to at various levels of global warming.

Participants were very interested in development of the PROVDE Dashboard and indicated that projections for the entire island of New Providence, instead of only the small area of the city of Nassau, would be most helpful. The indicators of damages from tropical cyclones as well as heat stress were most supported by participants. Participants indicated interest in providing further feedback on development of the Dashboard when further progress is made.

Presentation of the spatial analysis of New Providence based on limited publicly available data was made by the BUUR team, see Appendix for details. Participants identified further public information sources of spatial data, including some data on coastal hazards that was completed by Stanford University. Participants recommended contacting the Inter-American Development Bank to get spatial data that was part of the Sustainable Nassau project. However, participants were unable to state whether the Sustainable Nassau plans were actually being used to guide planning or activities in the city.

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6. Summary Part I

6.1. Adaptation challenges across the Iconic Regions

The four regions in focus for PROVIDE are very different in relation to both climate and social settings. Nevertheless, they have in common that adaptation to climate change depend on a range of both social and environmental factors that will affect limits of adaptation as well as the potential for managing emission scenarios that overshoot the goals of the Paris agreement. Common features across the regions include lack of economic capacity for adaptation, lack of expertise locally and regionally, and poor administrative coordination. Furthermore, all regions report examples where the impacts of climate change will affect adaptive capacity, including impacts related to migrations and to impacts on key economic sectors. Tables 6.1 and 6.2 summarize some of the most important adaptation challenges for each region.

Table 6.1. Summary of the most important adaptation challenges for Arctic Fennoscandia and Iberian Mediterranean

	ARCTIC FENNOSCANDIA	IBERIAN MEDITERRANEAN
CLIMATE CHANGE AND ECOSYSTEM IMPACTS		
Major climate change concerns	Increased likelihood of extreme precipitation Warmer and more unpredictable winters	Extreme heatwaves Wildfires Water scarcity and droughts Storms and dust storms Sea level rise Soil erosion and desertification
Critical ecosystem impacts	Loss of snow and ice habitats Loss of subarctic ecosystems Changing food webs New pests and disease vectors	Loss of agricultural productivity Abandoned farmland Degraded/lost agroforestry ecosystems Loss of forest cover Degradation of air quality Degraded/lost coastal and riverine ecosystems
ADAPTATION CONSTRAINTS		
Physical and biological	Northern coast limits northward shift of terrestrial biomes Long generation times limit genetic adaptation	Low water availability Dense urban areas Coastal population agglomerations
Economic and financial	Lack of economic capacity in small municipalities Many economic activities affected by weather and ecosystem changes: fisheries, forestry, herding, tourism	Low capacity for investments Lack of policy and fiscal incentives for adaptation Potentially low effectiveness of infrastructural interventions

	ARCTIC FENNOSCANDIA	IBERIAN MEDITERRANEAN
Human capacity	Outmigration from rural areas Lack of expertise and capacity in small municipalities	Lack of expertise, e.g., in public administration Lack of collaborative learning Outmigration from rural areas
Governance/ Institutions/Policy	Weak incentives for local adaptation actions	Poor mainstreaming due to fragmented approaches and policy, lacking horizontal and vertical integration and lacking human resources Poor development and use of climate services Transboundary risks: Portugal/Spain
Information/ Awareness/ Technology	Attitudes of facing whatever comes	Under-estimation of risks Mitigation overshadowing adaptation and DDR Climate model bias (hot model problem) Lack of information on cascading risks
Social/Cultural	Increasing land-use conflicts	Other socio-economic development issues higher priority in most sectors

Table 6.2. Summary of the most important adaptation challenges for the Upper Indus Basin and The Bahamas

	UPPER INDUS BASIN	THE BAHAMAS
CLIMATE CHANGE AND ECOSYSTEM IMPACTS		
Major climate change concerns	Extreme temperatures and heatwaves Highly variable precipitation patterns Disrupted monsoon cycles Flash floods and glacier lake outbursts Droughts	Increased risk of intense tropical cyclones Sea level rise leading to flooding and inundation
Critical ecosystem impacts	Loss of glaciers and snow habitats Loss of forest cover Impacts on desert ecosystem Disturbed crop lifecycles affecting agricultural yields Water stress affecting freshwater and mountain ecosystem	Loss of coastal ecosystems (coral reefs, mangroves, sea grass) and their ecosystem services
ADAPTATION CONSTRAINTS		
Physical and biological	Hard-to-reach areas, elevated topography	Limited land area constrains feasibility of adaptation measures
Economic and financial	Financial resource crisis Climate adaptation not prioritized Low economic capacities of provincial and local governments Economically important industries (agriculture and services) highly affected by climatic hazards Recently focused tourism industry might collapse	Significant social inequality exacerbates differential vulnerabilities Reliance on tourism and financial services increases economic risks
Human capacity	Poor adaptation knowledge among policy makers Poor knowledge and capacity for long term planning Outmigration from disaster-prone areas Rural to urban migration	Limited human personnel with adaptation expertise

	UPPER INDUS BASIN	THE BAHAMAS
Governance/ Institutions/Policy	Administrative challenges Transboundary nature of the Indus River system Low institutional coordination Institutions lack the tools to monitor climate and impacts Lack of cross-sectoral capacity planning Lack of insurance policies	Fragmented approach to adaptation policy, planning and implementation with responsibilities split into multiple agencies
Information/ Awareness/ Technology	Lack of comprehensible awareness raising in inaccessible disaster-prone areas Awareness raising mainly during disaster onset or post disaster Slow or absent technology advancement for climate monitoring and lack of early warning systems Lack of climate resilient infrastructure	Low awareness of extent of climate risks More focus on mitigation rather than adaptation
Social/Cultural	Climate change not a priority among other development issues Ignorance towards human activities that may exacerbate climatic events Poverty hindering investments in adaptation measures, especially among vulnerable communities Inequitable access to key resources for adaptive capacity Women lack representation at decision making positions	Climate change not a priority in comparison to other pressing development issues

6.2. Knowledge gaps

Tools for makings scenarios of future climate change are often available but these rarely take the social context of decision making and adaptation action into account. There is thus a need for tools that could facilitate detailed assessments of adaptive capacity at the local level in ways that identify weaknesses in adaptive capacity and point to potential short and long-term actions that lie within the mandate and responsibility of the users.

6.3. Implications for PROVIDE's Overshoot Proofing Methodology

The overshoot proofing methodology needs to take the complexity of adaptation into account, including social factors that are not directly linked to climate but affect adaptive capacity and thus the "soft" limits of adaptation. It also needs to consider that users have varying capacities regarding adaptation planning (from beginners to advanced) and be explicit about the role of PROVIDE's methodology in relation to other tools and support functions for adaptation.

6.4. Implications for PROVIDE's Climate Services Dashboard

A major challenge is to make the Dashboard matter in the practical work of municipal planners and other actors responsible for implementing adaptation actions in different governance contexts, and to ensure that it provides additional value in relation to existing tools and guidelines that may have been developed by national authorities and agencies.

6.5. Implications for further work in WP4 and regional stakeholder engagement

In addition to identifying stakeholders at a general level, there is a need to identify the most likely local and regional level users of the Dashboard, including those who are formally responsible for adaptation actions in different governance contexts, e.g., spatial planners and local and regional governments with responsibility for adaptation strategies and planning. One effective way might be to reach out to existing national or regional networks and/or coordinating agencies at the national level, but different approaches are likely needed for each region.

II. Insights from analyses of structural and strategic profiles

7. The role of spatial structure in relation to climate-change impacts and adaptation: From structure to strategy

Lead author: Sarantis Georgiou, BUUR Part of Sweco

7.1. Foundations

The structure of an urbanized landscape is an important parameter in climate change mitigation and adaptation due to the spatial nature of associated measures and strategies. Spatial planning for the management of (climatic) risk, necessitates the incorporation of a conceptualization of risk within the design-research and planning process (Klijn et al. 2015). This is both because "the spatial distribution of (…) risk is an outcome of [the] relationship between urbanisation and nature (…) [n]amely, land use/land cover patterns alter (…) processes and the likelihood of (…) hazards" (Kuzniecow Bacchin 2015), as well as because "development concerns the introduction and growth of new activities, and the successful mutual adaptation of the landscape and the population to these changes, leading to their maintenance and continued development" (Allen 1997).

Both in general climate change-related spatial planning and in the context of the PROVIDE project's inquiry into climate overshoot scenarios, the spatialization of climatic risk and corresponding responses is, essentially, an evaluation of their respective spatial impact and limits both to their deployment, and to their performance. The question that the elaboration of spatial and strategic profiles for the case-study Iconic Regions and Cities seeks to address is thus: How does a spatial system need to be adapted in order for the impacts of climate overshoot not to impede adaptation? This is approached through the mapping and cartographic analysis of the composition and configuration of a series of spatial systems, from the perspective of evaluating if and to what degree said composition and configuration is manifested according to the particularities of the specific climatic risks. Further, the evaluation is concluded by a characterization of the associated space in reference to the overall presence of the space necessary for mitigation and adaptation, and its specificity in terms of the possible measures and strategies it could host.

In the PROVIDE project, and contrary to 'traditional' approaches to climate-related spatial planning, the important issue is the design of the capacity of a spatial system to not only adapt to changing climatic conditions, but, also, that the associated measures and solutions steer the system back to a desired situation. As such, the project seeks to determine whether and how adaptation/mitigation actions can: 1) be effective to limit or avoid overshoot, 2) be effective under overshoot conditions, and 3) be effective in restoring climatic conditions to the desired levels during overshoot. With the emphasis on dealing with the effects of climate overshoot, the 'starting-from-limits reverse-impact-chain' methodology of the PROVIDE project is translated, in reference to the spatial conditions of the case-study Iconic Regions and Cities, into an inquiry in their spatial structure, where the 'limits' are the evaluation of said structure from the perspective of dealing with a particular climatic risk: if and to what extent appropriate space is available to be transformed and organized in such a way so at for the territories in question to be able to mitigate and adapt to the associated climatic changes.

7.2. Methodology

The overall approach for the development of the Spatial and Strategic profiles of the Iconic Regions and Cities is summarized in Figure 7.1. The mapping and cartographic analysis process is underpinned by the attempt to correlate the spatialization of various urban and regional systems (right) with the parameters of climatic risk (left). The latter refer to the concepts of exposure and vulnerability/sensitivity (Klijn et al. 2015) and, particularly, how these affect and are affected by the presence of appropriate spatial potential to address them, that is, either protect against them, or cope with them, or, ultimately, accommodate them (Meyer et al. 2015).

Resistance, resilience, adaptation, and mitigation against a stress/stressor are core components of the functioning of any complex system: for a system to be able to perform, the stress/stressor/changes have to be within its ability to address them, that is, the limits/thresholds of its associated capacity must not be breached. This means: 1) enlarging the limit/threshold range (i.e., increase the resistance of the system through defences), 2) moving the limit/threshold further from the system (i.e., increase the resilience of the system through embedding within it its exposure to the manifestation of a hazard), and 3) moving the system away from the limit/threshold (i.e., increase the adaptive capacity of a system through decreasing its vulnerability/sensitivity by safe-proofing its development) (van Veelen 2016). It is these limits/thresholds that are to be analysed through this project: all three indicate the spatial/physical and functional/institutional capacity of a system to implement and embed within it measures of resistance, resilience, adaptation, and mitigation. Adaptive capacity is precisely that, and it is defined as whether or not the system has the sufficient capital for such measures, as well as the possibility to reorganize it accordingly: potential and connectedness are the measures of adaptive capacity (Holling 2001), which gives the final expression of risk as seen in Figure 7.1 (Füssel and Klein 2006; Georgiou 2019; van Veelen 2016). As such, the extent to which spatial/physical and functional/institutional capital exists, as well as the extent to which this can be reorganized, determine the adaptability of a system, that is, the possibility of integrating and embedding relevant measures.

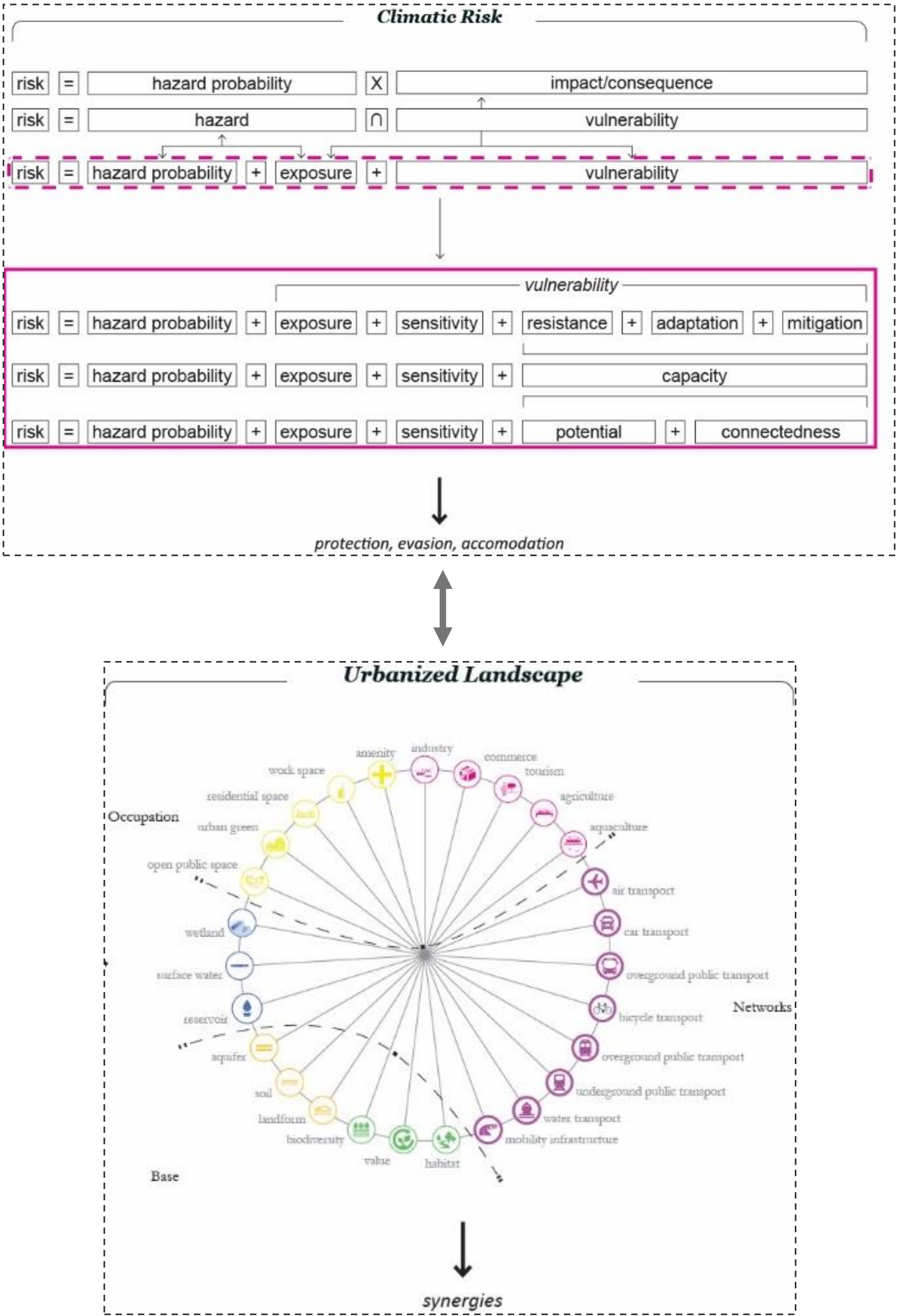

Figure 7.1 Theoretical, conceptual and analytical basis for the mapping and cartographic elaboration of the Structural and Strategic Profiles for the Iconic Regions and Cities, image by BUUR/PoS 2022

Reiterating, thus, what was described in the previous sub-section, the elaboration and development of the Structural and Strategic Profiles for the Iconic Regions and Cities are an inquiry into the presence of adequate potential and the possibility of its corresponding reorganization. Following (Alberti 2008), (Kuzniecow Bacchin 2015) and (Georgiou 2019), potential here refers to the ecological structure, the non-built-up-space system, and the mobility and surface hydrography networks. The corresponding evaluation is done according to the particularities of the specific climatic risks that are of relevance to the project and each of the case-study sites.

Finally, the selection of the various spatial systems that compose the case-study sites is based on complex socio-ecological/technical systems theory (McGinnis and Ostrom 2014; McHarg and American Museum of National History 1969; Ostrom and Cox 2010): "[i]n the layered approach, interactions are investigated between three layers which are said to determine the spatial contours of a region: the "base layer": the substratum, made up of the system of water, soil and the life forms inherent in them; the "network layer": the physical infrastructure of shipping routes, road transportation and railways; the "occupation layer": the spatial patterns resulting from human use of the substratum and networks, for example, urbanization and agriculture" (Meyer et al. 2015). Zagare (2018) proposes a 4th layer "governance" to account for the dynamics of the institutional frameworks, processes and tools that shape a system.

The outcome of such an approach is the ability to create composite images of a region that highlight the interrelationships between its elements. Based on the challenges faced by the four Iconic Regions and Cities, an indicative selection is shown in Figure 7.1. These are a selection of systems whose spatial and temporal distribution is directly related to the adaptation needs of the Iconic Regions and Cities as described in the PROVIDE project proposal: water availability, primary production, rain/storms/snow and avalanches, sea level rise and wave heights, flooding (coastal/tidal, fluvial, pluvial), temperature changes and drought, biodiversity, pollution, transport, economy, culture, and urban expansion.

As such, the aforementioned composition and configuration of the spatial extent of the Iconic Regions and Cities and the evaluation of the spatial limits to their adaptive capacity (their potential and connectedness) are done according to this selection of spatial systems. It is, thus, the interrelationship between the ecological structure, the non-built-up space and the infrastructural networks, on one hand, and the various urban and territorial systems on the other that is mapped and cartographically analysed to determine their correspondence with the manifestation of a particular climatic risk and the ability to address it.

7.3. Workflow

The overall methodology for the development of the spatial and strategic profiles for the Iconic Regions and Cities is illustrated in Figure 7.2. Through the project progress, the specificity of the case study sites, and the particularities of the climate risks to be addressed, the mapping and cartographic analysis delineates a series of appropriate spatial scales (spatial extents). Through these (and a corresponding resolution) a series of spatial systems belonging to different layers (Meyer et al. 2015) is mapped and further quantitatively and qualitatively analysed. Said analysis is done on the basis of established criteria (indicators, variables and metrics) that, each time, pertain to the risk at hand (Kuzniecow Bacchin 2015). The first step thus corresponds to the elaboration of the overall 'spatial profile' of the Iconic Region and City, while the latter corresponds to the 'strategic profile.' The difference between the two is that the first is a description of the current situation, while the latter is an evaluation of its performance when confronted with a risk. For each different risk, different criteria (and, thus, different indicators, variables, and metrics) will be touched upon, stemming from the particular functions and services the corresponding case-study site has to perform and provide (Millennium Ecosystem Assessment 2005).

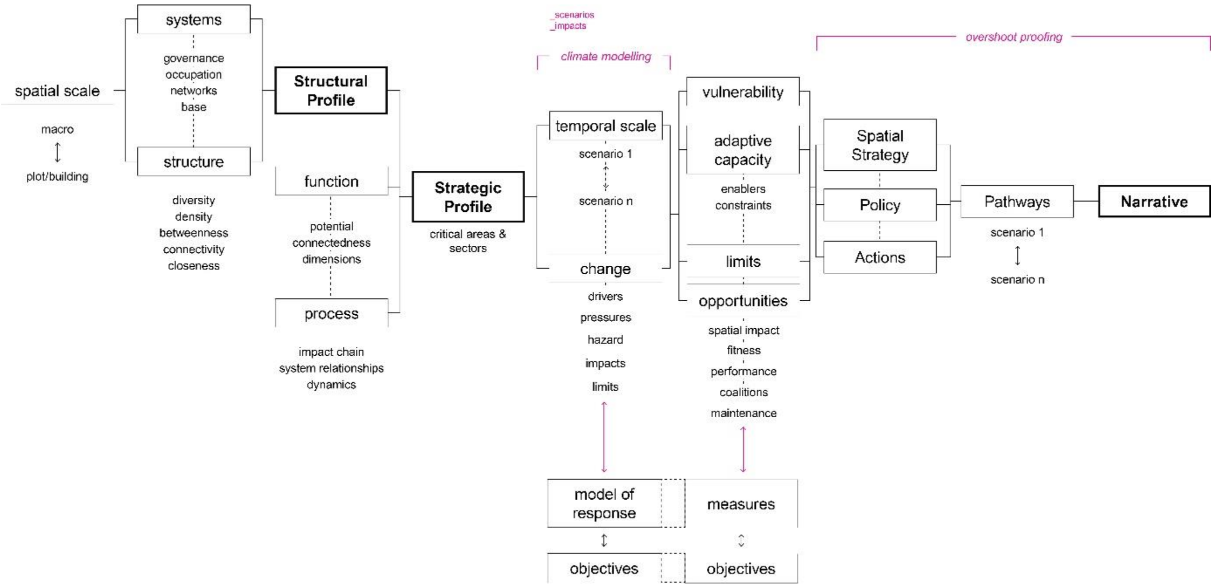

Figure 7.2 Methodological flow diagram of the work process, image by BUUR/PoS 2022

Risk mapping takes the form of the evaluation of the spatial extent from the perspective of its capacity to deal with a particular risk, that is, the correspondence of its spatial structure and the specificities of the spatial manifestation of said risk. In other words, the Strategic Profile is an indication of the spatial limits that should not be in order for the territory in question to be able to deal with a particular risk. The critical role of risk mapping has been established in scholarship and practice (Pieterse et al. 2013) and is of particular relevance to the inquiry of adaptation needs, thanks to the fact that it can be used to show how the structural profile of a region and its various systems will be impacted by a hazard. The importance of risk mapping rests, thus, in its ability to indicate the impacts of a hazard on a spatial system, its different characteristics that may be of relevance to policy and plan making, as well as, through showing how adaptive capacity (potential and connectedness) is affected, indicate adaptation needs. As such, it is a crucial element for the move from the structural profile of a region to how it should be adapted.

The difference between 'traditional' risk mapping and the one that is carried out within the scope of overshoot planning for the PROVIDE project is that instead of overlaying the spatial and temporal characteristics of a hazard (represented in a hazard map) over some aspects of a region [e.g. the composition and configuration of a spatial system, or the characteristics of the affected aspects like economic loss, fatalities etc. (de Moel et al. 2015)], mapping here takes on the role of characterizing the composition and configuration of an urbanized landscape in reference to the issue and task at hand, that is, highlight the spatialization of the particular patterns of manifestation of a specific climatic process in terms of the corresponding urbanization patterns that signify adaptive and mitigative capacity. The resulting Strategic Profile is, essentially, a map that illustrates spaces of critical importance and their inherent characteristics in reference to adaptation and mitigation to the risk at hand. Through the employment of different climatic and socio-economic scenarios, the Structural Profile is subsequently evaluated from the perspective of changes in vulnerability and adaptive capacity through the limits and opportunities of a determined mode of response, resulting in a series of mapping narratives of adaptation. Said scenario-based projection of adequate land availability for specific adaptation and mitigation actions is an elaboration of the feasibility and the performance of overall adaptation strategies to address overshoot conditions. The present chapter and chapter 8-11 deal with the Structural and Strategic Profiles, while the subsequent steps will be carried out during the next phases of the project.

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8. Structural and strategic profile: Bodø, Norway

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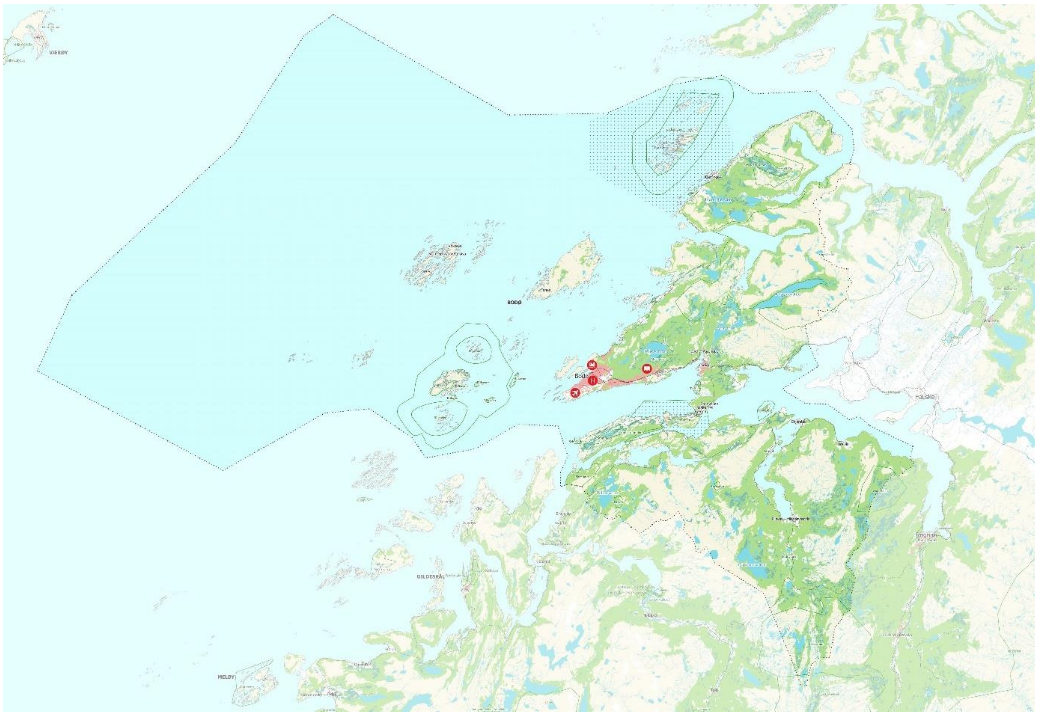

Figure 8.1 Base map Bodø municipality, image by BUUR/PoS 2022

Figure 8.2 Base map Bodø urban zone, image by BUUR/PoS 2022.

8.1. Introduction

Bodø is a city in northern Norway, in Nordland County, with a population of almost 53,000 people and an area (on land) of almost 1400 km² (for more general info, see Section 2.2 Introduction to Bodø Municipality, Nordland County, Norway). That huge area is in contrast with the compact town itself, located on a flat peninsula surrounded by sea, mountains, islands, and fjords.

The place where Bodø is located has a history that dates back to the Vikings. However, the current town did not flourish until the 19th century, as a small city focused on fishing and sea trade. Around 1900, the harbour and breakwater were constructed, an important milestone for the urban development. At that time, the town had about 6,000 inhabitants, living in colourful wooden houses, organized according to a square grid parallel to the coastline. The city had a compact structure and was surrounded by swamps and farmland. Along the harbour were the main larger buildings: warehouses, church, hospital, schools. However, during World War II, Bodø was almost completely razed to the ground during a German bombing raid: up to 80% of the houses were destroyed. The reconstruction lasted until about 1960. The town was rebuilt and enlarged, with wider streets but a similar square grid as before. Several main axes were created, and the centre received a number of central plazas and parks. The general building height was increased to three storeys, the area reserved for commercial functions increased. The centre remained focused on the harbour (Marthinussen & Bjørklund 2017).

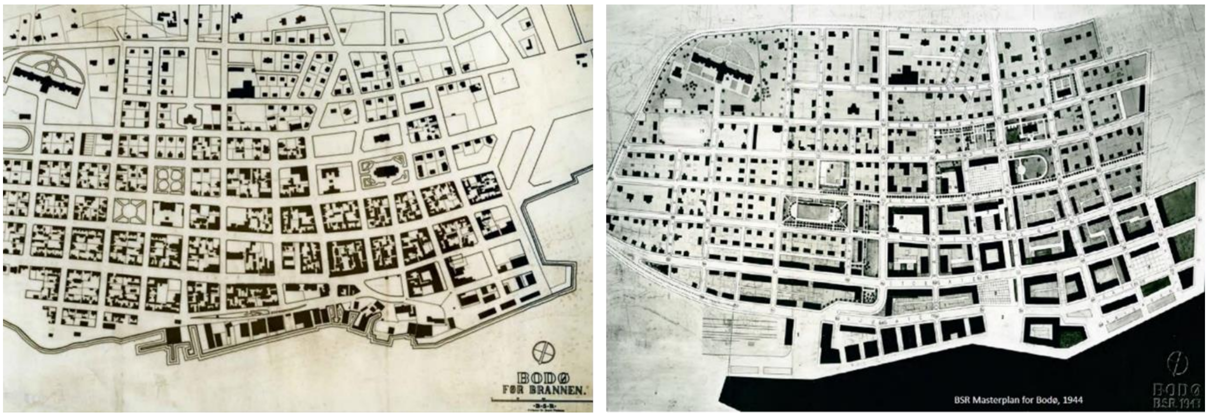

Figure 8.3 Bodø before the bombing in 1940 (left), and the plan for reconstruction in the 1950s and 1960s (right) (Marthinussen & Bjørklund 2017, pp. 31-32)

At the same time, a large NATO airport was built south of the city, which soon occupied more than half of the peninsula. Bodø also grew rapidly in area and population. A large merger with the adjacent municipalities increased the surface of the municipality to the present area. The urban area grew mainly eastward and northward, along the coastline. In the south, the airport blocked further growth, and inland the mountains made growth impossible. In Mørkved, east of the centre, a new university campus was founded around which an entire city district grew. Northwards, new suburban neighbourhoods were built. However, Bodø's horizontal growth was halted in 2000 to avoid urbanizing the remaining (flat) open space. Since then, Bodø has mainly focused on densification of the centre. In three blocks along the harbour, high-rise was allowed, one hotel tower has already been realized. At the same time, work was done on urban renewal with the construction of the new library and concert hall right next to the water. The building, with its sober but stylish architecture, gives the entire waterfront a new elan. Another important evolution is that more housing is being allowed in the centre, which also increases the liveliness.

Figure 8.4 Bodø city in 1950 (left) and in 2000 after the expansion towards the east and north (right) (Marthinussen & Bjørklund 2017, p. 33).

In 2012, the decision was made to move the NATO air base to Trondheim. Although a disaster for the local economy in Bodø, this decision also creates new opportunities. A new, civilian airport will be built more to the south, so that a significant part of what is now NATO territory can be redeveloped as a new, mixed-use city district – covering almost the same area as the current city centre.[25]

Bodø is a relatively small town, in an imposing landscape. With its plans for urban renewal and expansion, it is playing a pioneering role in Norway. At the same time, these plans represent a unique opportunity to prepare the city for the future: radically opting for sustainable urbanism and climate security. The climate risks for the urban area are well known and include sea level rise, higher probability of extreme storms, heavier precipitation with an impact on rainwater runoff and risk of flooding (see also Sectionr 2.3.5 Climate-related risks in Bodø municipality). None of these risks represent significant danger to residents today. Nevertheless, it is crucial that the projects planned today for the Bodø of (the day after) tomorrow, consider this changing future.

8.2. Structural profile

8.2.1. Soil and topography

The urban area of Bodø lies on a fairly flat peninsula, but the rest of the municipality has a much more jagged relief with quite a few mountains. One third of Bodø's territory is above 300 m sea level, one third below 60 m (see Figure 8.5). Most of the municipality consists of rocky ground with large boulders and not very fertile soil. Water permeability is also low (see Figure 8.6 and Figure 8.7). On the peninsula, the soil consists of sediments left by the sea with higher permeability. This zone, like the flatter coastal zones elsewhere in the municipality, is also more fertile, and so are some of the valleys carved by glaciers during the last ice age.

The subsoil of Bodø consists of various rocks from different time periods, the most important being lime, sandstone, granite and quartzite. In the northern part of the municipality, we see a lot of quartzite and slate, in the south gneiss and granite dominate.[26]

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[25] For more information, see https://bodo.kommune.no/planprosesser/horing-og-offentlig-ettersyn-kommunedelplan-for-hernes
[26] See https://geo.ngu.no/kart/berggrunn_mobil/

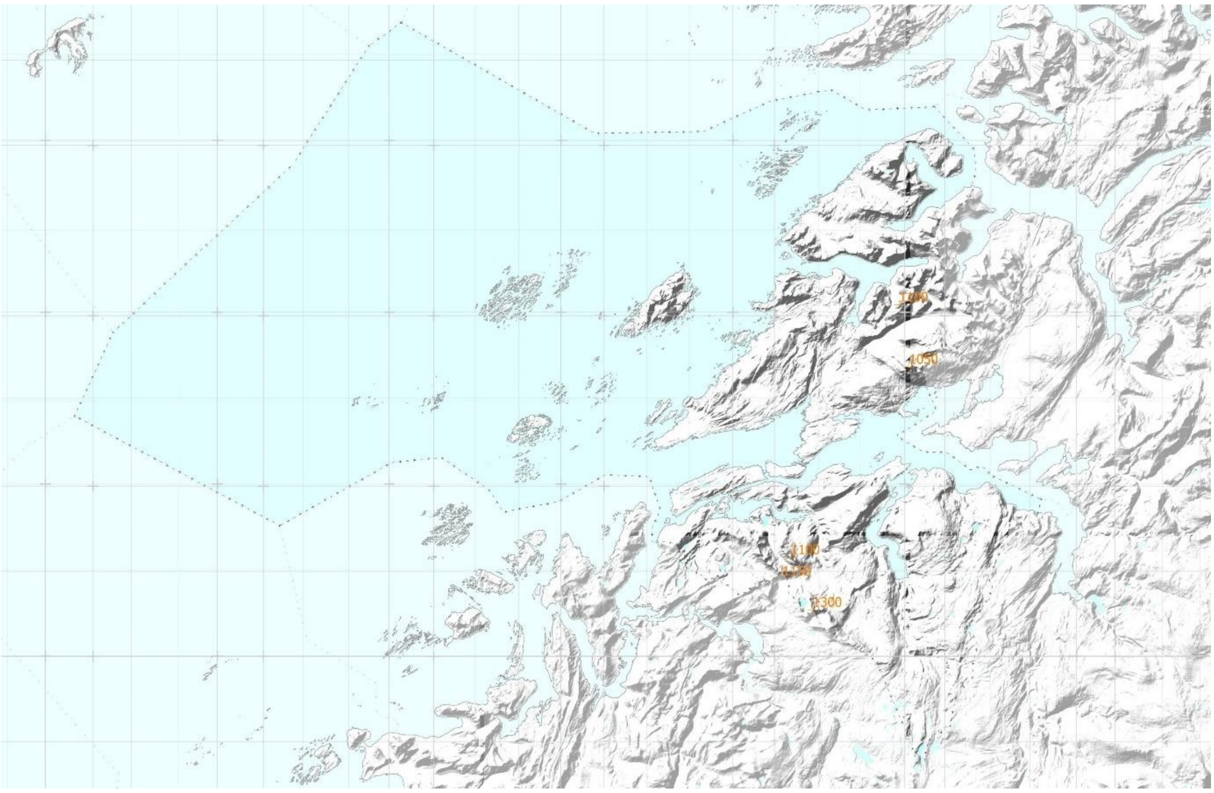

Figure 8.5 Topography, image by BUUR/PoS 2022

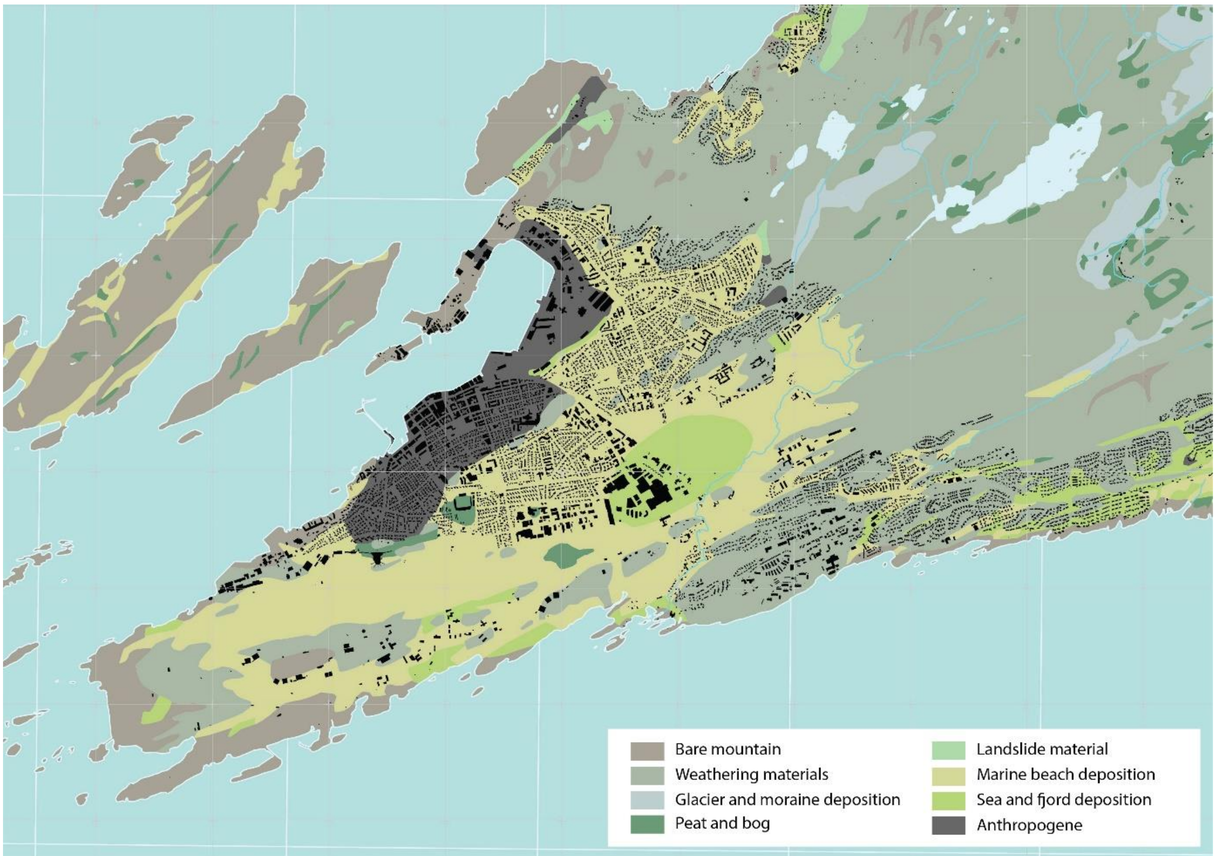

Figure 8.6 Sediment map, image by BUUR/PoS 2022

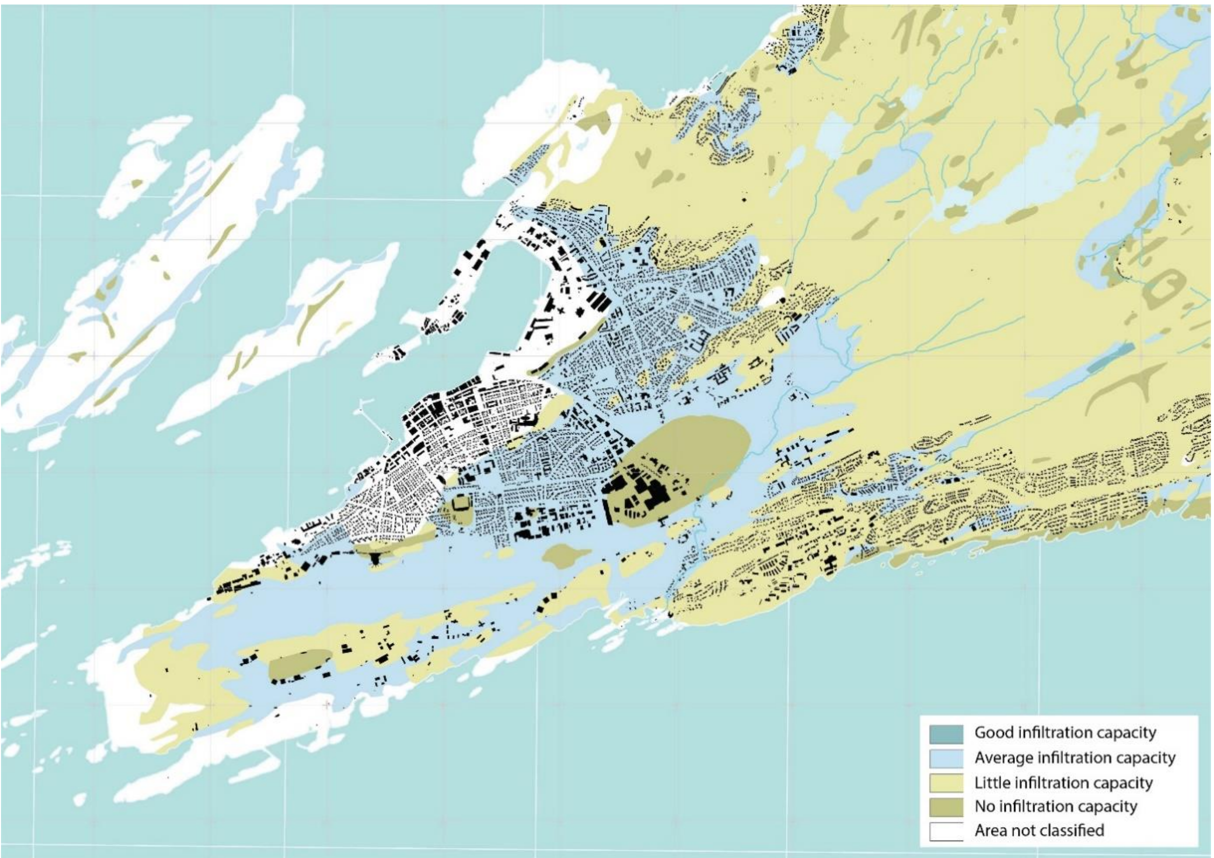

Figure 8.7 Soil infiltration capacity, image by BUUR/PoS 2022

8.2.2. Water

Bodø has many water-rich areas, with lakes and an extensive network of small streams and rivers. These have a high nature value and are also attractive for recreation and fishing. As visible in Figure 8.8 and Figure 8.9, there is not really a single catchment area, but the water network consists of numerous small streams that flow directly from the higher, mountainous areas to the sea. These streams are fed by rainwater and meltwater. Whereas in the natural zones these streams are very numerous and widely branched, in the urban area of Bodø we see a much lower density of open streams. In the urban area, rain and melt water is mainly drained through the urban sewage system and only to a limited extent along natural, open watercourses.

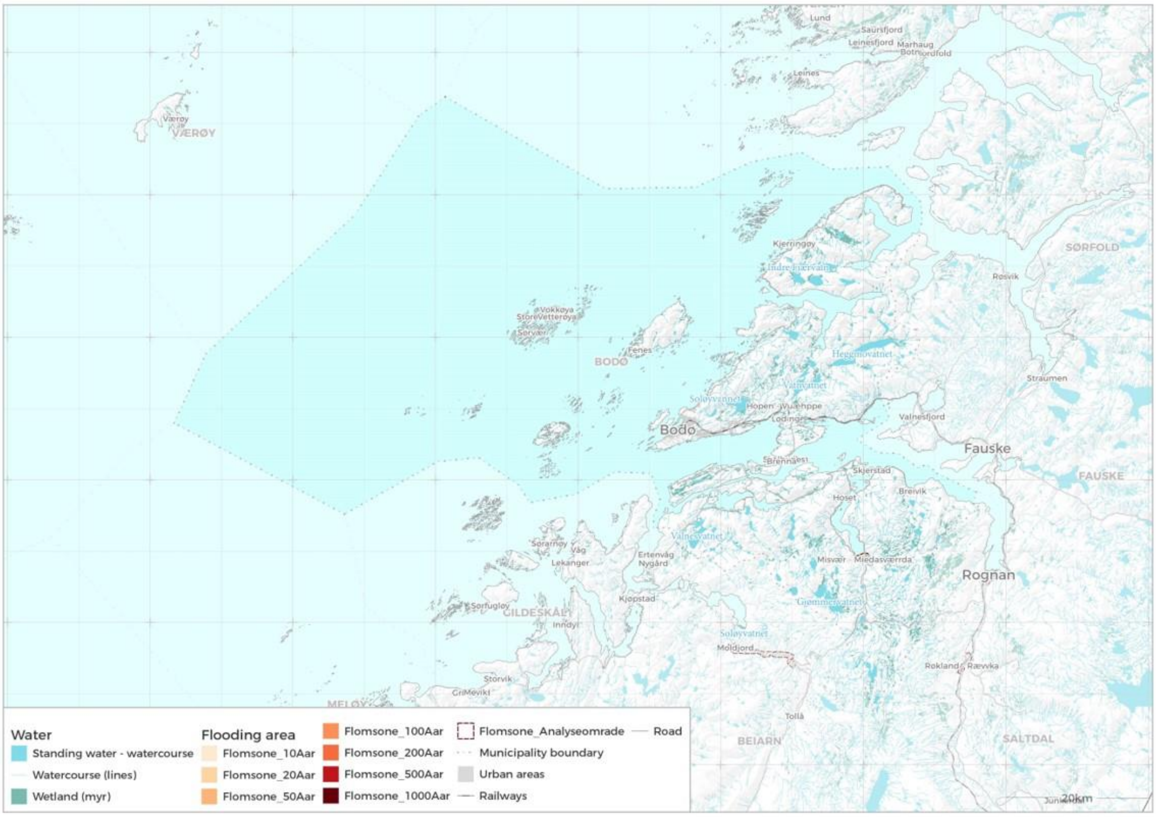

Figure 8.8 Water system Bodø municipality, image by BUUR/PoS 2022

Figure 8.9 Water runoff streams city zoom, , image by BUUR/PoS 2022

8.2.3. Land cover

The municipality of Bodø, with its enormous size, consists for a very large part of undeveloped space. Only 2,5% of the municipality's surface is built-up space, another 2,5% is used for agriculture. 88,9% of the surface is nature, including 39,1% forests. The remaining 6,1% are open waters, like lakes and rivers.

The most intensively used space, for construction and agriculture, is on the peninsula and in the flatter coastal zones. Some wetlands are also used for agriculture. After several decades of horizontal growth, the boundary of the urban area is now clearly defined and forms a compact island amidst the open space.

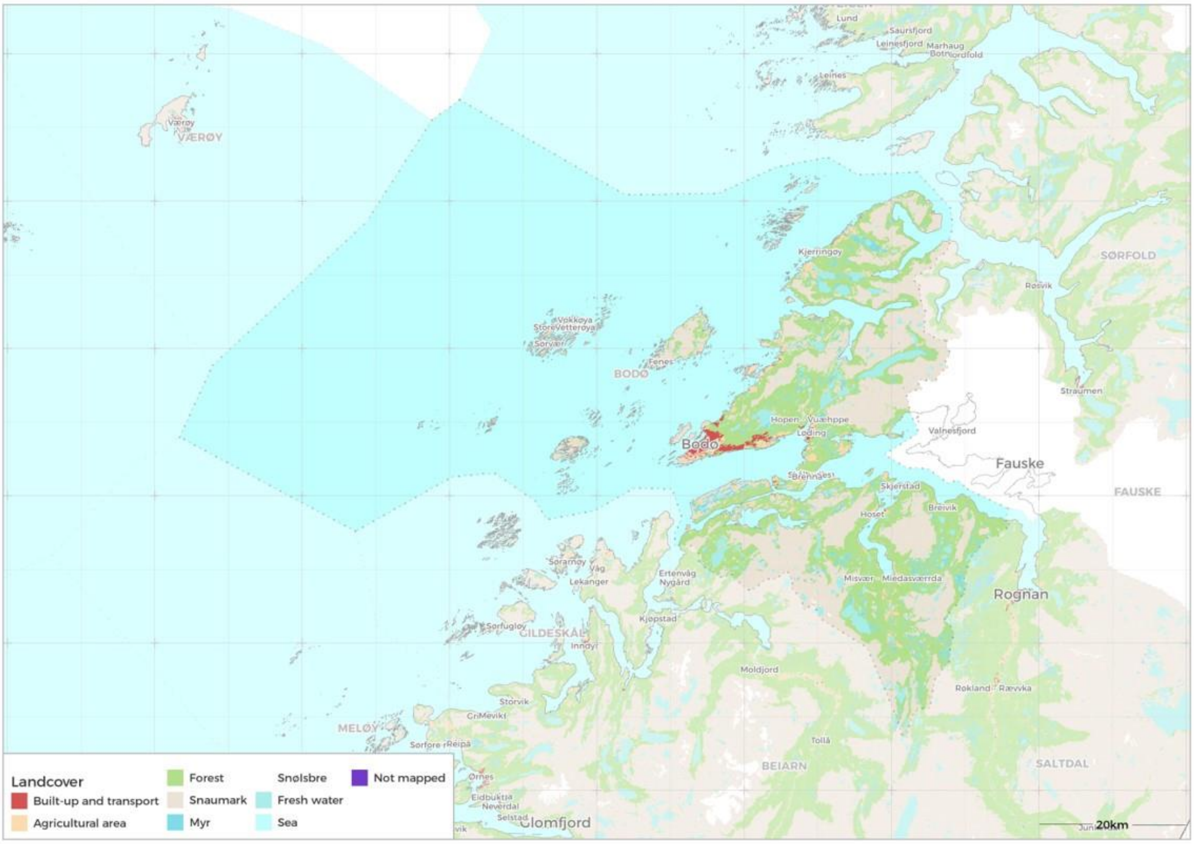

Figure 8.10 Land cover map (municipality), image by BUUR/PoS 2022

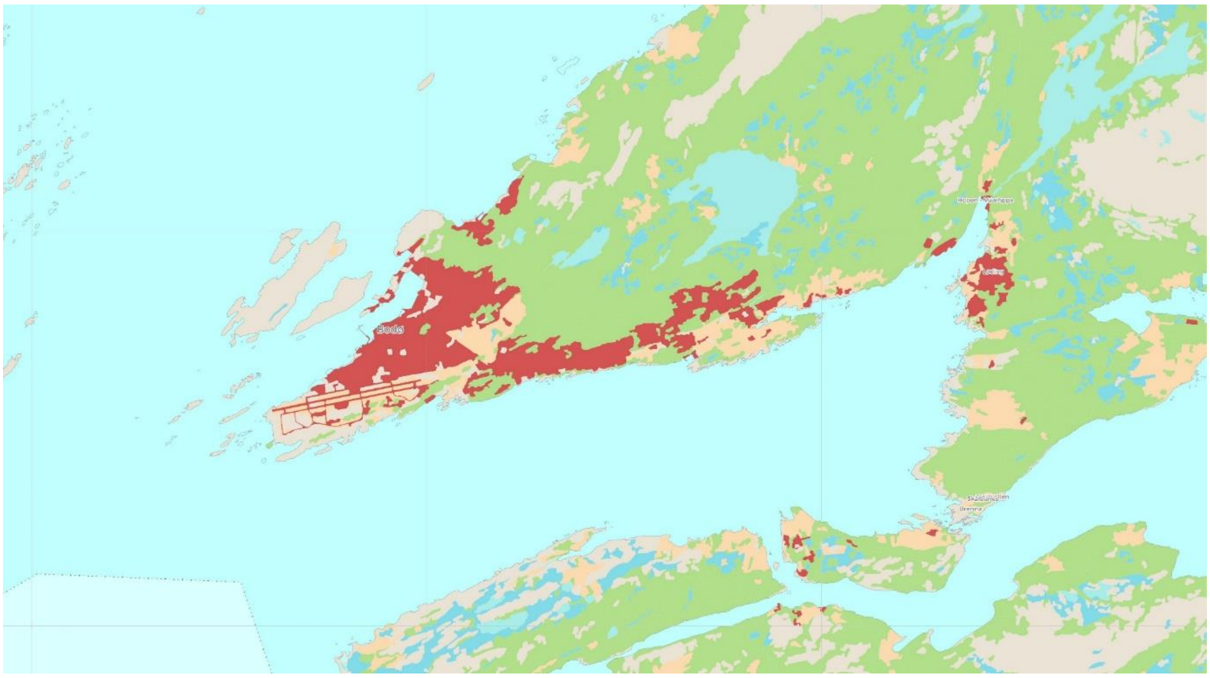

Figure 8.11 Land cover map (city zoom), image by BUUR/PoS 2022

8.2.4. Ecology[27]

The natural areas in the territory of Bodø have regional and national importance and are diverse in character, offering very different habitats, including coastal zone and fjords, mountainous areas, lakes, and wetlands. However, most of the nature in Bodø is culturally influenced, through agriculture and reindeer husbandry, fishing, recreation, forestry (and deforestation), among other things.

The most popular area for nature, sports and recreation is Bodømarka, with an area of about 150,000 ha – this is the whole area north and north-east from the city centre. It includes large forests and lakes, but also hiking and bike trails, areas for weekend and holiday homes, fishing zones. Central in Bodømarka is the Soløyvatnet lake.

The municipality of Bodø contains (parts of) two national parks.[28] In the north lies Sjunkhatten National Park, a water-rich, mountain landscape that is glacier formed and very diverse. In the south Bodø touches upon Saltfjellet – Svartisen National Park, Norway's largest natural park that is also mountainous and contains the largest glacier of the country. Next to the national parks, Bodø contains many natural reserves of different character. Many are located in the wetlands and are protected habitats for birds, like Straumoya, Loddvatnet or Strandavassbotn. Some natural reserves are coast-related, like the dune reserve Fjaere or the coastal system of Skjelstad. Also, a lot of islands are protected, like Bliksvaer and Karlsoyvaer, both with coastal wetlands that are real bird paradises and Ljonesoya that is a reserve for Eider ducks. In the south of Bodø there are also valuable birch forests with orchids.

[27] Information from the Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022) and the Grønnstrukturplan for Bodø Kommune (Bodø Kommune 2017)
[28] https://bodo.kommune.no/miljo-klima-og-naturbruk/naturmangfold/verneomrader/ (2022)

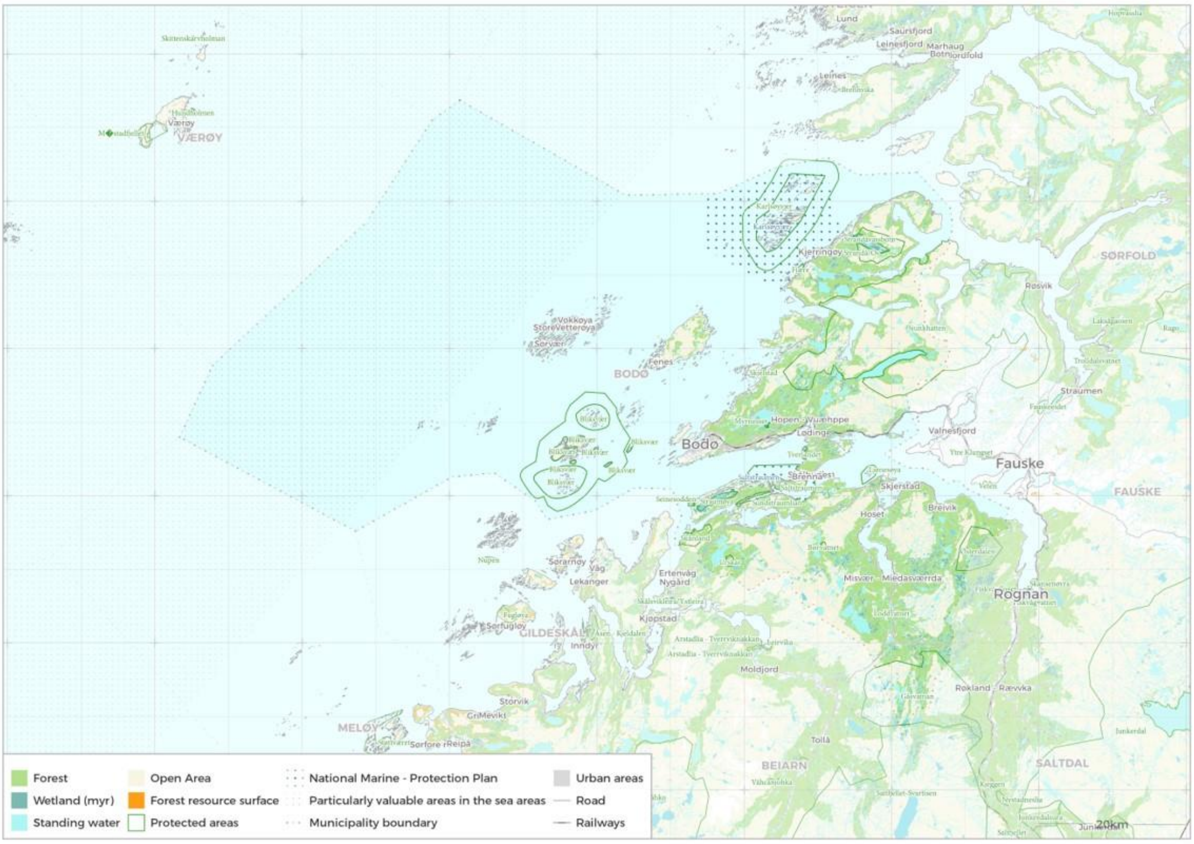

Figure 8.12 Map of ecotopes and natural protection zones, image by BUUR/PoS 2022

The inhabitants' access to green spaces in Bodø was analysed in 2017.[29] The study looked at which urban areas had access within 200 m to sufficiently accessible green spaces of min. 500 m². The analysis shows that the green spaces in the urban area are sufficiently distributed to cover a reasonably large part of the population. In addition, most residents also have quick access to the large green areas outside the city, such as Bodømarka and the green areas along the coast. However, the green areas in the city centre do not form a continuous network and are mainly isolated fragments.

[29] See Grønnstrukturplan for Bodø Kommune (Bodø Kommune 2017)

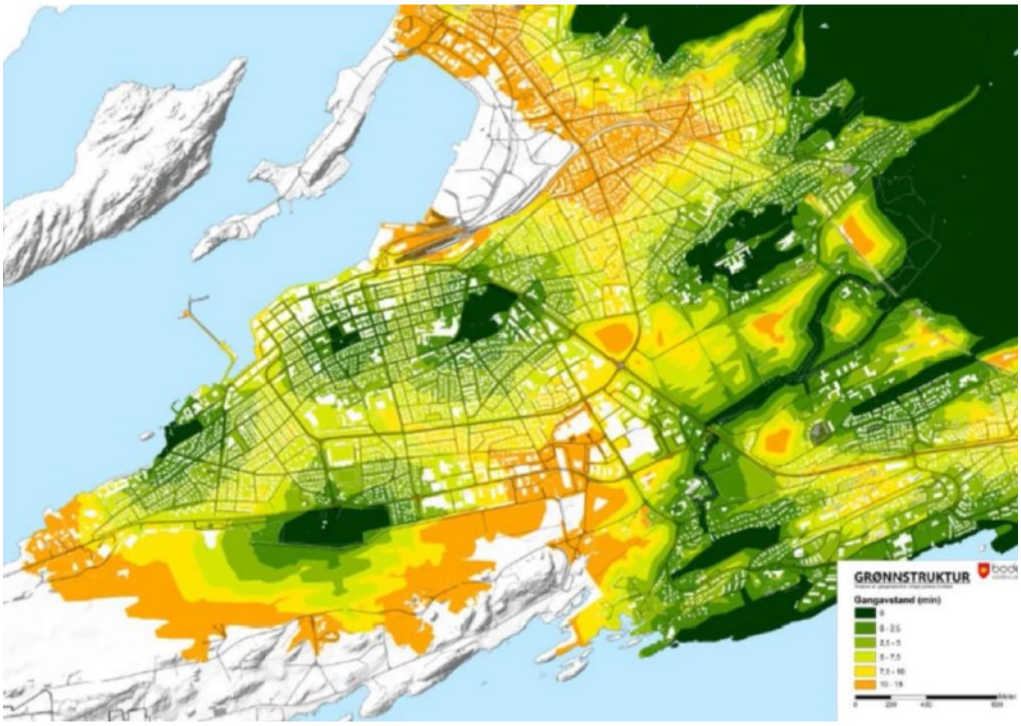

Figure 8.13 Existing green structure and access to green in the urban area (Bodø Kommune 2017, p. 27)

8.2.5. Agriculture[30]

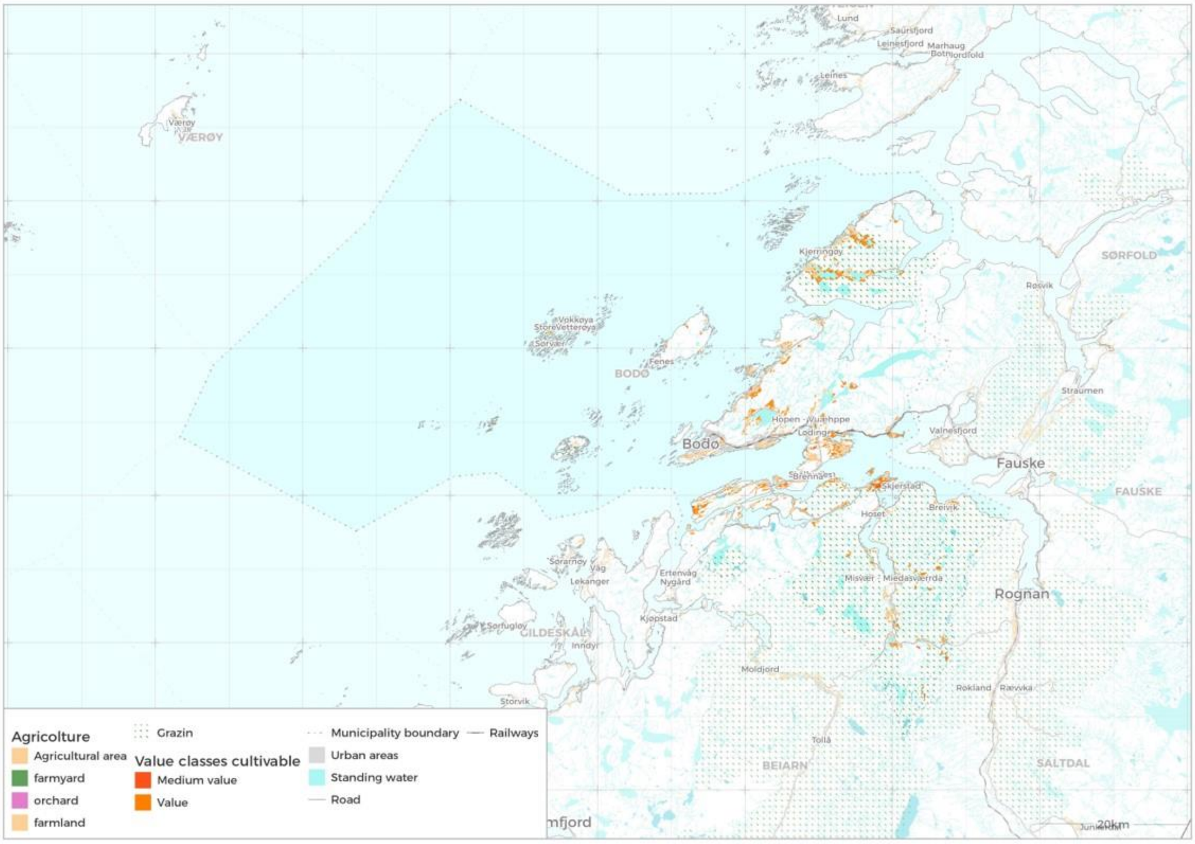

Figure 8.14 Map of agricultural uses, image by BUUR/PoS 2022

The little space in Bodø used for agriculture (2,5% of the entire surface of the municipality) is strictly protected from further urbanization by the KPA 2022 (Bodø Kommune 2022). Most of the agricultural land in the Nordland County is used as grassland for livestock. In Bodø, a special role is played by the areas Fjær and Godøynes which have an important cultural significance as traditional rural villages with a small-scale parcel structure as little islands in a forested landscape.

[30] Information from the Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022)

Figure 8.15 Agriculture with a cultural significance: Fjær (left) and Godøynes (right) (Google Maps 2022)

Of specific interest is also the agricultural zone Rønvikjordene,[31] right next to the urban area of Bodø. It lies in the south of the district Rønvika and has an agricultural history of over 100 years. It has seen a lot of development pressure in the past decades but managed to survive and is now protected as a local food supply at short distance from the city centre, also for educational purposes. Another area for urban agriculture is Andelslandbruk in the neighbourhood of Fenes.

Figure 8.16 Rønvikjordene agricultural zone (Google Maps 2022)

An important point of interest for agriculture are also the reindeer grazing zones, with the most important in Duokta (between Sørfolda and Saltfjorden) and in Saltfjellet. Bodø is of particular interest to reindeer in winter, due to the milder climate in the coastal zones, but the mountainous zones are also popular in spring and summer. Besides the specific grazing zones, there are also the migration routes that are of great importance. Reindeer herding is both of economic and cultural importance in the area.

[31] See also https://no.wikipedia.org/wiki/R%C3%B8nvikjordene (2022)

Other important economies are forestry and fishery. Almost 14% of the productive forest area in Norway lies in Nordland County, and 33% of the timber from broad-leaved forests comes from this county.[32]

8.2.6. Transport networks[33]

Bodø is well connected to several transport networks, but the large distances between the city and other urban areas makes travelling time consuming. The main highway that makes north-south connections in Norway is the E6, passing the municipality at around 50 km from the city centre. Via this highway, there are around 650 km to get to Trondheim, the closest big city. But also visiting smaller, more adjacent cities always demands large distances to be covered. Due to this, Bodø is a quite car-oriented city, with 26,000 passenger vehicles registered for 53,000 inhabitants – including 12% electric cars.

Other important transport means for longer distances are of course the airport and the ferry connections. Bodø is an important regional hub for transportation of people and goods, with the port and airport as major pillars. As a regional port hub, Bodø has fast boat connections to most of the adjacent islands, and a ferry to the Lofoten Islands around 80 km away from the coastline.

Bodø train station is the terminus for the Nordlandsbanen that follows the E6 and offers one day or one night train to Trondheim, and regional and local train connections to Mosjøen and Rognan.

For local transport, there is a modern bus network between the centre and the surrounding villages. Efforts are also being made to improve the bicycle network. The largely flat profile of the urban area fosters cycling, but weather conditions and strong winds create a major barrier.

This translates in a modal split that is dominated by car use (62% of all displacements) and a low use of bicycles (9%). Also, public transport is not very popular for internal displacements (5%). Walking counts for 24%.[34]

[32] https://www.ssb.no/en/jord-skog-jakt-og-fiskeri/jordbruk (2022)
[33] Information from the Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022)
[34] Klima- og energiplan (Kommune Bodø 2018)

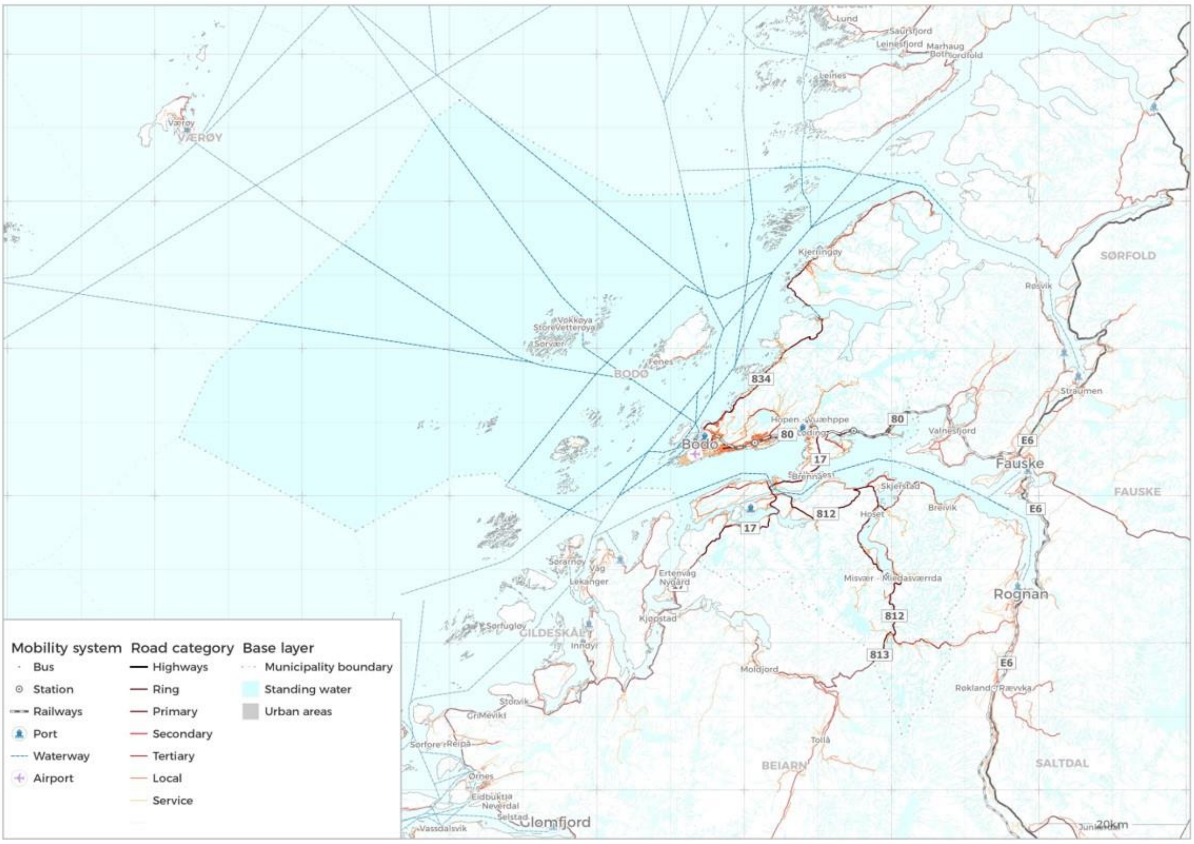

Figure 8.17 Map of transport networks, image by BUUR/PoS 2022

8.2.7. Land Use

The entire built-up area of Bodø municipality contains 831 ha of residential land and 288 ha of economic zones. Recreation, schools and other public facilities count for 337 ha. Of the public space, 1410 ha is used for transport and other infrastructure and 212 ha are green and/or recreational spaces.[35]

The urban area of Bodø is clearly structured. The centre at the harbour contains the highest building density and most mixed functions, such as commerce, hotels and restaurants, the town hall and the cathedral, the library and cultural centre, and a number of schools. Other important functions are located more outside the centre: the railway station in the northeast, the Nordland Hospital just below, more to the south an extensive school and sports campus. Both to the north and to the southwest, the port contains important economic zones. In addition to industry, quite a few large-scale retail centres and even recreational functions have settled here. A similar mixed zone is located in the southeast of the centre, along the entrance road Rv 80, with in addition to classic large-scale retail also a big shopping mall (City Nord), a sports hall and the swimming pool. Here you also find the aviation museum, directly linked to the airport.

The urban neighbourhoods outside the centre are mostly residential in character, with supporting functions such as schools and commerce for daily use. Mørkved is also home

[35] https://www.ssb.no/en/natur-og-miljo/areal (2022)

to the main campus of Nord University. Around the campus, a residential district has also developed here, which is one of the few districts in Bodø that also continues higher up the hills.

Bodø is strongly committed to urban renewal. Since the decision was taken to stop the horizontal growth of the city, they follow a polycentric growth model, which focuses on four central locations: the centre, the new district Hermes, the new airport and associated economic zone and the commercial zone around City Nord.[36] Especially in the centre the focus lies on urban renewal, with the redevelopment of the waterfront (including the already realized new library and cultural centre) and the refurbishment of the shopping street Storgata.

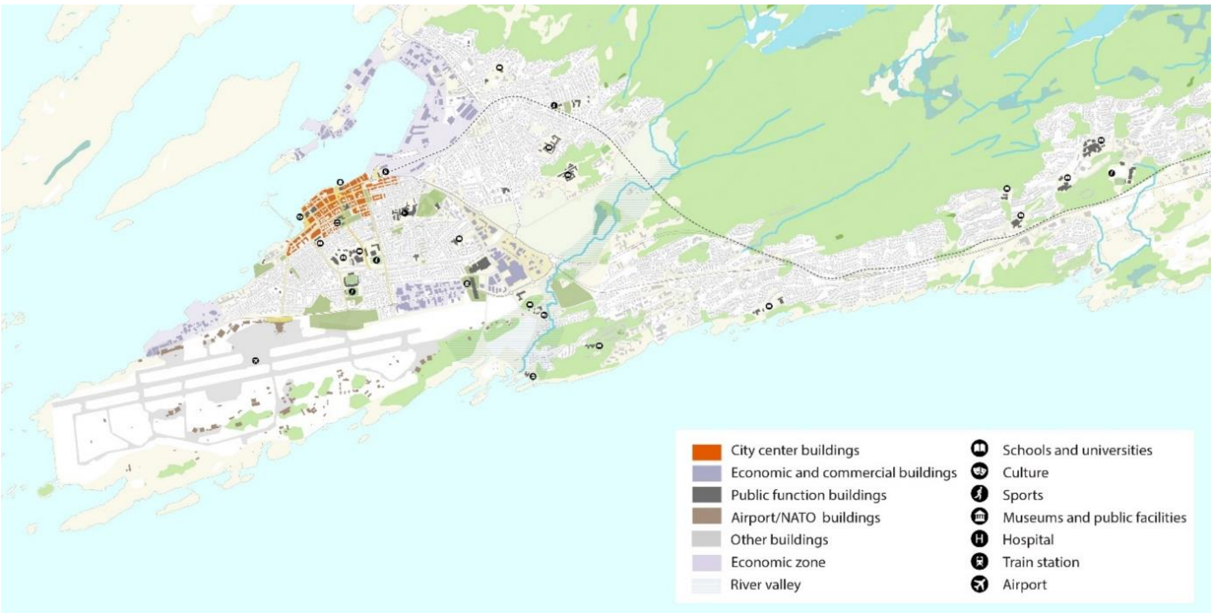

Figure 8.18 Urban structure of the urban area, image by BUUR/PoS 2022

[36] Marthinussen & Bjørklund (2017)

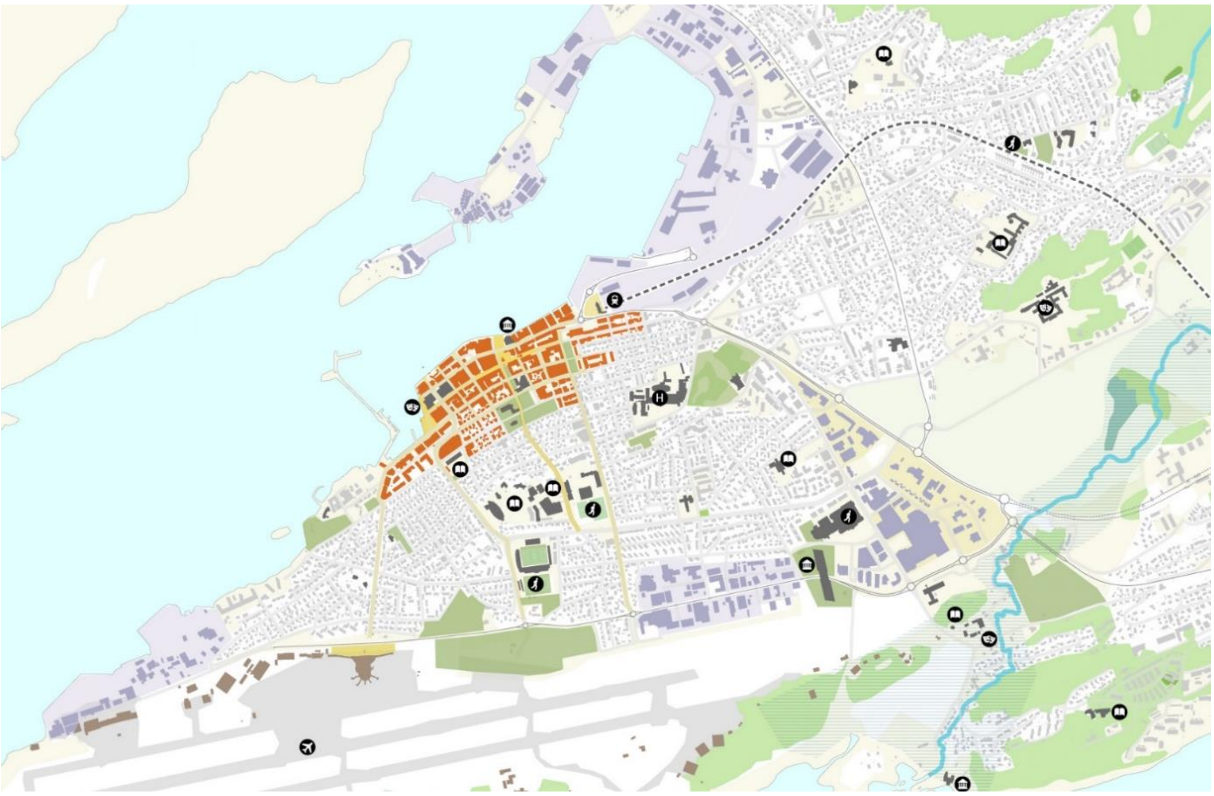

Figure 8.19 Urban structure of the city centre, image by BUUR/PoS 2022

8.2.8. Building morphology

Apart from the waterfront zone and the adjacent central building blocks, most of the buildings in Bodø are rather small scale and low rise. 66% of residents live in detached houses (open or semi-detached), 27% live in apartments. The average family size per home is 2.09 residents. In addition, the municipality has about 2700 vacation homes, scattered throughout the open space.[37]

[37] Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022), p. 11

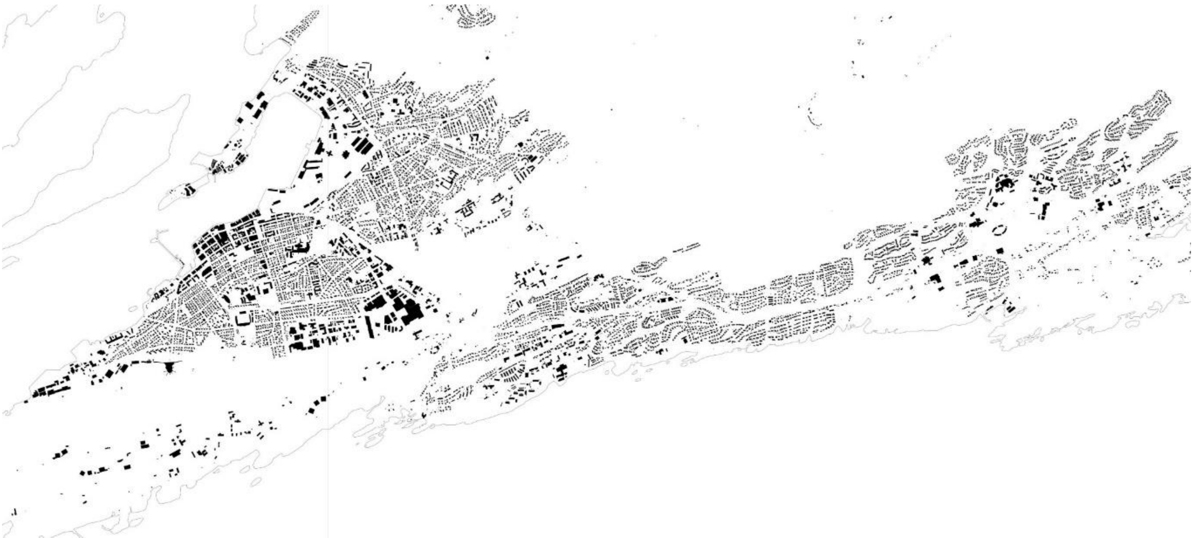

Figure 8.20 Building morphology in the urban area of Bodø, image by BUUR/PoS 2022

In the city centre, a square grid defines the layout of the streets and buildings. Close to the waterfront the building blocks are densely built, leaving little space for inner courts and without much green space. Further outside, the buildings blocks are built with up to eight single, mostly freestanding houses on private plots. These blocks are much greener, including sometimes large trees. In a few cases there are larger buildings integrated in this tissue, like public facilities or small-scale apartment buildings.

Figure 8.21 Urban building blocks with high density (up left), single housing in the urban grid (top right), scattered individual houses in a suburban style (bottom right) and single housing compounds with collective public space (bottom left) (Google Maps 2022)

Outside of the centre, the grid structure is less defining and many of the more suburban districts have typical curvy roads and a more organic building structure, adapting to the topography. Also, here the large majority of the houses are freestanding single-family houses, sometimes interspersed with larger facilities, small clusters of row houses or small-scale apartment buildings.

Figure 8.22 The morphological structure of the suburban districts east of the centre

Figure 8.23 The morphological structure of the urban grid in the city centre

8.2.9. Population density

85%, or 45,000 of Bodø's 53,000 inhabitants live in the urban area. In addition, 3,200 residents live in Løding and 2,300 in Skivika and Løpsmarka. The remaining 1,500 people are scattered in smaller village centres such as Skaug, Kjerringøy, Saltstraumen, Misvær and Skjerstad.[38] The entire municipality has a density of approximately 40 inhabitants / km^2.

[38] Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022), p. 10

Bodø currently has an annual growth rate of 1% (approx. 500 new inhabitants per year), but this is expected to decrease to approx. 0.7% per year (approx. 350 additional inhabitants).[39] The KPA 2022 sets a clear objective that this growth should be concentrated in the city centre and the new district Hernes (p. 8).

In the new urban district of Hernes, a development is planned with about 15,000 additional homes and economic functions for about 20,000 additional jobs.

8.2.10. Governance and spatial planning

Much of the information included in this report, is derived from various planning documents published by Bodø Municipality. The city has an active and well-organized set of planning instruments, of which the areal municipal plan (Kommunedelplan Arealdel, Bodø Kommune 2022), green structure plan (Grønnstrukturplan, Bodø Kommune 2017) and climate and energy plan (klima- og energiplan, Bodø Kommune 2018) are the main ones for spatial planning. These documents contain a great deal of information about the city's structure and challenges and formulate important ambitions but are rarely compelling visual or even cartographic documents. Ambitions are rarely put on a map, nor are they otherwise communicated in a recruiting way. The spatial plan contains a technical zoning plan, but no structure plan or other more strategic plans.

Things are different when it comes to the master plan for the new district of Hernes. Here numerous visions, design proposals and graphic concepts have been elaborated, which convey a great ambition and also manage to make it tangible. At present it is still unclear which concrete choices will be made and what the new district will look like exactly, but the sustainable ambitions are very clear.

A similar ambition is also evident in the various international collaborations Bodø is involved in, such as European research projects, but also the ISOCARP conference in Bodø in 2017. What concrete results these collaborations deliver for local residents is not yet entirely clear.

However, the planning practice in Bodø shows that important and positive decisions have recently been made that strongly support the sustainable development of the city. Especially admirable is the clear decision to stop the horizontal growth of the urban area and resolutely opt for densification in the centre.

8.3. Strategic profile

8.3.1. Local climate risks[40]

Climate change is expected to increase the average temperature in Nordland by about 5°C by the end of the century, especially in winter. At the same time, rainfall will increase by about 15% and the severity of precipitation will also increase. The expected rise in sea level until 2100 is between 16 and 54 cm[41].

In this chapter we look at two specific climate risks in more detail and examine the spatial regulatory systems that play a role in adaptation strategies for these risks. In doing so we try to identify how these systems function today and whether they are capable of

[39] Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022), p. 6
[40] See also chapter 2.3.5 "Climate-related risks in Bodø municipality"
[41] Kommunedelplan Arealdel 2022-2034 (Bodø Kommune 2022), pp. 23-24

performing their regulatory function – and where this is less or not the case, what weaknesses cause this and what opportunities there may be to (partially) remedy this.

The two climate risks we are looking at are flooding from increased precipitation (both fluvial and pluvial flooding) and flooding from rising sea levels.

8.3.2. Sea level rise

8.3.2.1. Adaptation strategies

Coastal cities such as Bodø are obviously sensitive to sea level rise. In general, three broad groups of adaptation strategies can be distinguished: (physical) protection measures, risk avoidance through changing land use and disaster management.[42]

- (Physical) protection measures
    - construction of new infrastructure
    - adaptations to buildings
    - natural buffers such as wetlands
- Risk avoidance through land use change
    - new developments only outside risk zones
    - relocation of activities and infrastructure away from risk zones
- Disaster management
    - modelling & risk analysis
    - warning systems
    - emergency plans
    - insurance

Initially, we examine the regulatory system formed by the coastline, and the extent to which it can act as a (physical) protective belt.

8.3.2.2. Regulation systems: coastline

A crucial role here is played by the coastline and how it is shaped. Figure 8.24 shows how the coastline in Bodø looks like today. The map makes a distinction between the urbanized coastline, with quays, buildings and other built structures encroaching right up to the coastline, and the more 'natural' coastline. For not urbanized sections of the coastline, a distinction has been made between the rockier segments and those that consist of beaches, wetlands and/or mouths of streams. This distinction was done based on visual desktop research and is just a preliminary analysis. In the case of the latter, the difference in elevation is likely to be very limited but may involve natural buffering through nature-based solutions. Although highly subject to tides and extreme weather events, these types of coastal habitats are adaptive by nature and can "grow" through sediment supply and are less subject to erosion. For the rockier segments, this is also possible, but further research is needed to better map them.

[42] https://eri.iu.edu/erit/strategies/sea-level-rise.html (2022)

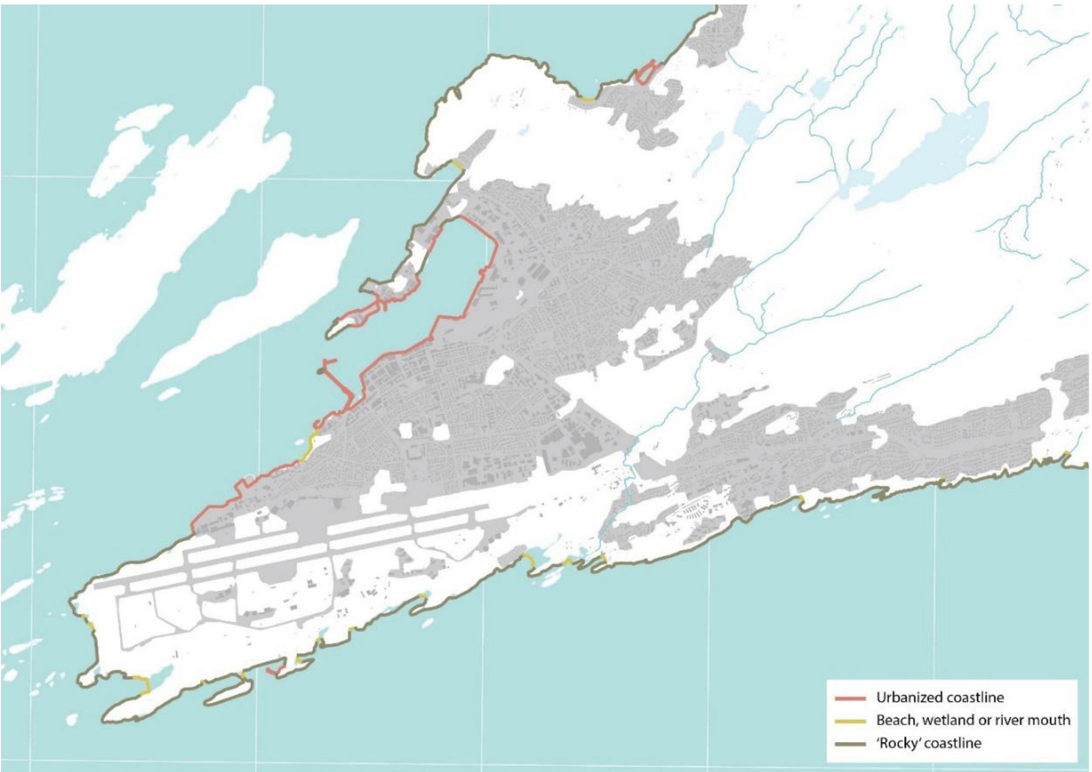

Figure 8.24 Preliminary analysis coastline peninsula Bodø, image by BUUR/PoS 2022

The urbanized segments present two concrete risks. On the one hand, the exposure of buildings and people is highest, because the built-up area here has often advanced directly until the coastline. On the other hand, they consist of 'grey infrastructure', which can provide high protection but is not adaptive and can lead to immediate catastrophic consequences if it fails in extreme conditions. Again, additional research is needed to get a better idea of the exact design of this coastline and the existing system of breakwaters, dikes, and quay walls.

Currently, the urbanized segments are mainly located on the north side of the peninsula, the neighbourhoods in the southeast respect a large distance from the coastline and here there is no harbour infrastructure. The current airport also respects this distance. How this situation will evolve in the future with the realization of the new urban district and the rebuilt airport more to the south of the peninsula is currently unknown but should be included in the study in order to fully assess future risks.

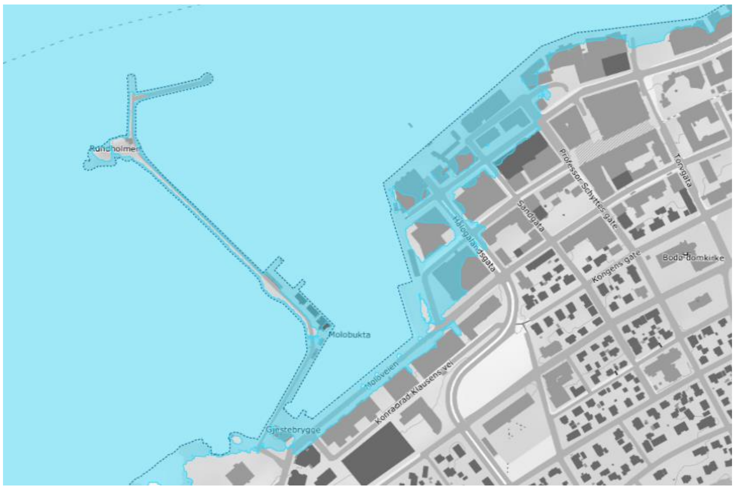

Figure 8.25 Sea level rise and risk areas

Recently, an analysis of Bodø's exposure to coastal flooding has been carried out for the harbour area (see Figure 8.25).[43] More information on the methodology and the concrete results would greatly help to advance the research on this regulation system.

In order to optimally map the vulnerability of this regulation system, additional information on sea currents and on the concrete predicted sea level rise in the different climate overshoot scenarios is also needed.

8.3.3. Pluvial and fluvial flooding

8.3.3.1. Adaptation strategies

The expected increase in precipitation amounts, both average and during extreme weather events, brings an increase in the risk of pluvial and fluvial flooding in Bodø, especially in the urban area on the peninsula. Here, runoff precipitation from the city's paved surfaces meets precipitation water discharged through open or channelled waterways.

Adaptation strategies for this type of flooding, consist of both measures to protect against the floods themselves, and strategies that reduce the amount of rainwater runoff, such as buffering and natural infiltration. In certain circumstances, accelerated drainage can also be a solution.[44]

- Flood protection
    - protection measures on building scale
    - physical protection infrastructure
    - temporary (emergency) protection
    - warning systems
    - insurance
- Water buffering

[43] https://www.an.no/bodo/var/varoy/deler-av-bodo-sentrum-kan-sta-under-vann-om-70-ar-sjekk-om-stormflo-kan-ramme-deg/s/5-4-909154 (2022)
[44] https://eri.iu.edu/erit/strategies/flooding.html (2022)

  - lakes, ponds & wetlands
  - water squares & other urban above ground buffering
  - storage sewers & other underground buffering
  - rainwater harvesting & storage
- Infiltration
  - increasing soil permeability (reduction of impermeable surfaces)
  - natural buffering systems
  - bioswales & infiltration strips
  - underground infiltration systems (horizontal/vertical)
- Drainage
  - improving above ground drainage (deepening rivers)
  - above ground drainage systems
  - underground reverse drainage (including infiltration)
  - underground drainage systems

Initially, we are investigating the 'green-blue' network on the Bodø peninsula to examine how the green space of Bodø is structured and what role it can play for infiltration but possibly also for buffering rainwater.

8.3.3.2. Regulation systems: green-blue network

Bodø is a very green municipality with extensive nature reserves occupying most of its surface area. A green character also prevails in the urban area itself. This is primarily due to the morphology of the buildings, which largely consist of detached houses on fairly large, green-filled plots. This set of gardens plays an important role in the green character of the urban area but is probably strongly fragmented by fences and the paved areas of buildings, garden sheds, terraces, parking lots. Obviously, the streets also form a barrier in this network. Without a detailed study it is not immediately possible to determine how much the fragmentation weighs on the climate adaptive and regulating character of this garden landscape. From experience with garden landscapes in other cities, we can expect that the cooling character of the gardens is high, but the biodiversity rather average to low due to intensive maintenance and mowing management. Soil permeability is usually high in gardens, but they play only a partial role in rainwater buffering because rainwater from paved surfaces (traffic infrastructure, roofs) is usually drained into the sewer system and does not infiltrate into gardens.

In between are other, more public green areas such as public parks and bigger green areas within the urban tissue, for whom it is difficult to assess if they have a public or a private character. Other green spaces are the ones related to infrastructure (along roads and crossings, on parking lots, …) that are smaller in size but form a bit more continuous network, being connected to the infrastructure network.

Areas with very little green space, and therefore very low soil permeability, are mainly the centre and some of the economic zones at the port and along the Rv80 road and the airport. The centre is very densely built up and the rigid grid structure of the building blocks leaves little room for greenery. The economic zones have a much lower building density, but here it is mainly the extensive car parks, road infrastructure and paved storage areas that provide a very low proportion of green space.

Figure 8.26 Analysis of the green areas on the urban peninsula: together they cover a large area, with only locally (downtown, industrial zones) large, petrified areas, image by BUUR/PoS 2022

So, in general it can be stated that Bodø has a very green character, also within the urban area. If the small-scale, individual gardens are omitted from the map though, the green network presents a much more fragmented picture, with few green structures that can play a role as a green corridor. Also, the role of the green spaces as a buffer for rainwater is unclear. If the private gardens are not part of such a system, it will be too limited in size and not even enough distributed.

Within the green urban network, water streams do not play a major role. Most of the natural streams have been covered up and there are no clear green-blue corridors present in the urban tissue where this can be undone rapidly. However, this is definitely a strategy that needs to be further investigated. The most continuous green structures are the ones connected to the road infrastructure. These can play a role for water infiltration but are usually too narrow to be developed into real green-blue corridors.

One real green-blue corridor exists however, along the river that runs from Rønvikjordene to its southern mouth in the sea. Large parts of this corridor are still intact and form an important natural area (also used for food production). Further investigation will be necessary to understand better how the corridor crosses the road infrastructure and the more built-up areas in the south, to see if there are improvements necessary.

Figure 8.27 However, most of the green space in the urban area of Bodø seems to consist of private green space; private gardens and other green areas that fulfil a garden function. Here, permeability and biodiversity can be used, but the chances for water buffering are limited, image by BUUR/PoS 2022

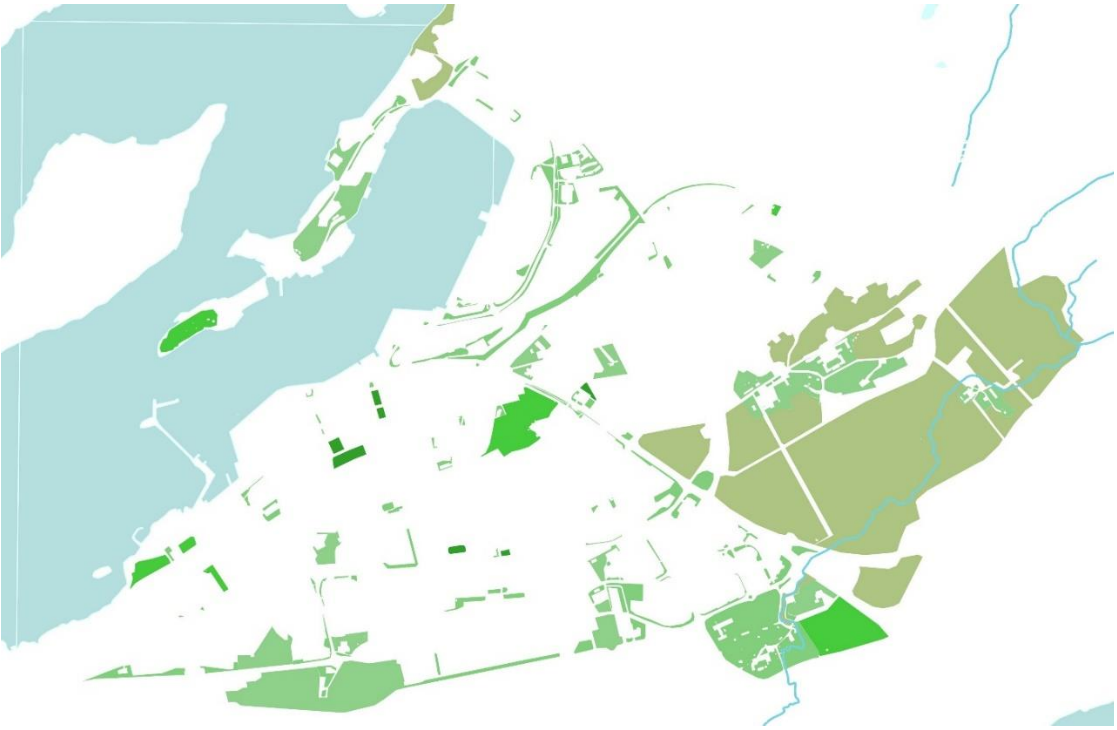

Figure 8.28 The green spaces with a more public character (parks, but also green spaces along road infrastructure and (public or private) parking areas) have a greater chance of being used for water buffering, provided they are well designed so that the functionality of the space can be maintained. This also applies to green areas outside the urbanized area, but here there is a risk that water buffering will conflict with agricultural use, image by BUUR/PoS 2022

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9. Structural and strategic profile: Lisbon Metropolitan Area, Portugal

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9.1. Introduction

The Lisbon Metropolitan Area is being confronted with increased surface and air temperatures, resulting in high stress from heat and the associated heat-island effects (as described in 3.1, 3.2, 3.3 and 3.4 in this report). As such, there is a need for the urbanized landscape to be planned, designed, and engineered in ways that provide for heat regulation. The purpose of this chapter is to evaluate the capacity of the spatial structure of the Lisbon Metropolitan Area to regulate heat. For this, we aim to identify the degree to which the composition and configuration of the various spatial systems that compose the territory in question correspond to the capacity to regulate heat.

The specific heat-regulating functions are summarized in Figure 9.1. Measures that can mitigate heat stress range from shading devices, increase in surface water and vegetation (for evapotranspiration), unsealing paved soils to absorb heat, as well as introducing a network of cool spaces to allow for ventilation and the overall lowering of surface temperatures ("Urban Green-Blue Grids for resilient cities" n.d.; (World Bank 2021)). These follow the ecosystem services-functions paradigm (Millennium Ecosystem Assessment 2005). While heat regulation is the primary interest, drought and air quality regulation are also relevant due to the interconnected nature between them (the absence of moisture in the soil directly affects its capacity to regulate heat, while the different particles in the air affect both its temperature as well as its reflectivity and light absorption indices).

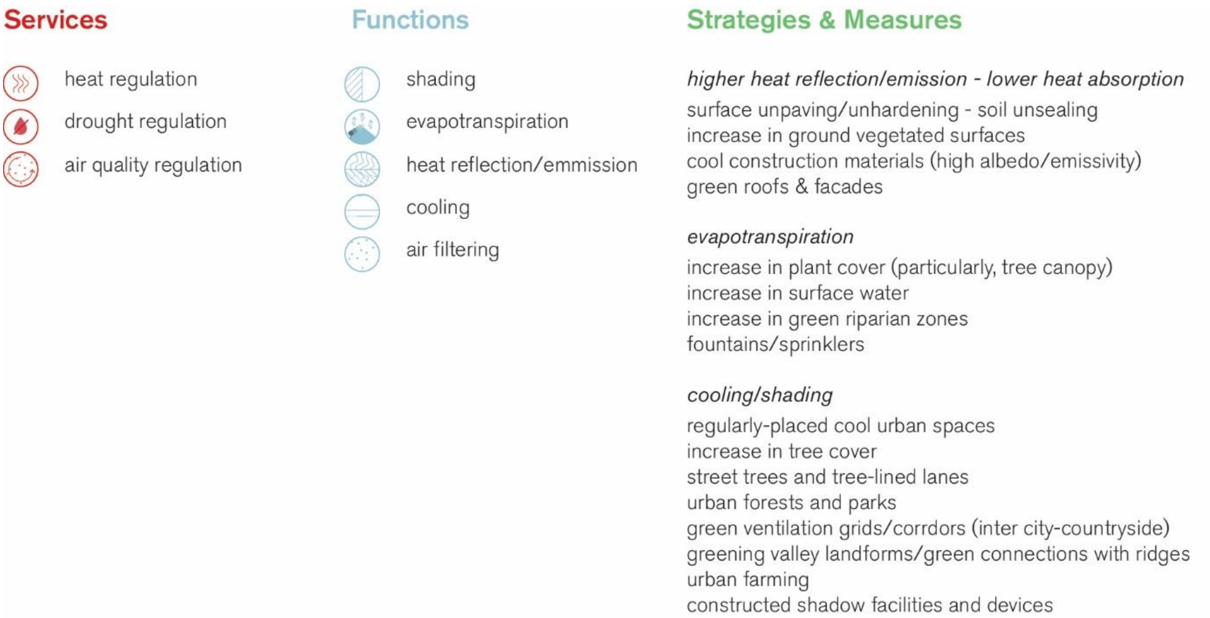


Figure 9.1 Ecosystem services, functions and associated strategies and measures for heat-stress management (image by BUUR/PoS 2022, adapted from Millennium Ecosystem Assessment 2005; World Bank 2021; "Urban Green-Blue Grids for resilient cities" n.d.)

The above measures can be based on 'nature-based solutions' that is, green-blue devices, as well as on anthropogenic and technological solutions. For the purposes of this part of the work, the space of the Lisbon Metropolitan Area and the Municipality of Lisbon will be treated from a 'nature-based solutions' lens, with focus on the existence and network of green and blue spaces (or spaces that could be green and/or blue). Other measures such as the materials of the buildings (for light, and thus, heat reflection and emission) will not be incorporated at this stage. Consequently, the spatial structure will primarily be evaluated on the basis of increasing its green cover and its configuration for overall cooling. The indicators for cooling devices and the variables of the spatial morphology that will be looked upon are summarized in Figure 9.2.

Figure 9.2 Indicators for spatial planning for heat-stress management (adapted from World Bank 2021; Alberti 2008; "Urban Green-Blue Grids for resilient cities" n.d.)

The overall process of the elaboration of the Structural and Strategic Profiles for the Lisbon Metropolitan Area and the Municipality of Lisbon is shown in Figure 9.3. The various spatial systems and the spatial layer they belong to are illustrated on the left, where a selection of them (ecological structure, open space and infrastructural networks) are positioned as regulation systems. These three correspond to the organization of potential and its configuration in reference to heat regulation. The general mapping of the composition and configuration of the spatial extent is subsequently evaluated on the basis of its interaction and relationship with these three systems. On the right, the criteria according to which said evaluation is carried out are listed.

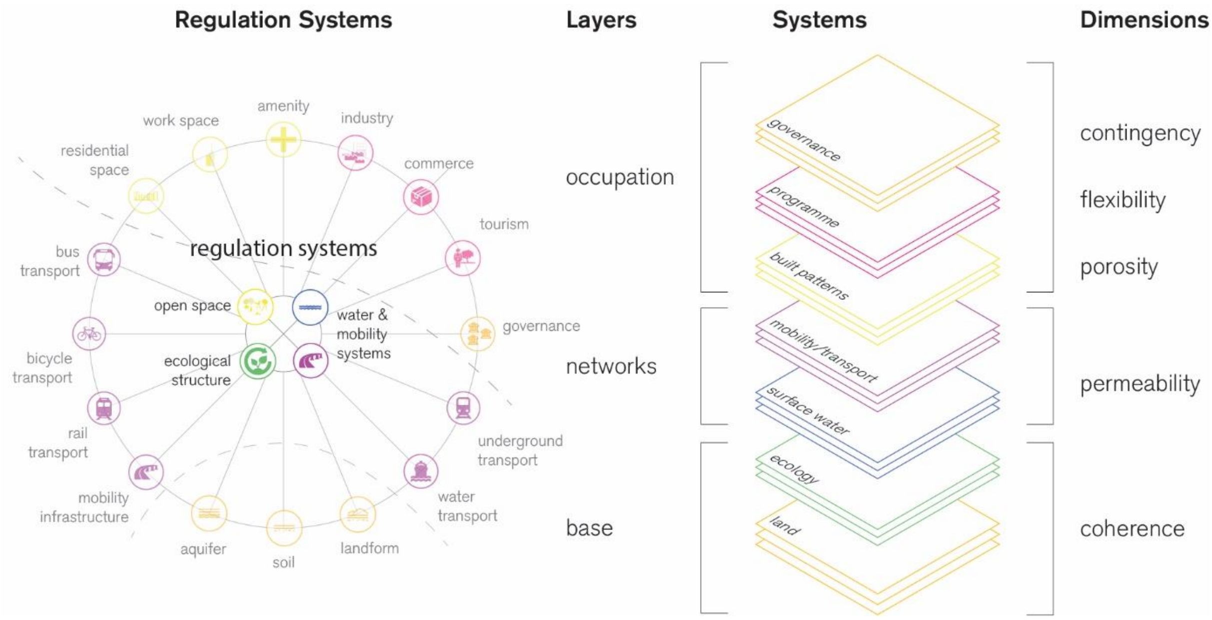


Figure 9.3 Methodology for the evaluation of spatial structure and the elaboration of a strategic profile in reference to heat-stress management, image by BUUR/PoS 2022

9.2. Spatial profile

The Lisbon Metropolitan Area is embedded within a spatial context populated, primarily, by the agriculture- and forestry-related sectors. Figure 9.4 displays the extensiveness of irrigated cropland and pastures, as well as the prevalence of woodland formations (mostly broad-leaved or mixed coniferous/broad leaved forests) and vineyards, olive groves and fruit plantations. Within this type of land use and land cover, the built-up ('urban') space is located, almost exclusively, towards the edge of the Tagus estuary, with other (smaller) settlements areas dispersed throughout.

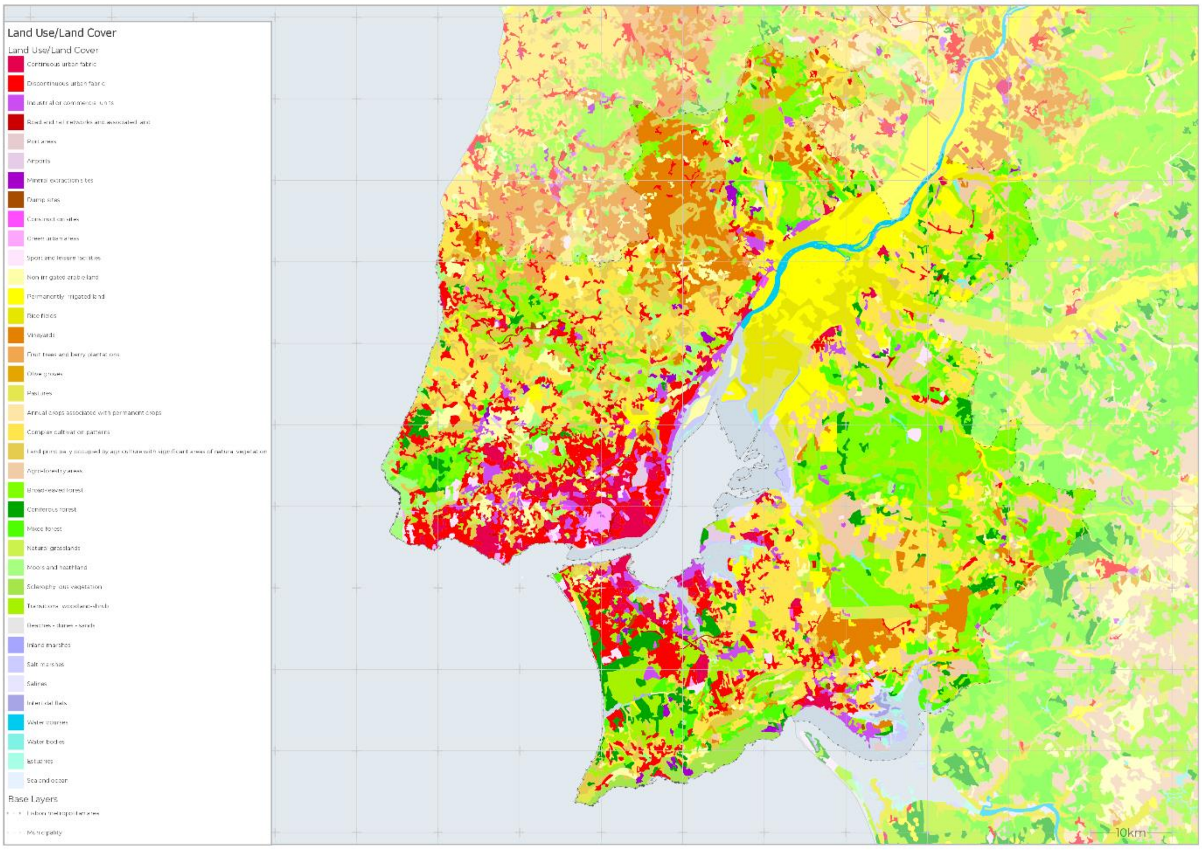


Figure 9.4 Land cover of the Metropolitan Area of Lisbon and its surrounding context (© BUUR PoS 2002, with data from "Copernicus Land Monitoring Service" n.d.)

Taking a closer look at the land use and land cover composition of the Metropolitan Area itself, Figure 9.5 validates the previous insight: almost 60% of the area is covered by croplands, pastures, and forests, with a significant percentage of herbaceous vegetation, while all other land use and land cover classes take up together the remaining around 20%. A zoom-in to the Municipality of Lisbon reverses the previous picture: around 60% of the land is covered by a dense urban fabric, road infrastructure and industrial/commercial built units. From a climate risk perspective and, particularly, mitigating heat stress, the above understanding necessitates and emphasis on both how agricultural and forestry configurations can assist in lowering surface temperatures, as well as how associated measures and solutions can be retrofitted within and throughout the built environment.

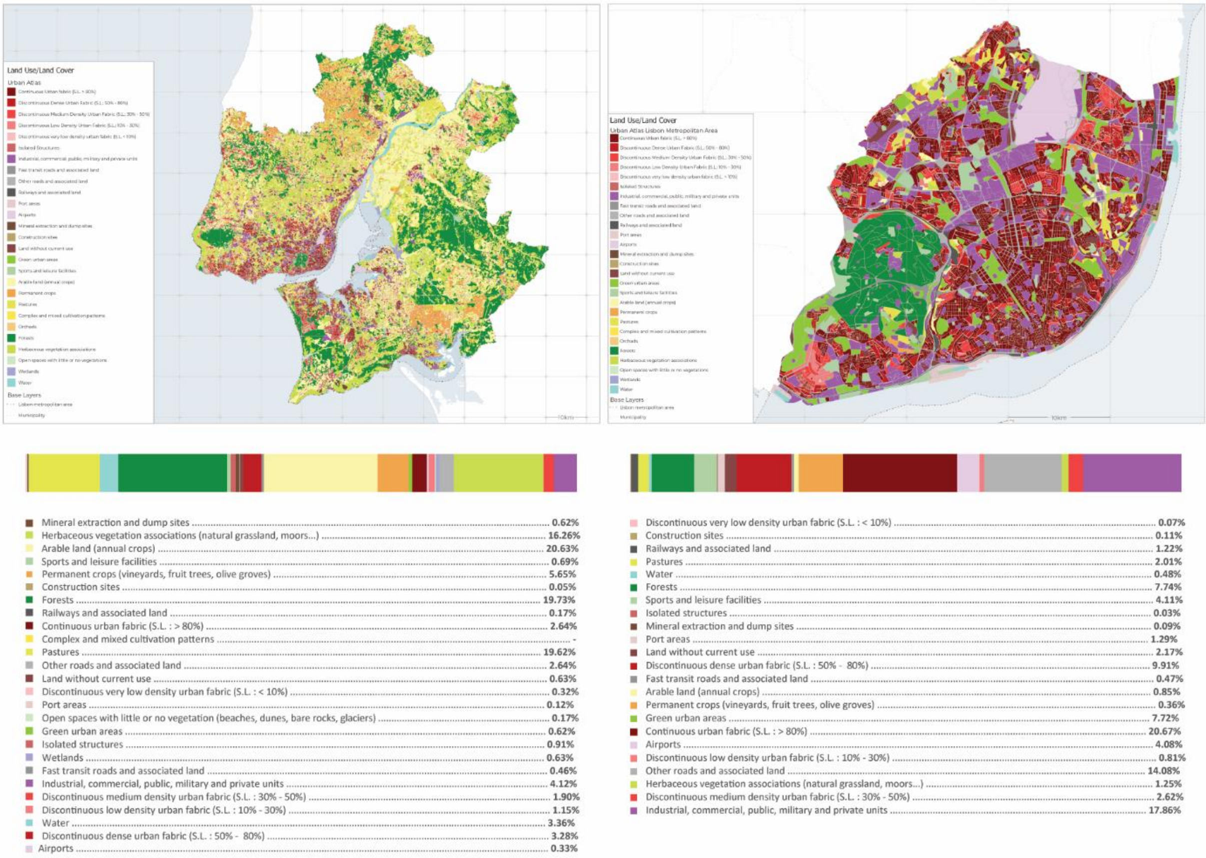


Figure 9.5 Urban Atlas for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (below) (© BUUR PoS 2002, with data from "Copernicus Land Monitoring Service", n.d.)

Looking at population levels in correlation with land use and land cover (Figure 9.6), not surprisingly the urban fabric is associated with higher numbers of people than the rest of the agricultural and forestry mosaic of the Metropolitan Area. The exodus of demographic groups from the countryside to the urban cores has been documented as an issue affecting the vulnerability and adaptive capacity of the region and, therefore, adaptation scenarios and mitigation solutions will have to take this phenomenon into account.

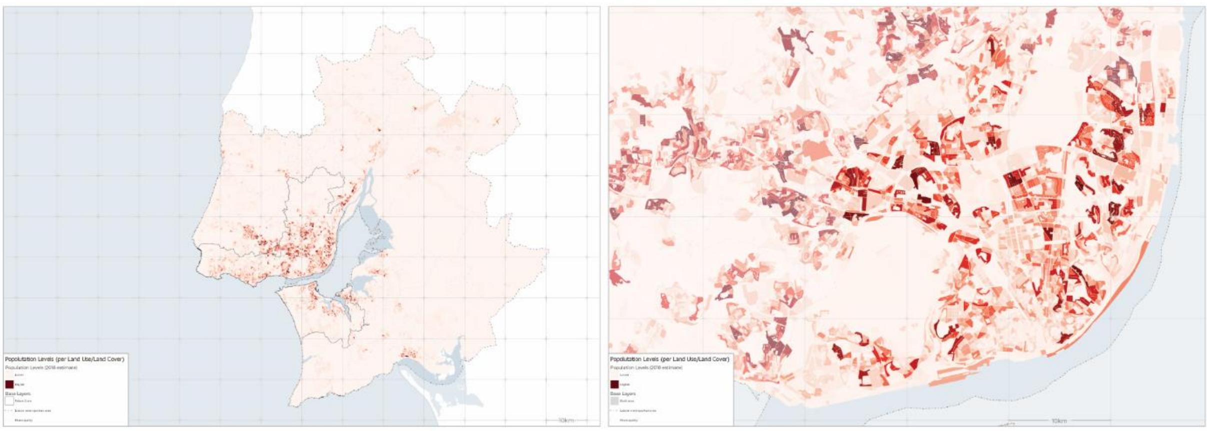


Figure 9.6 Population levels per Urban Atlas class polygon, image by BUUR/PoS 2022, with data from "Copernicus Land Monitoring Service" n.d.)

9.2.1. Systems and form

9.2.1.1. Base

Soil and topography

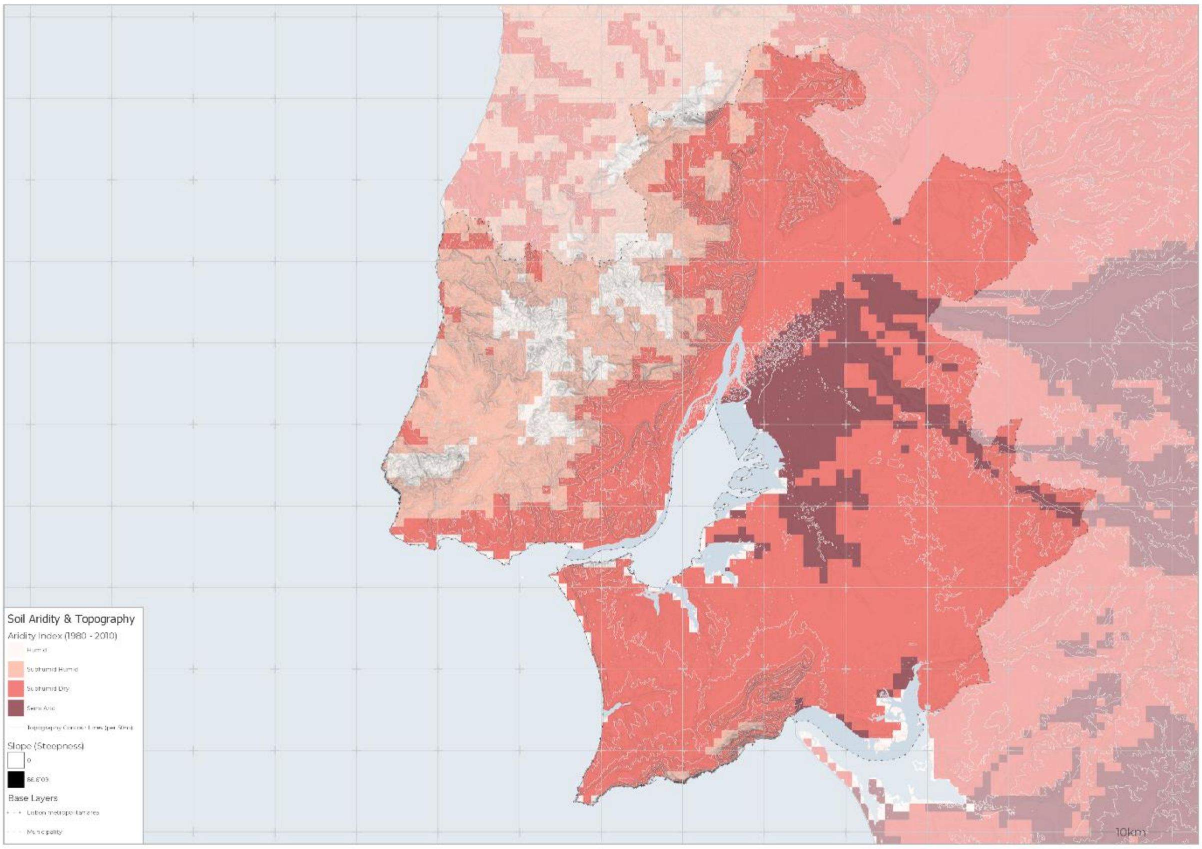


Figure 9.7 Soil aridity and topography for the Metropolitan area of Lisbon and its surrounding context, image by BUUR/PoS 2022, with data from "Instituto da Conservação da Natureza e das Florestas" 2020)

The aridity of the soil (important indicator for heat absorption by the soil, as well as for the overall performance of vegetation and precipitation of possible heat-mitigation options) is shown in Figure 9.7. Here most of the space in the Metropolitan Area is characterised as 'Semi-humid Dry', with a significant proportion as 'Arid' or 'Semi-humid Humid' and a small percentage as humid. The above classification is associated, respectively, with high degree of urbanization and soil sealing and/or intensive and extensive agricultural practices and/or a mostly flat terrain, or the presence of herbaceous vegetation and forestry and more rugged terrains. This emphasizes the need to include geomorphology as an important parameter in the elaboration of heat mitigation measures and adaptation scenarios for the entire territory.

Geomorphology

Figure 9.8 illustrates the extreme difference in landform between the northern and the southern parts of the Metropolitan Area. The former is characterised by an extensive array of ridges and valleys, while the latter is, primarily, a flat terrain that occupies slightly more than half the extent of the entire Metropolitan Area (see Figure 9.9). Such a striking difference reinforces the need for landform-contextual elaboration of heat mitigation solutions and the associated adaptation scenarios. The municipality of Lisbon exhibits a picture similar with the Metropolitan Area, albeit with a higher degree of balance between the different landform classes. Still, however, the historical centre and more dense urban fabric seem to be situated in the more rugged part of the municipality, while urban extensions and built-up spaces of lower densities occupy the less rugged terrain.

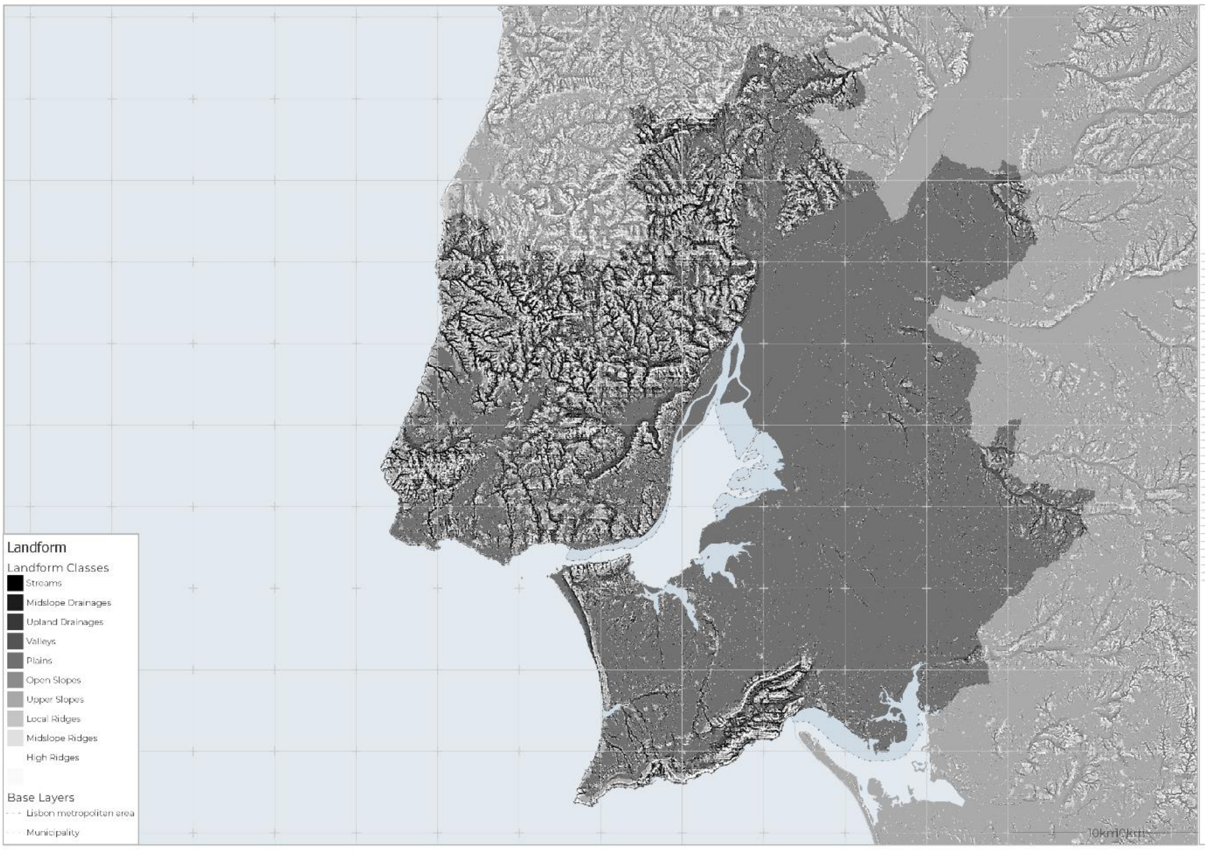


Figure 9.8 Landform classification for the Metropolitan Area of Lisbon and its surrounding Context, image by BUUR/PoS 2022, with data from "Copernicus Land Monitoring Service" n.d.)

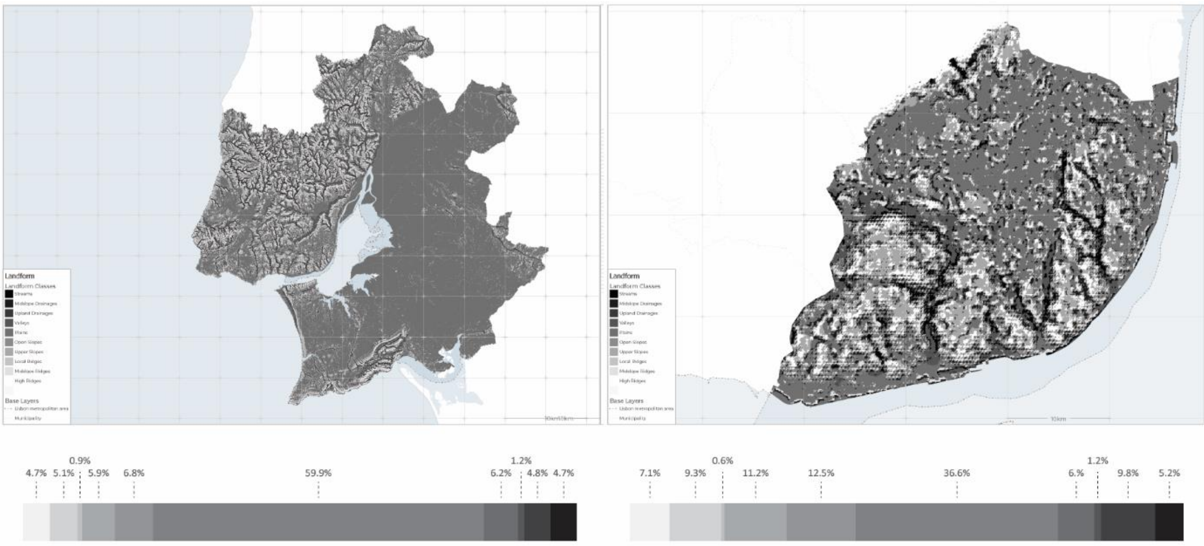


Figure 9.9 Landform classification for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (below), image by BUUR/PoS 2022, with data from "Copernicus Land Monitoring Service" n.d.)

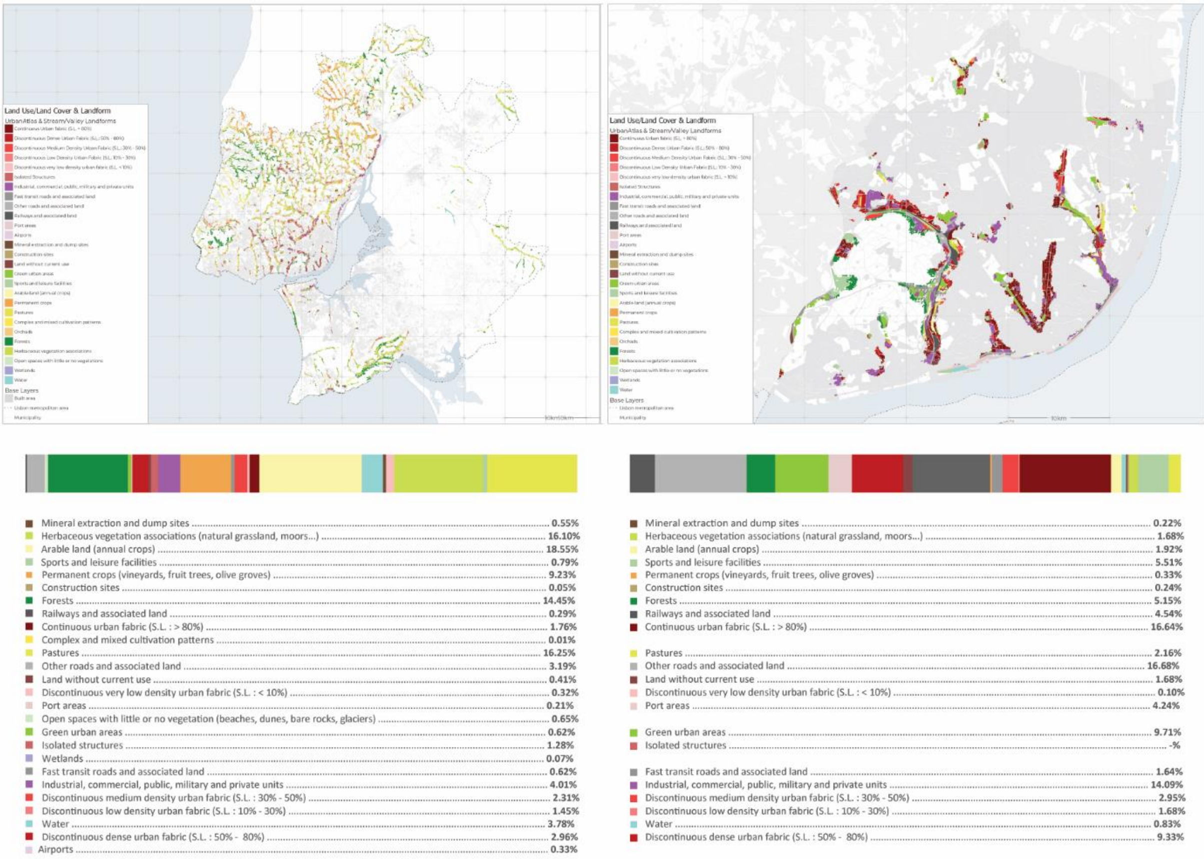


Figure 9.10 Urban Atlas at the valley and stream landform formations for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (bellow), image by BUUR/PoS 2022, with data from "Copernicus Land Monitoring Service" n.d.)

In terms of land use and land cover composition of the repressed landform formations at the scale of the Lisbon Metropolitan Area (see Figure 9.10), these seem to be, primarily occupied by vegetated covers (herbaceous vegetation, forests, agriculture, and pastures), while at the scale of the Municipality of Lisbon, dense urban fabric, road infrastructure, and industrial and commercial units dominate. This picture, together with the prevalence of flat terrains, further reinforces the necessity for a comprehensive heat-regulation strategy that considers the mixture of agricultural land with more intense vegetation throughout the flat landforms (either solely spatial mixite, of functional mixite e.g., agroforestry regimes), and the adaptive infusion or transformation of urban functions with appropriate heat mitigation measures.

Ecological structure

The ecological structure of the Metropolitan Area of Lisbon comprises large formations of high-density vegetation (mostly forests), as well as a network of protected areas (see Figure 9.11). The selection that has been done according to intensity of vegetative land cover (primarily) is thanks to the fact that a network of dense woodland cover is characterised by the potential at delivering cooling performance. As such, while other land cover classes (e.g., herbaceous vegetation, grassland) are, also, significant for, e.g., heat absorption, these are featured, primarily, in the overall land use and land cover analysis. Similarly, the municipality of Lisbon exhibits a network of big parks, gardens and forests that can be conceived of as the ‘spine’ of a comprehensive ecological structure (see Figure 9.12).

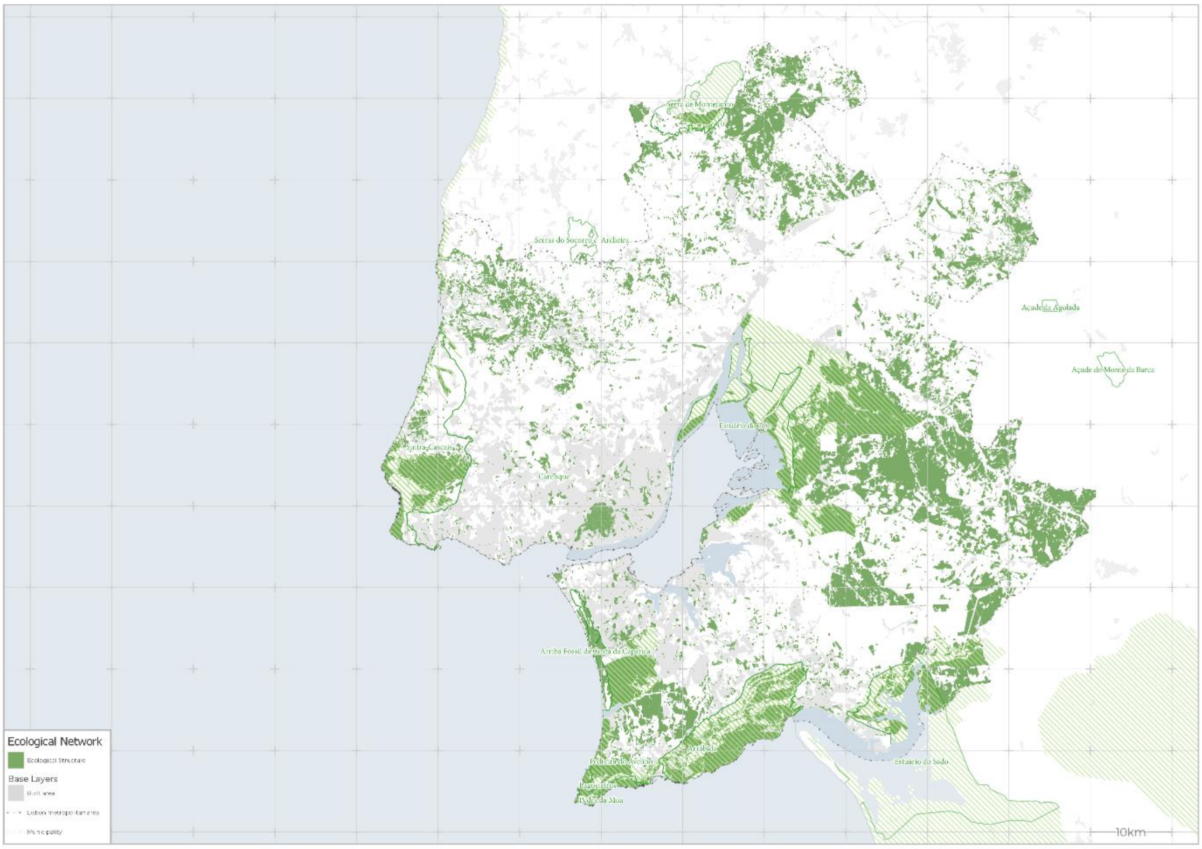


Figure 9.11 Major ecological structure for the for the Metropolitan Area of Lisbon and its surrounding context: large forested and intensely vegetated areas, “National network of Protected Areas” and “Sites Designated under the Habitats Directive ‘RN2000/SIC-Zec”, image by BUUR/PoS 2022 with data from “Copernicus Land Monitoring Service” n.d.

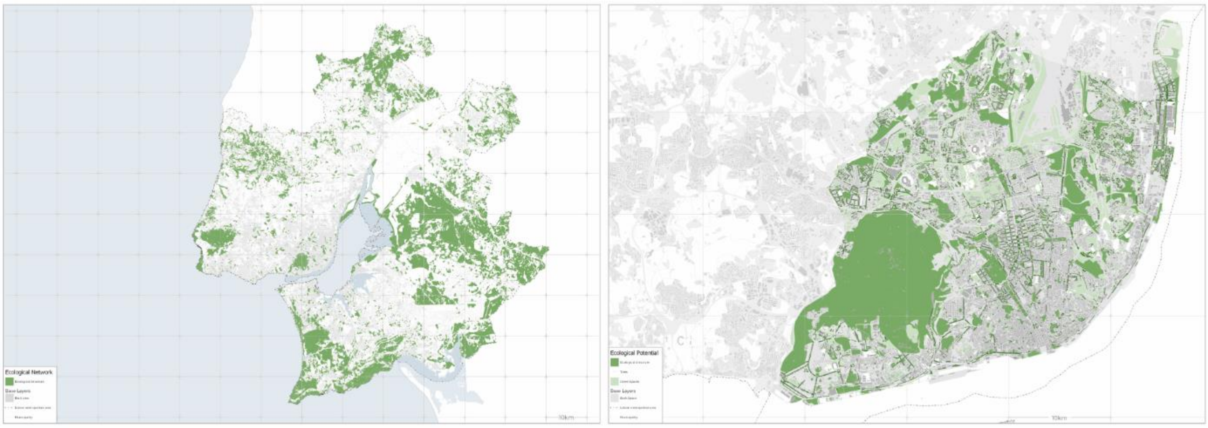


Figure 9.12 Ecological structure for the for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right): large forested and intensely vegetated areas, “National network of Protected Areas”, “Sites Designated under the Habitats Directive ‘RN2000/SIC-Zec” and “Grandes parques e Jardins de Lisboa” (image by BUUR/PoS 2022 with data from “Copernicus Land Monitoring Service”, n.d.; “Sistema Nacional de Informação Geográfica” 2018; “Instituto da Conservação da Natureza e das Florestas” 2022; “Câmara Municipal de Lisboa” 2022)

9.2.1.2. Networks

Surface hydrography

Although the significance of surface water systems in heat regulation is not always evident, for the purposes of this study the water network is approached as a possible agent for the population of the region with relevant heat stress mitigation devices and the overall organization of the associated adaptation scenarios. The Metropolitan Area of Lisbon is characterised by the Tagus estuary that divides it in two parts, with an extensive system of rivers, canals and ditches that occupy its territory (the latter two mostly in reference to agricultural areas).

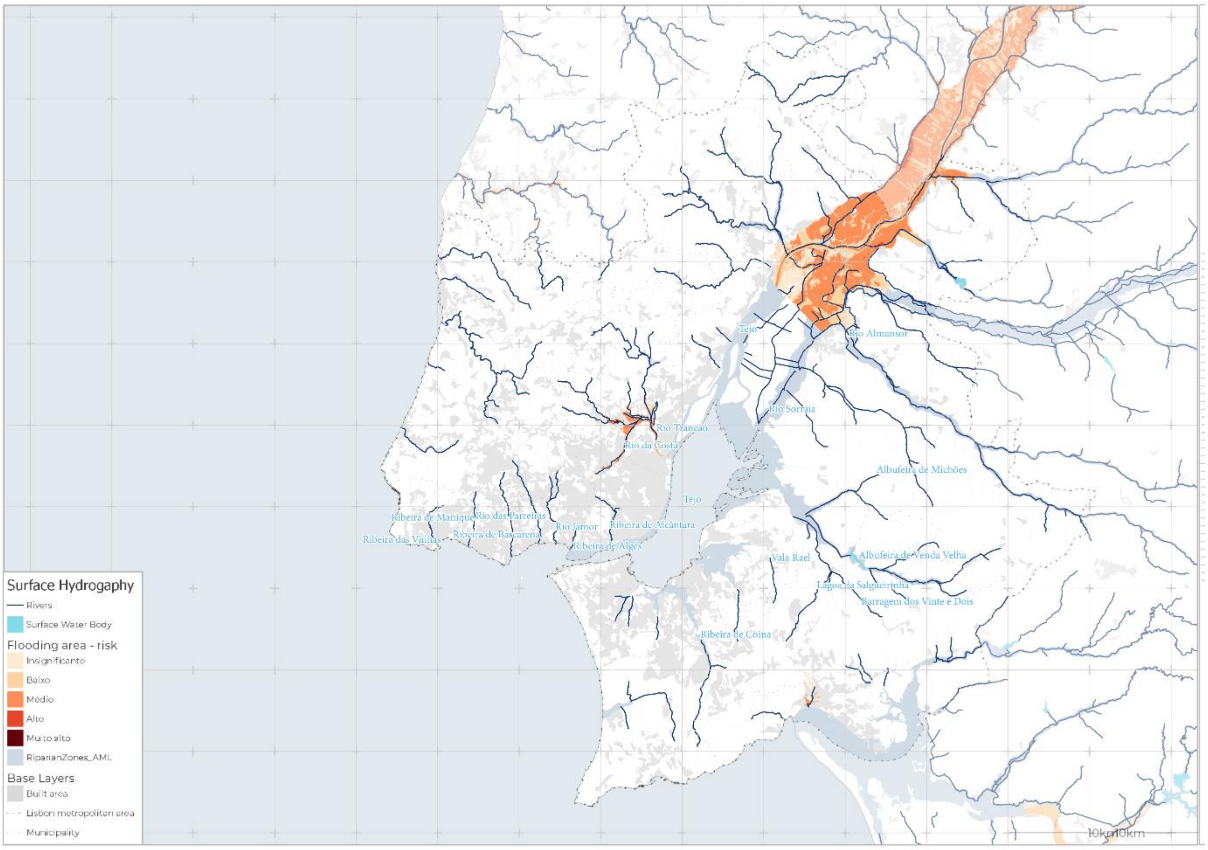


Figure 9.13 Surface hydrographic system for the Metropolitan Area of Lisbon and its surrounding context (image by BUUR/PoS 2022 with data from "Instituto da Conservação da Natureza e das Florestas", 2018; "Instituto da Conservação da Natureza e das Florestas" 2015); "Copernicus Land Monitoring Service" n.d.; "Geofabrik", 2022)

Figure 9.14 draws a more complete picture of the surface hydrographic systems and the various water-related events and phenomena. The northern part of the Metropolitan Area features a significant network of smaller streams, while the southern part is mostly occupied by larger rivers (following, evidently, the landform as discussed previously). The larger rivers are associated, mostly, with cultivated land, either within the estuaries and river floodplains themselves or outside (where, also, the majority of hydrogeological risk is found). However, the municipality of Lisbon exhibits a significant lack of surface water systems: both waterways as well as retention water formations.

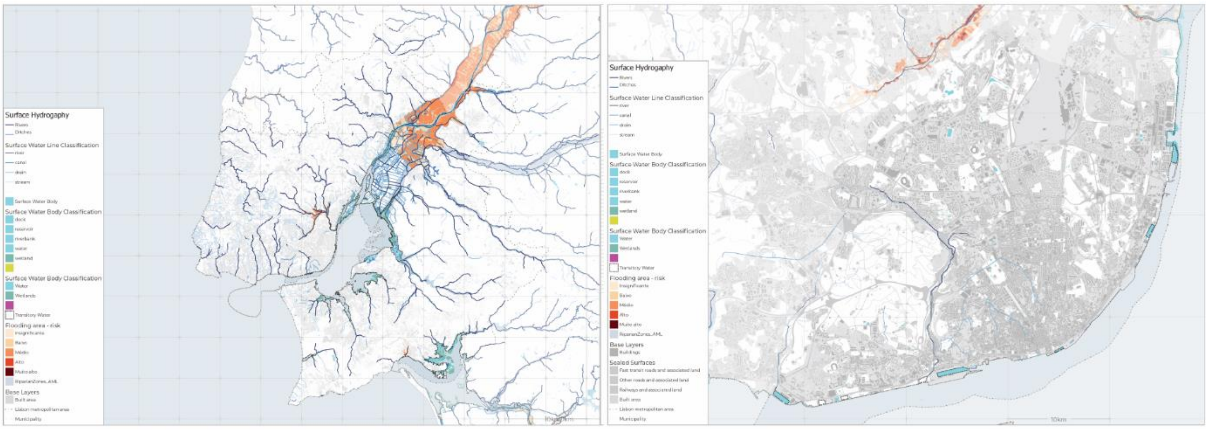


Figure 9.14 Surface hydrographic system for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) (image by BUUR/PoS 2022, with data from "Instituto da Conservação da Natureza e das Florestas" 2018; "Instituto da Conservação da Natureza e das Florestas" 2015; "Copernicus Land Monitoring Service" n.d.; "Geofabrik" 2022)

Mobility infrastructure

The mobility infrastructure system, also, shows difference between the northern and the southern part of the Metropolitan Area (see Figure 9.15). These are related, observably, with the presence of various settlement patterns and lower degrees of agricultural land, as well as with the landform, where the northern part features a capillary network of roads, while the southern is characterised by a main axis of movement east to west and secondary movements north to south.

Figure 9.16 illustrates how the mobility system encircles the mouth of the estuary and traces the highly urbanized region around the coast, on the one hand, and, on the other, how a comprehensive network of crossing movements structures the connectivity of the urbanized region with the entire territory.

Figure 9.15 Mobility infrastructure for the Metropolitan Area of Lisbon and its surrounding context (image by BUUR/PoS 2022 with data from "Portal de dados abertos da Administracao Publica" n.d.; "Câmara Municipal de Lisboa" 2022; "Geofabrik" 2022)

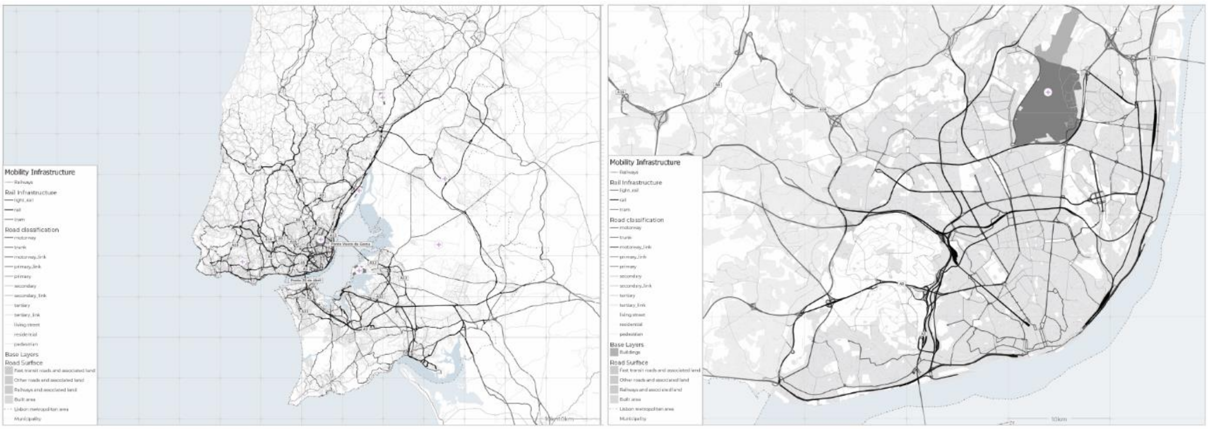


Figure 9.16 Mobility infrastructure for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) (image by BUUR/PoS 2022, with data from "Portal de dados abertos da Administracao Publica" n.d.; "Câmara Municipal de Lisboa" 2022; "Geofabrik" 2022)

Transport networks

Figure 9.17 shows how the transport networks highlight a similar configuration with the overall mobility and land use and land cover systems, with a railroad network that follows the general movement of tracing the urbanized coasts of the mouth of the estuary, and various transport modes populating the settlement areas. Interestingly, the buffer of 300 m that is suggested for the proximity between public transport stops and stations exhibits profound coverage in the both the Metropolitan Area as well as the municipality of Lisbon (see Figure 9.18).

A reflection regarding the transport networks is that their importance to heat regulation rests, primarily, at the scale of everyday movement (between residences, work spaces, and/or amenities). It is important that there is sufficient space along those routes to mitigate the experience of heat. Therefore, the overall structure of transport infrastructure loses relevance in the regional scale if one is to approach it from the perspective of heat regulation.

However, large-scale transport nodes, like airports and ports, not only occupy a large portion of land (and, therefore, contribute to the heat related performance of the territory), but also form nodes within the physical mobility infrastructure system. They are thus connected with the general regional and urban movement. As such, it is important to note the presence of multiple airports and ports (as well as the planning of new ones) which will have to be considered for the formulation of adaptation narratives for the entire territory, as well as for the elaboration of specific contextual physical and spatial heat-regulation solutions and measures, per land-use/land-cover class and physical and spatial characteristics.

Figure 9.17 Transport infrastructure for the Metropolitan Area of Lisbon and its surrounding context (image by BUUR/PoS 2022 with data from "Portal de dados abertos da Administracao Publica" n.d.; "Câmara Municipal de Lisboa" 2022; "Geofabrik" 2022)

Fig. 9.18 Transport infrastructure for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with 300 m buffer zone overlay from public transport stops (image BUUR/PoS 2022 with data from "Portal de dados abertos da Administracao Publica" n.d.; "Câmara Municipal de Lisboa" 2022; "Geofabrik" 2022)

9.2.1.3. Occupation

Built form

Intensity- and form-wise, urbanization patterns exhibit different characteristics in different areas: i.e., the centre of Lisbon is characterized by dense urban blocks, while, further, form and intensity become less compact and/or less dense (see Figure 9.19, 9.20 and 9.21). The importance of built-up patterns for heat regulation rests on their configuration: the proximity of high-rise buildings, the layout and intensity of urban blocks, and the open space within them affect the manifestation of heat (U.S. Environmental Protection Agency 2012), and suggest measures ("Urban Green-Blue Grids for resilient cities", n.d.).

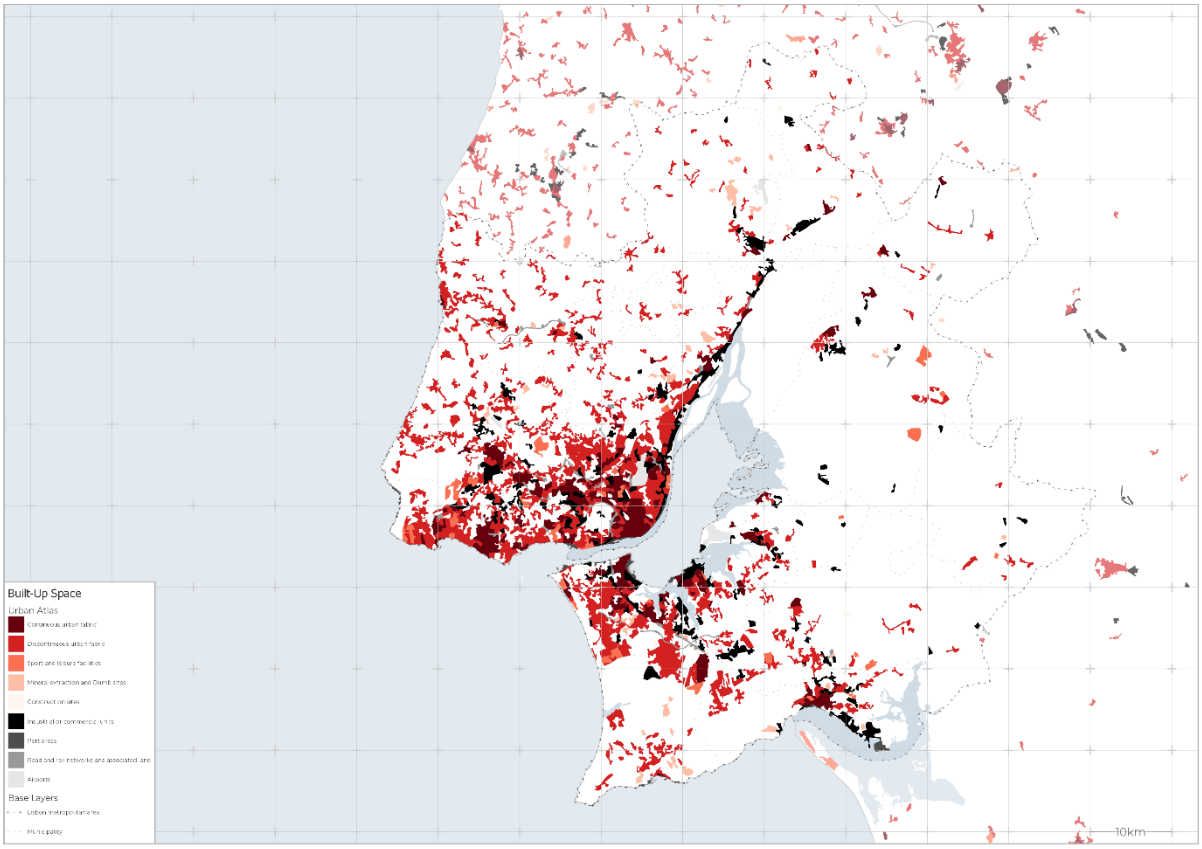


Figure 9.19 Intensity of built-up space for the Metropolitan Area of Lisbon and its surrounding context (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)

Figure 9.20 Built-up space for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) (BURR PoS 2022, with data from "Geofabrik" 2022)

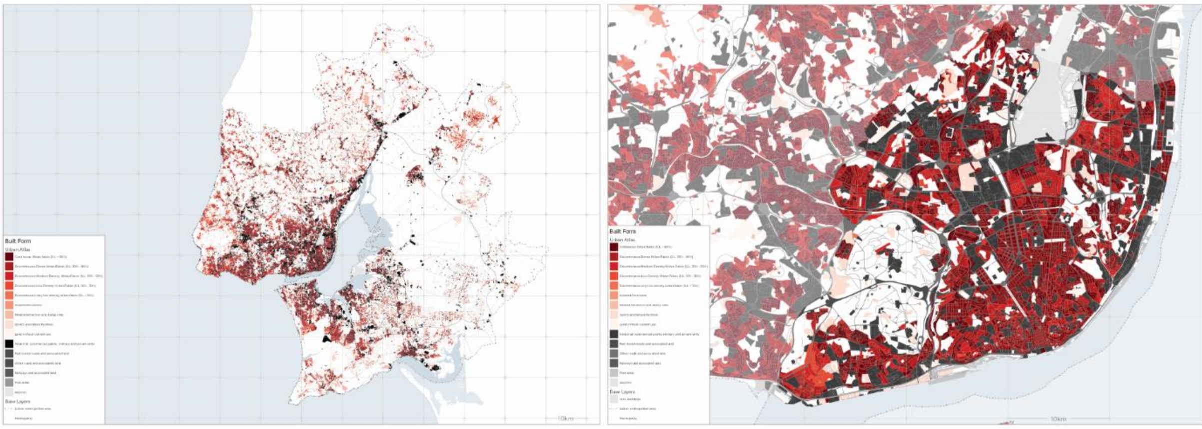


Figure 9.21 Intensity of built-up space for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) (image by BUUR/PoS 2022 with data form "Copernicus Land Monitoring Service" n.d.)

Spatial programmes

The distribution of various everyday spatial programs and urban functions within and throughout the territory is mapped in order to discern patterns of use that may be affected by heat stress and/or patterns of use according to which to plan for the associated heat regulation. The corresponding significance of both can be seen in Figures 9.22 and 9.23.

Figure 9.22 displays the various zones of secondary and tertiary economic activity of the region in reference to the hierarchy of the mobility network. As becomes evident, these are organized around major mobility and transport infrastructural axes. As such, any climatic risk that might affect patterns of movement may directly affect the economic activity throughout the territory. Similarly, the significance of the presence of people in and around these zones position them at the forefront for heat mitigation measures in order to lessen the experience of heat stress. Finally, the hierarchical importance of the mobility network illustrates how it seems appropriate that it be used as a spine for the elaboration of a territory-wide cooling spatial planning, design, and engineering project.

Figure 9.22 Correlation between spaces of secondary/tertiary sector economic activity and the hierarchy of the mobility network (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.; "Geofabrik" 2022)

Figure 9.23, on the other hand, makes the case for the evaluation of the overall distribution of everyday spatial programs and functions to correspond to patterns and potential of cool spaces (not surprisingly, the Municipality of Lisbon and, particularly, its centre, exhibit abundance in such programs and functions).

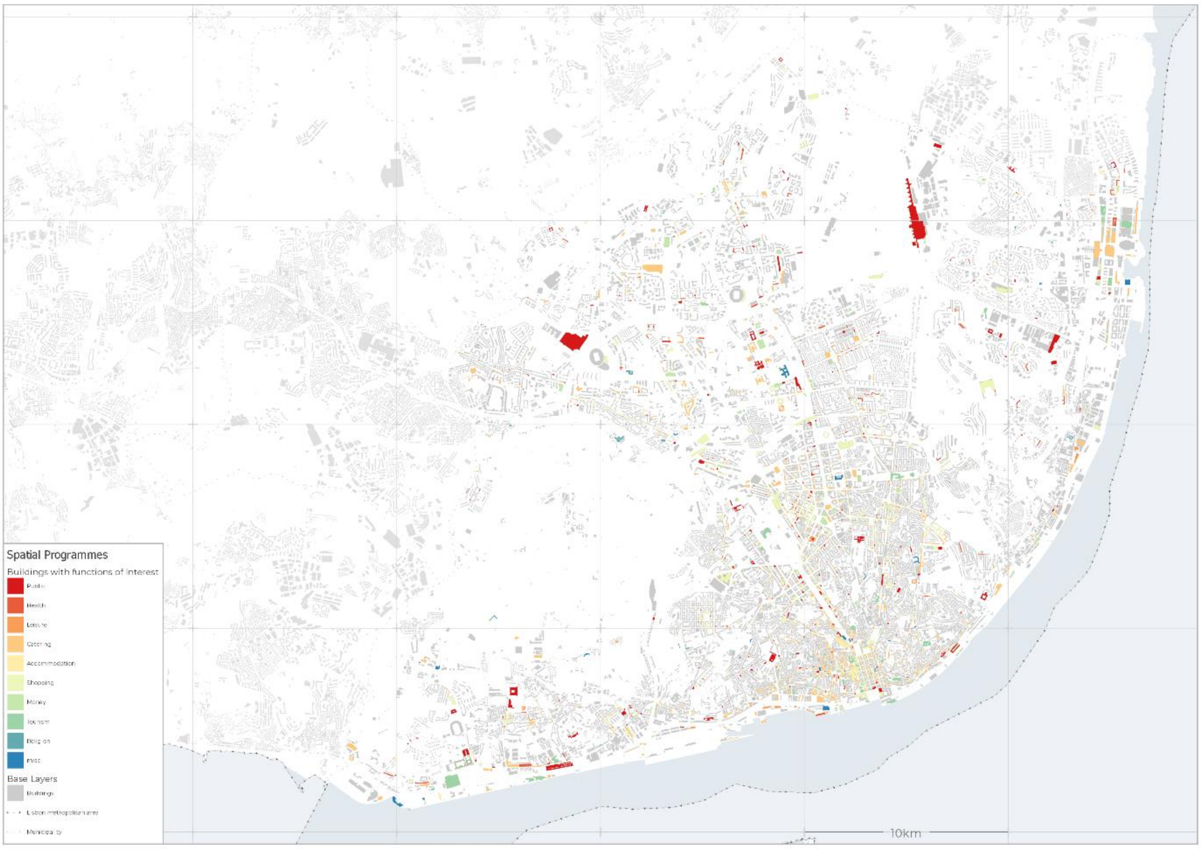


Figure 9.23 Land use, spatial programmes and urban functions for the municipality of Lisbon (image by BUUR/PoS 2022 with data from "Geofabrik" 2022)

Governance

Governance (at this stage) is concerned with those parts of the territory that are under a regime of protection due to their importance for the ecological performance of the region. This includes the Natura 2000 network, as well as the nationally defined areas of preservation for the entire country of Portugal (ecological corridors also fall under this category). For the Municipality of Lisbon, the established network of parks and gardens is indicative of areas of public governance of ecologically important spaces (see Figure 9.24).

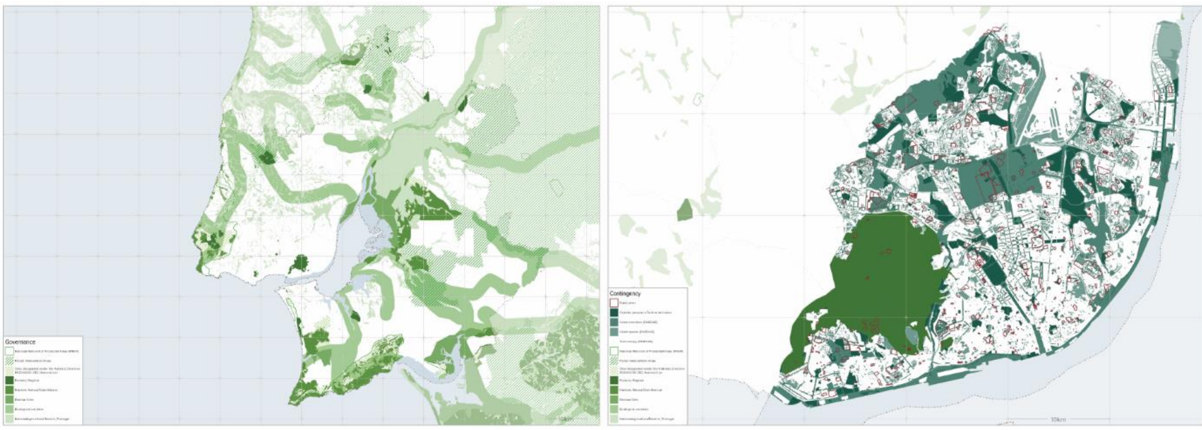


Figure 9.24 Cumulative representation of protected areas of ecological value for the Lisbon Metropolitan Area (left) and the Municipality of Lisbon (right), with indication of plots of public ownership and/or significance for the smaller scale (image by BUUR/PoS 2022 with data from "Rede Nacional de Áreas

Protegidas (RNAP)" 2018; "Habitats Naturais e Semi-Naturais - Plano Setorial da Rede Natura 2000" 2008; "Corredor Verde" 2022)

9.3. Strategic profile

The Strategic Profile for the Metropolitan Area of Lisbon in reference to heat stress regulation is an inquiry into the presence of appropriate potential and its configuration, as well as how this relates to the rest of the territory's spatial systems. Said potential refers to, essentially, the system of open/non-built-up space. Figure 9.25 illustrates this through a categorization of land use and land cover classes for the municipality of Lisbon. Continuous urban fabric and industrial and commercial units take up the majority of the space, leaving little adequate (and flexible) space for mitigation and adaptation measures. This signifies that the other (more or less prominent) land use and land cover classes will feature greatly in heat regulation strategies (namely, forests and green urban areas), and that more point interventions will need to be deployed in this highly urbanized landscape.

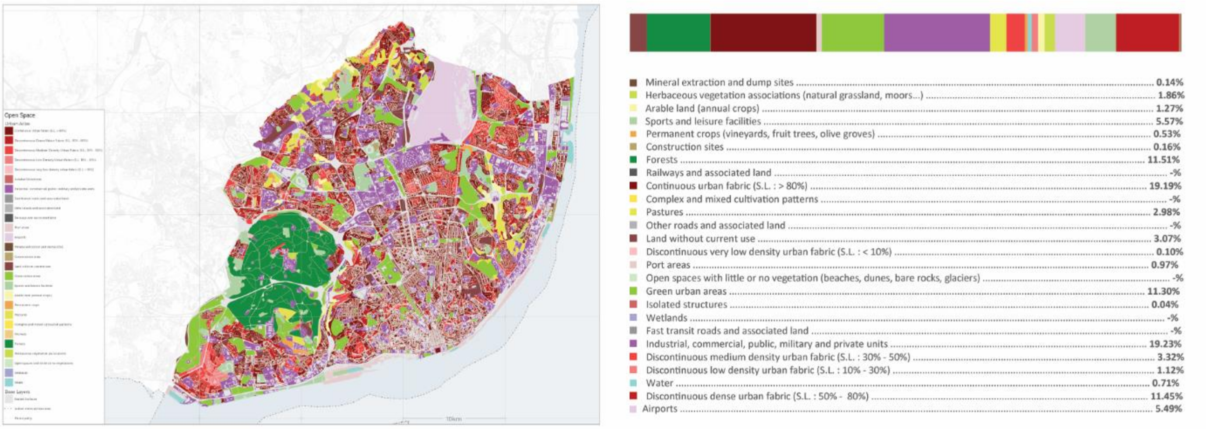


Figure 9.25 Urban Atlas at the non-built-up space for the municipality of Lisbon (BURR PoS 2022, with data form "Copernicus Land Monitoring Service" n.d.)

9.3.1. Regulation systems

The spatial systems that compose the spatial capacity of the Lisbon Metropolitan Area and the Municipality of Lisbon – the ecological structure, the system of non-built-up spaces, and the infrastructural networks – are analysed in reference to their inherent correspondence with the particularities of heat regulation. For the first two, the focus is on size and proximity, while the latter is approached in terms of the land use and land cover composition of its surroundings, where the issue is to gauge the degree to which they can function as a spine to support a broader heat regulation spatial planning, design, and engineering project. The three regulation systems will in the next sub-section be correlated with the rest of the spatial systems from the perspective of heat mitigation and adaptation.

9.3.1.1. Ecological potential

Ecological potential follows the previous analysis of the ecological structure of the Metropolitan Area. A subsequent analysis of the patches and corridors is done based on their size and proximity. Size is in indicator of types of cooling devices, namely, forests and large urban parks. The categorization of green spaces identifies spaces of at least 200m^2 and spaces of at least 2.5 hectares. It has been found that the latter size is the minimum for an urban forest, while the former is the minimum for an adequately cooling urban green space. Similarly, cool spaces should not be further than 300 m apart, so that the air movement and ventilation capacity of the system is not hindered ("Urban Green-Blue Grids for resilient cities" n.d.).

The maps in Figure 9.26 and Figure 9.27 illustrate the above aspects. The ecological potential and the network it creates will be further evaluated in reference to the general occupation patterns of the urbanized landscape further down this chapter. Of specific interest is whether there is sufficient open green space to cover the entire urban population, both in terms of green patches of adequate size, and in terms of the existence of 'gaps' characterized by the absence of green within a radius that exceeds 300m. The preliminary analysis shown here already indicates the need for further integration of the exiting green spaces, as well as the design of new ones.

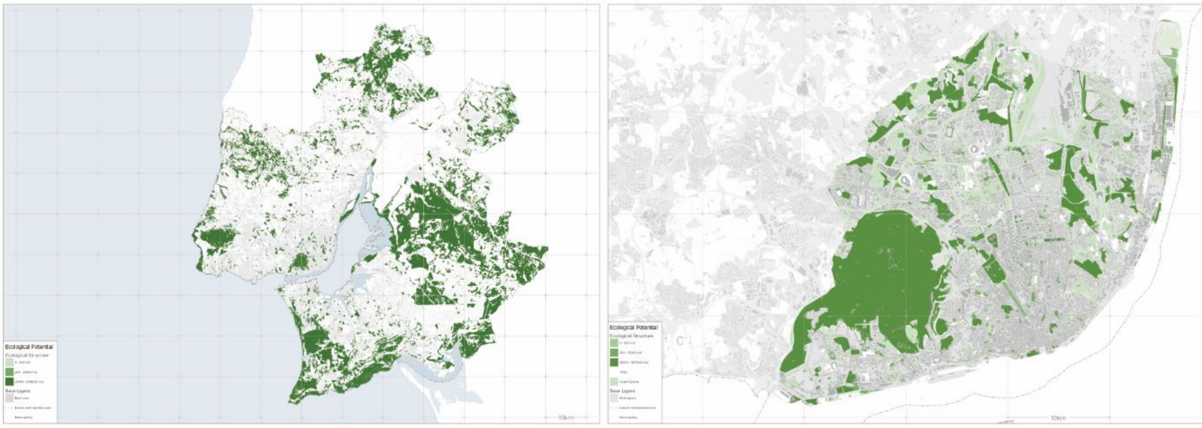


Figure 9.26 Ecological potential per size for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right), image by BUUR/PoS 2022

Figure 9.27 Ecological connectedness per 300 m buffer zone for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right), image by BUUR/PoS 2022

9.3.1.2. Spatial potential

Overall spatial potential (differentiated by ecological potential) refers to the system of non-built-up spaces of the spatial extent. Similarly, to the ecological potential, this is classified according to size and proximity. The difference lies in the different land use and land cover classification (and, by extension, the possibilities for heat regulation planning), such that spatial potential is approached to determine necessary measures that the existing ecological potential is unable to address. As shown in Figure 9.28 and Figure 9.29, the coverage of large open spaces takes up most of the space of the Municipality of Lisbon.

However, further analysis is needed to determine the degree of flexibility of manipulation of said spaces (a function of their use and cover classes, as well as ownership patterns).

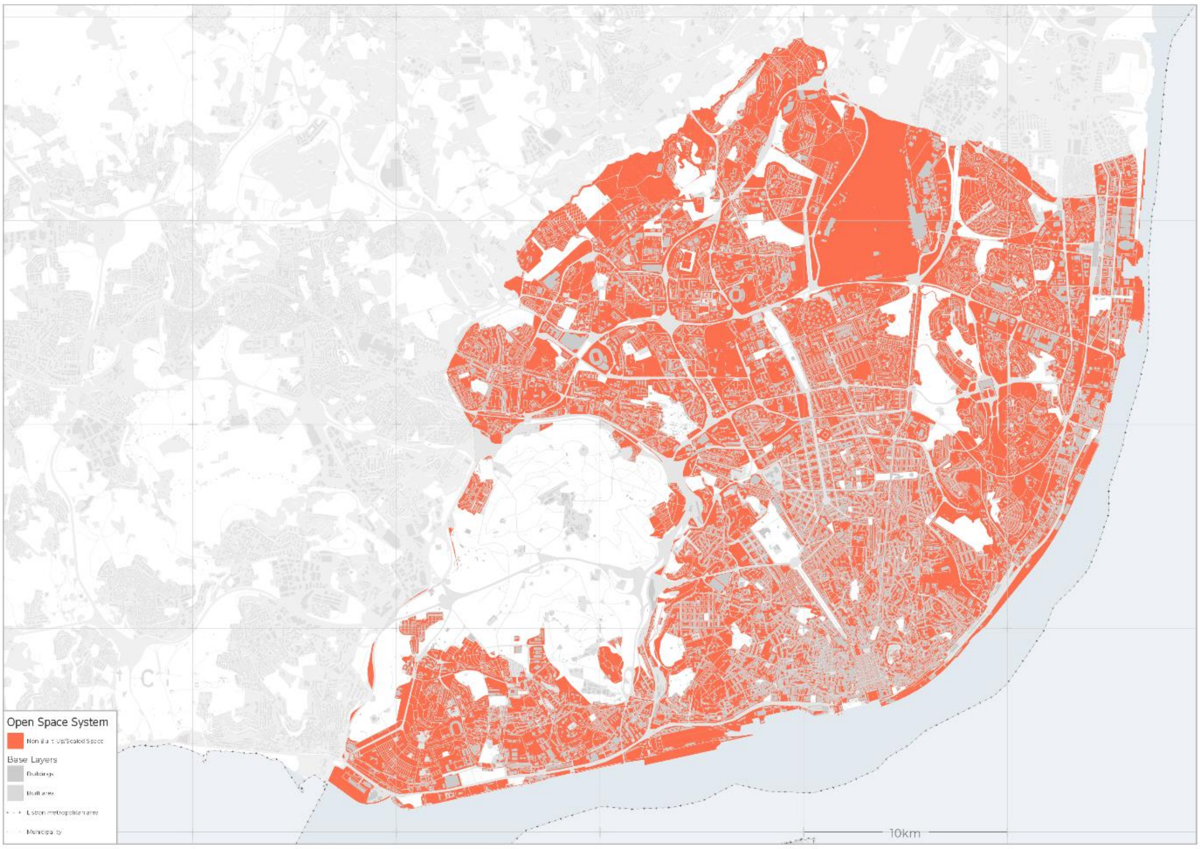


Figure 9.28 Non-built-up (and non-ecological) space for the municipality of Lisbon, image by BUUR/PoS 2022

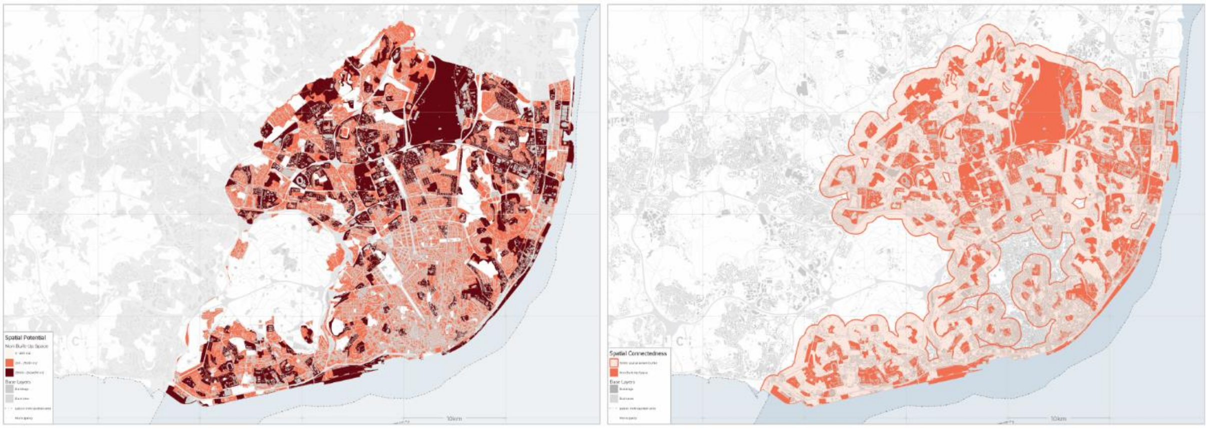


Figure 9.29 Size categorization and spatial connectedness of non-built-up space for the Municipality of Lisbon, image by BUUR/PoS 2022

9.3.1.3. Infrastructural potential

Infrastructural potential refers to the possibility of organizing mitigation and adaptation measures along the major networks of the territory. Two different types of networks are being discussed here: surface hydrography and mobility, and the issue is the evaluation of the degrees that different land use and land cover classes take up their respective buffer zones. For the purposes of this project, riparian zones are classified according to

“Copernicus Land Monitoring Service” (n.d.) and a 6 m buffer around the watercourse axis (Pötz et al. 2010) (see Figure 9.30). The mobility infrastructure system is categorized in five classes with respective buffers of: 822 m for the motorway, trunk and railway axes, 117 m for the primary roads, 85 m for the secondary and tertiary courses, 36 m for minor axes and 6 m for the very small roads (Viganò et al. 2016) (see Figure 9.31).

As regards the surface hydrographic system (see Figure 9.30), for the Lisbon Metropolitan Area, the riparian zones are mainly associated with irrigation for agricultural lands and pastures, as well as associated herbaceous vegetation. For the Municipality of Lisbon, they form, largely, part of the mobility infrastructure and, secondarily, of the urban fabric (primarily dense urban fabric). As such, the capacity of the surface water network to host heat regulation devices articulates the need for the embedding of said measures and solution within and throughout the agricultural and urbanized mosaics.

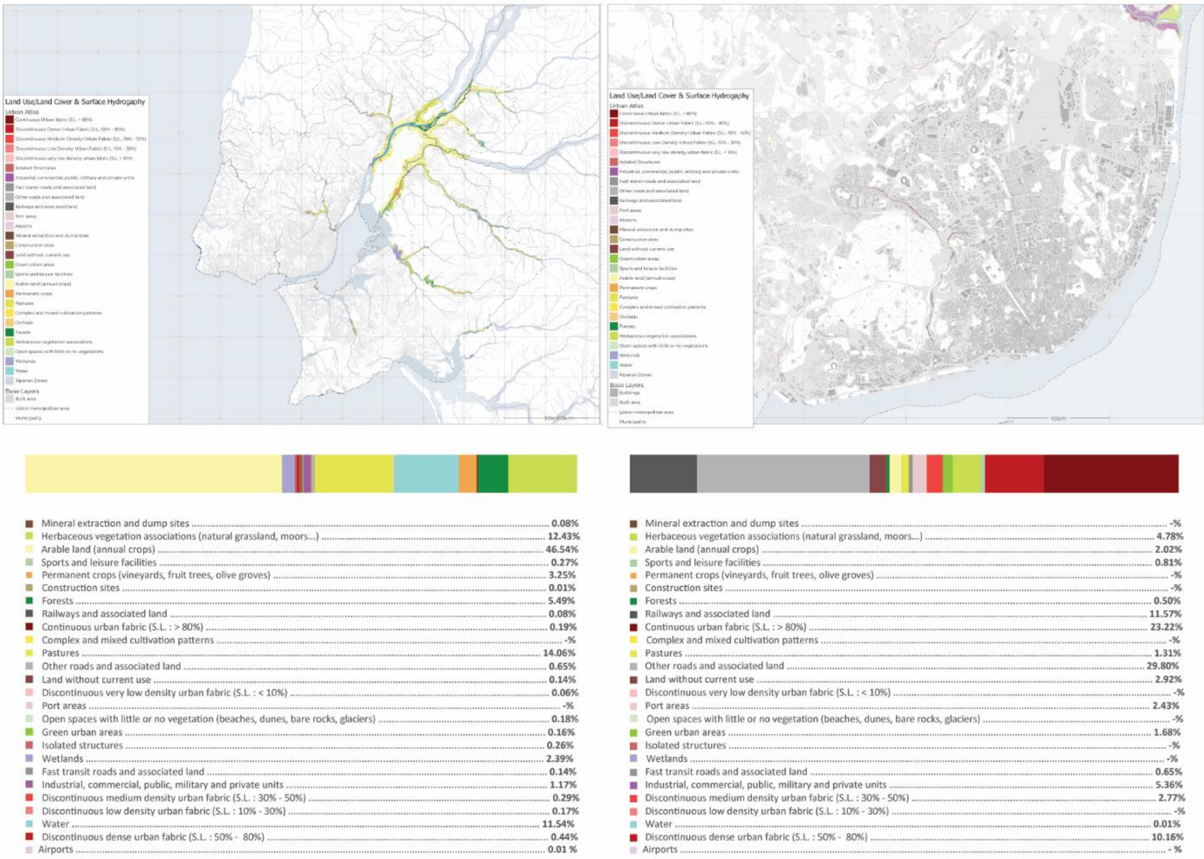


Figure 9.30 Urban Atlas at the riparian zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from “Copernicus Land Monitoring Service” n.d.)

A similar image is being gauged by the land use and land covers of the mobility infrastructure buffers that are primarily characterized by herbaceous vegetation, arable land, pastures, forests and to a lesser degree industrial/commercial units and dense urban fabric, for the Lisbon Metropolitan Area, and, for the Municipality of Lisbon primarily dense urban fabric and industrial/commercial units, and secondarily green urban areas (see Figure 9.32). This picture is, almost identically, replicated throughout the five different classed of the hierarchical categorization. The mobility infrastructure traverses and connects herbaceous vegetation formations, croplands and pastures, forests and urban green areas, industrial and commercial units, and the densest instances of the urban fabric (see Figure 9.33 to Figure 9.37). This signifies the capacity of the road network to organize a territory-wide cooling spatial plan, organize a mixture between intense vegetation and agricultural uses and covers, enhance, protect and connect the existing herbaceous vegetation structures and woodland covers, provide for cool spaces in close proximity and/or in tandem with work environments and amenities, as well as the residential areas. A further classification of the above associated spaces in reference to their inherent capacity at hosting the corresponding heat regulation measures and/or being transformed accordingly needs to be done and will be discussed further down this chapter.

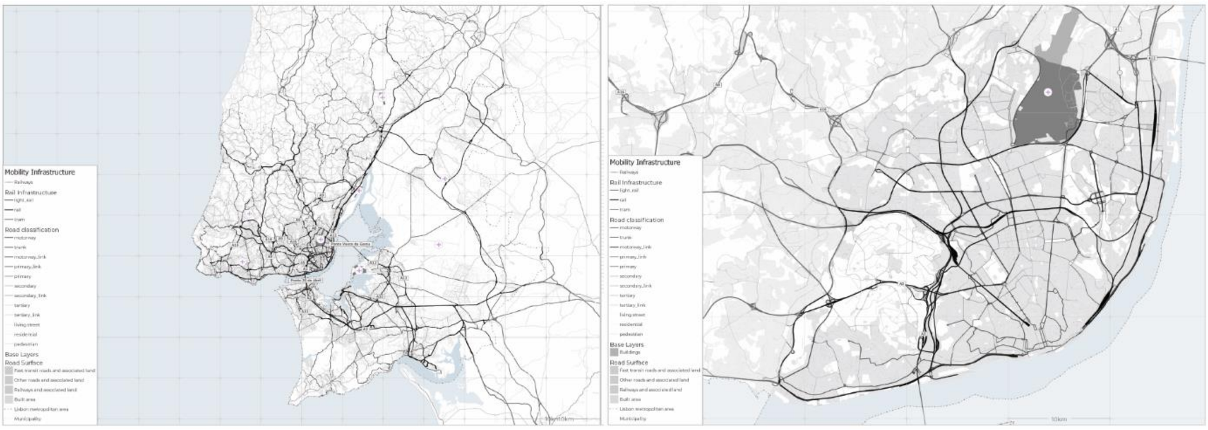


Figure 9.31 Classification of mobility infrastructure for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right), image by BUUR/PoS 2022

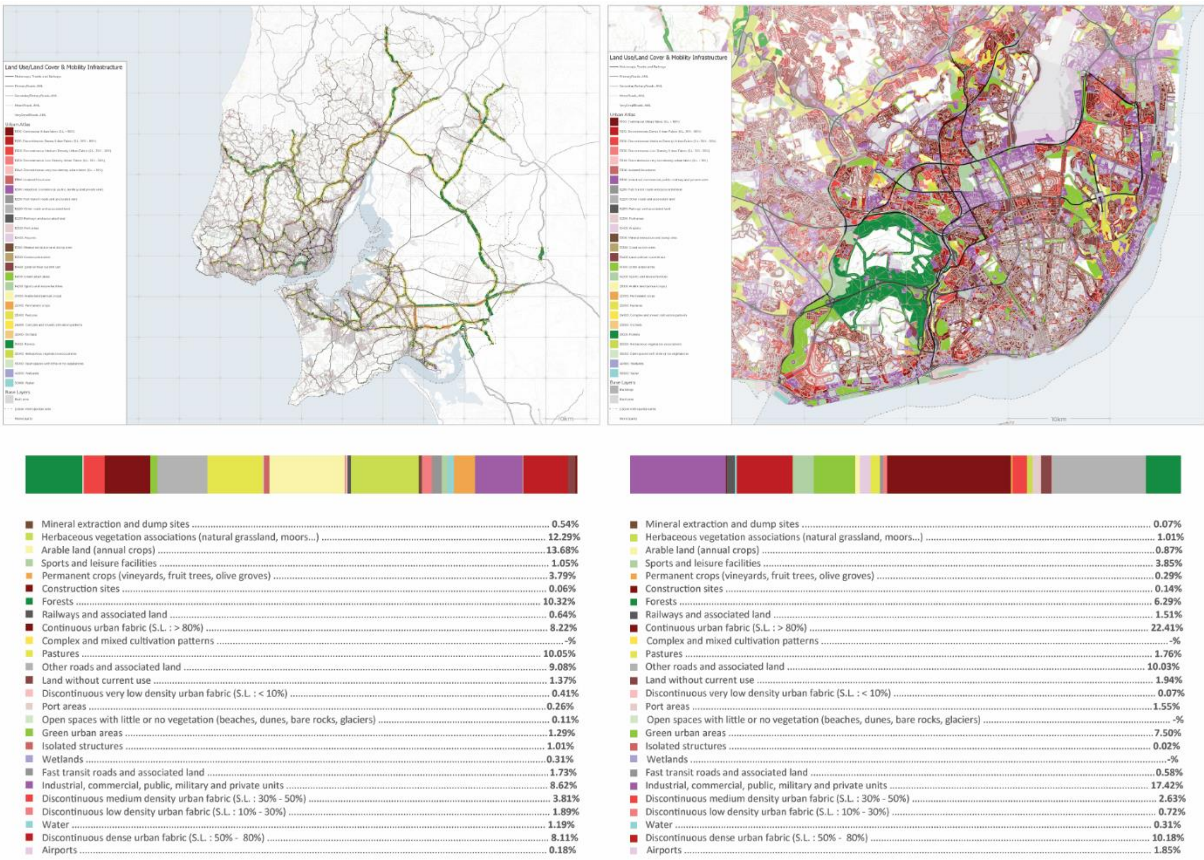


Figure 9.32 Urban Atlas at the mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated

classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d. (https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018))

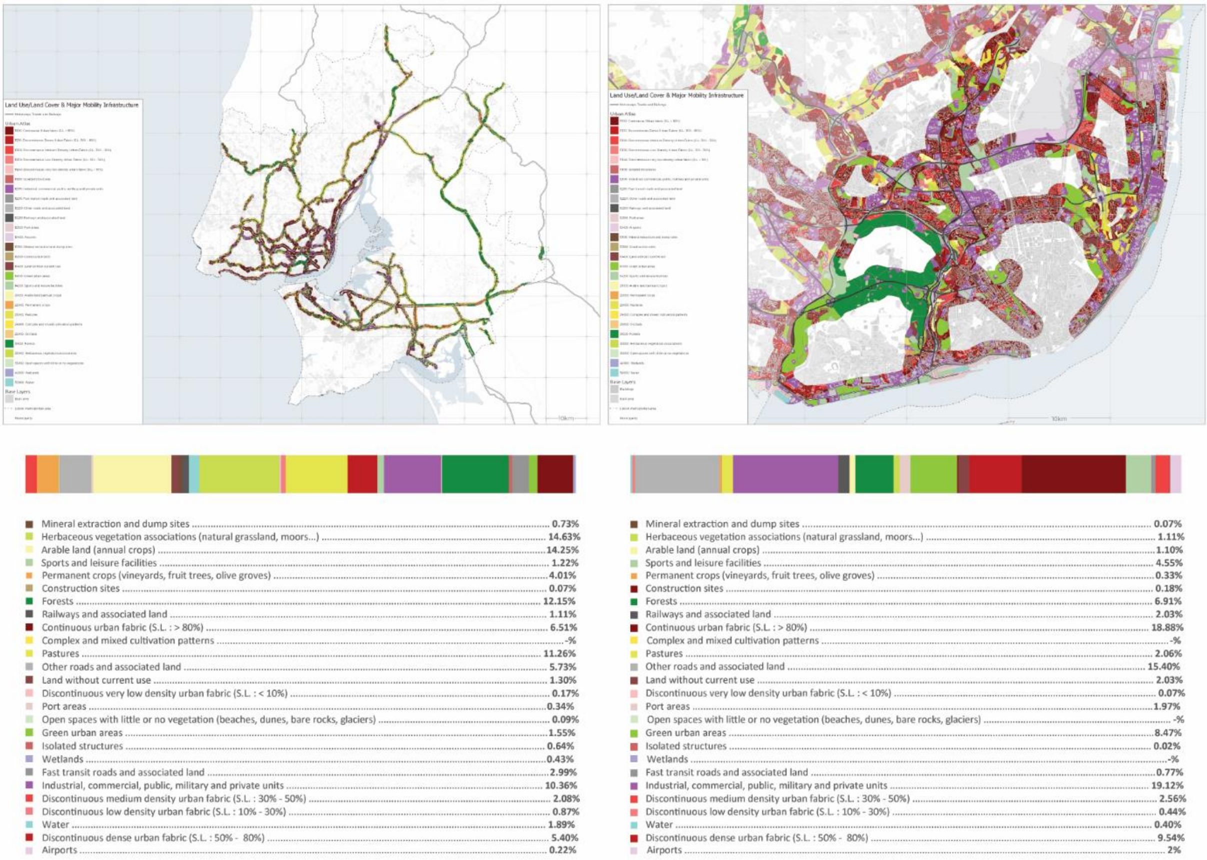


Figure 9.33 Urban Atlas at the major mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)

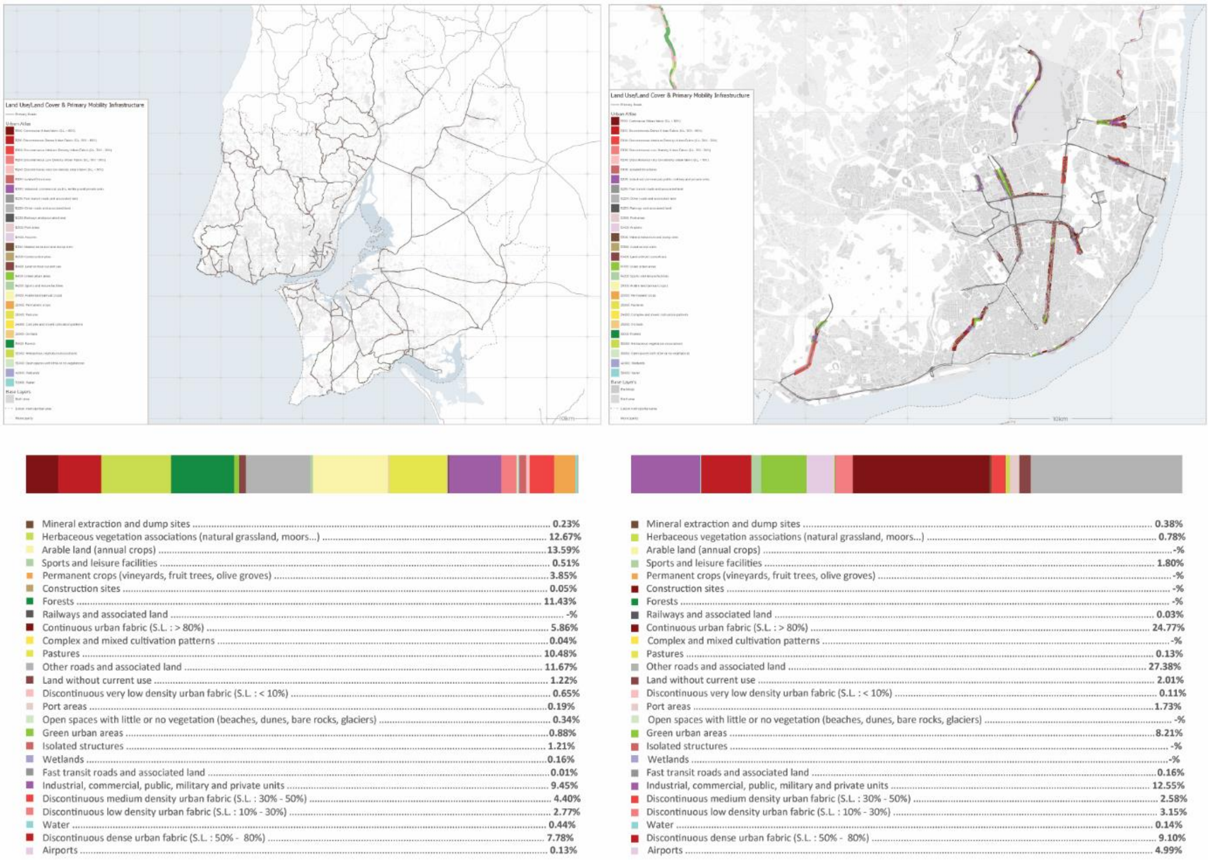
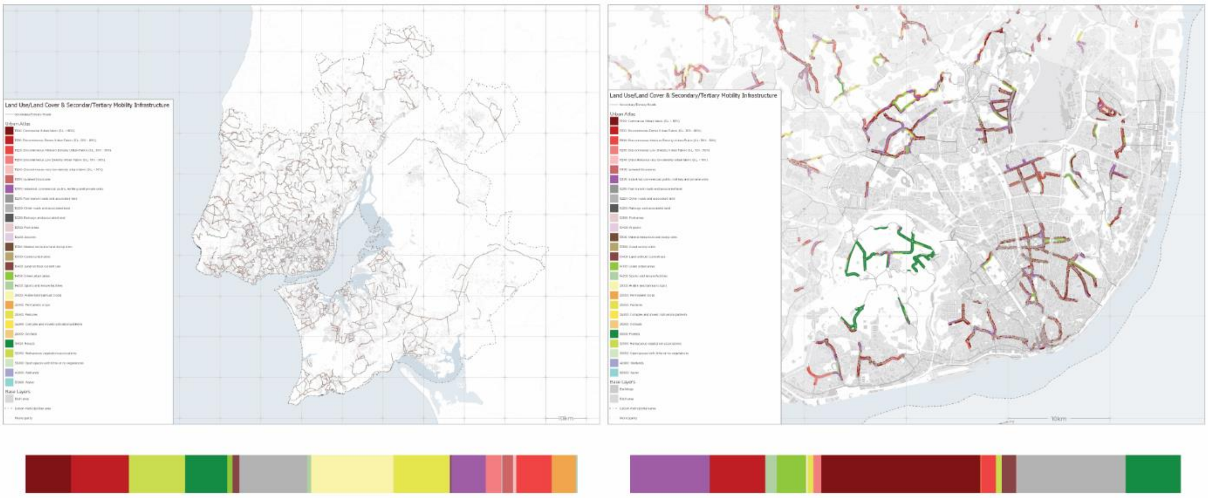


Figure 9.34 Urban Atlas at the primary mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)



Mineral extraction and dump sites	0.27%
Herbaceous vegetation associations (natural grassland, moors...)	10.20%
Arable land (annual crops)	14.92%
Sports and leisure facilities	0.69%
Permanent crops (vineyards, fruit trees, olive groves)	4.42%
Construction sites	0.02%
Forests	7.61%
Railways and associated land	-%
Continuous urban fabric (S.L. : > 80%)	8.26%
Complex and mixed cultivation patterns	-%
Pastures	10.13%
Other roads and associated land	12.34%
Land without current use	1.21%
Discontinuous very low density urban fabric (S.L. : < 10%)	0.61%
Port areas	0.04%
Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	0.08%
Green urban areas	1.01%
Isolated structures	1.91%
Wetlands	0.08%
Fast transit roads and associated land	-%
Industrial, commercial, public, military and private units	6.25%
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	6.40%
Discontinuous low density urban fabric (S.L. : 10% - 30%)	2.88%
Water	0.13%
Discontinuous dense urban fabric (S.L. : 50% - 80%)	10.48%
Airports	0.05%

Mineral extraction and dump sites	-%
Herbaceous vegetation associations (natural grassland, moors...)	1.05%
Arable land (annual crops)	0.33%
Sports and leisure facilities	2.09%
Permanent crops (vineyards, fruit trees, olive groves)	0.11%
Construction sites	0.03%
Forests	9.97%
Railways and associated land	-%
Continuous urban fabric (S.L. : > 80%)	28.92%
Complex and mixed cultivation patterns	-%
Pastures	0.99%
Other roads and associated land	19.79%
Land without current use	2.61%
Discontinuous very low density urban fabric (S.L. : < 10%)	0.08%
Port areas	-%
Open spaces with little or no vegetation (beaches, dunes, bare rocks, glaciers)	-%
Green urban areas	5.33%
Isolated structures	0.02%
Wetlands	-%
Fast transit roads and associated land	-%
Industrial, commercial, public, military and private units	14.46%
Discontinuous medium density urban fabric (S.L. : 30% - 50%)	2.72%
Discontinuous low density urban fabric (S.L. : 10% - 30%)	1.41%
Water	-%
Discontinuous dense urban fabric (S.L. : 50% - 80%)	10.05%
Airports	0.05%

Figure 9.35 Urban Atlas at the secondary and tertiary mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)

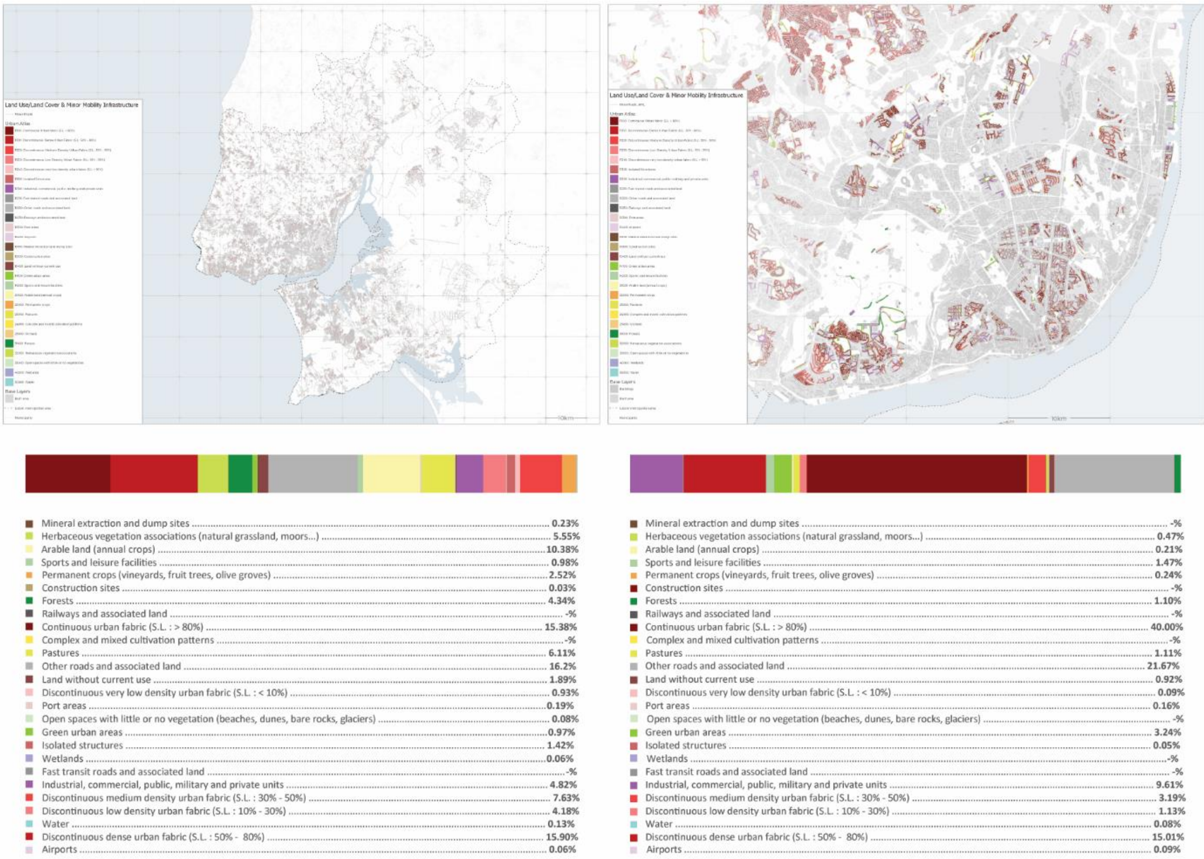


Figure 9.36 Urban Atlas at the minor mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)

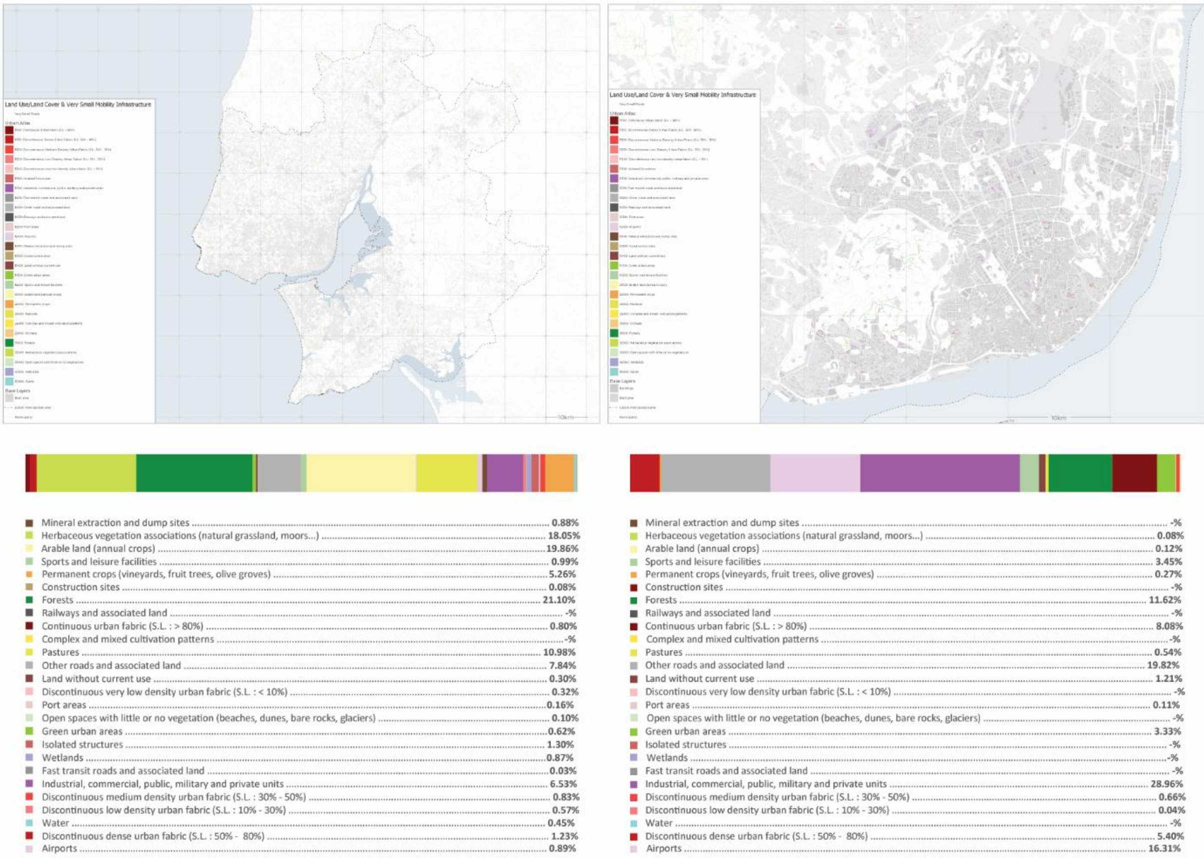


Figure 9.37 Urban Atlas at the very small mobility infrastructure buffer zones for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) with calculation of Class Area Proportion (CAP) for the associated classes (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d.)

9.3.2. Spatial dimensions for heat regulation

This section is concerned with the evaluation of the spatial structure of the Lisbon Metropolitan Area and the Municipality of Lisbon from the perspective of heat regulation. This evaluation is done through looking at the characteristics of the regulation systems in relation with the overall urbanized landscape according to specific criteria for heat-related performance. Said criteria follow Kuzniecow Bacchin (2015) and are as follows: coherence, permeability, porosity, flexibility, and contingency, and each looks at the aforementioned interrelationship in reference to a particular need for appropriate heat stress management, namely, the ground system, the territorial appropriation of cooling spaces, their significance for everyday life, their inherent capacity to provide for heat regulation, and their correspondence with existing management regimes.

9.3.2.1. Coherence

Coherence signifies the organization of the composition and the configuration of land use and land cover throughout a spatial extent in reference to a particular issue (here: heat stress regulation) according to the base layers (soil, topography, geomorphology, ecological structure) (Kuzniecow Bacchin 2015). For the purposes of heat stress regulation, this implies the cooling of urbanized landscapes that sit on valley and stream landform formations, the increase of vegetation throughout flat landform formations and along riparian corridors and the planning and design of ecological corridors that bridge the gaps between existing areas of ecological value (Pötz, Anholts, and de Koning 2014; Pötz, Bleuze, and Alleg 2010). That is, the determination of limits to heat stress mitigation and adaptation is related with: 1) the evaluation of the possibility that corresponding devices be infused within the those parts of the city that rest on repressed geomorphological structures, 2) the re-naturalization and further greening of riparian zones, 3) the increase in vegetation on plain fields, and 4) the utilization of the mobility infrastructure network as carrying structures to connect areas of ecological value that have more than 300 m distance between them. The spaces themselves are, further, categorized according to the level of cooling potential which is a factor of their land use and land cover class (following (Bryan Ellis, Michael Revitt, and Lundy 2012).

The maps of Figure 9.38 show the resulting network of cooling spaces and the rate of cooling potential for the Metropolitan Area of Lisbon and the municipality of Lisbon.

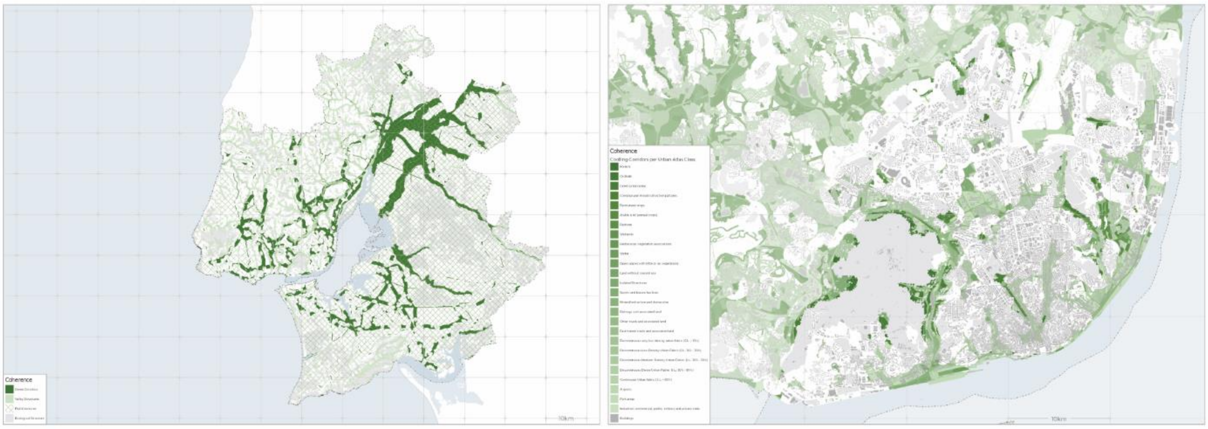


Figure 9.38 Cooling spaces in coherence with the geomorphology and the ecological structure for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) per degree of cooling potential, image by BUUR/PoS 2022

9.3.2.2. Permeability

Permeability signifies the organization of the composition and the configuration of cooling spaces throughout a spatial extent so as to allow for ventilation (thus, reducing the heat island effect) by connecting urban cores with the (cooler) surrounding countryside and allowing air currents to move (Martin, Schauvliege, and Tijskens 2005; Ministerium für Klimaschutz Klimawandel in Nordrhein-Westfalen 2011). This implies the utilization of the mobility infrastructure and surface hydrographic networks and carrying structures for said permeability by infusing them and their corresponding buffer zones with cooling devices. That is, the determination of limits to heat stress mitigation and adaptation is related to the degree of existence and degree of cooling potential of spaces along the aforementioned corridors, as well as the resulting cooling effect for the territory.

The maps of Figure 9.39 show the resulting cooling network, further categorized (as above) according to land-use/land-cover-based cooling potential (Bryan Ellis et al. 2012)), for the Metropolitan Area of Lisbon and the municipality of Lisbon.

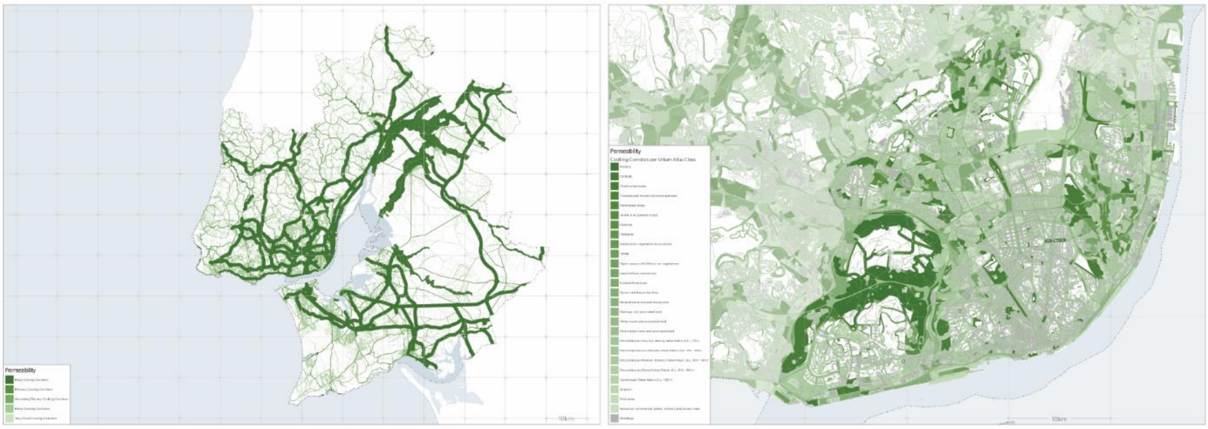


Figure 9.39 Cooling corridors permeating the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right) per degree of cooling potential, image by BUUR/PoS 2022

9.3.2.3. Porosity

Porosity refers to the presence of "spaces of significance" (Viganò et al. 2016). For the purposes of this work, 'spaces of significance' pertain to cool spaces along everyday inhabitant routes, e.g., from residence to work, amenities and/or public transport stops. Figure 9.40 shows the relationship between population levels and: 1) health service provision, 2) proximity to the major ecological structure, 3) proximity to large non-built-up spaces, and 4) public transport stops. Figure 9.41 does the same for tourist attractions.

The point here is to inquire on if and to what extent places of everyday mitigate the experience of heat also for the population at large.

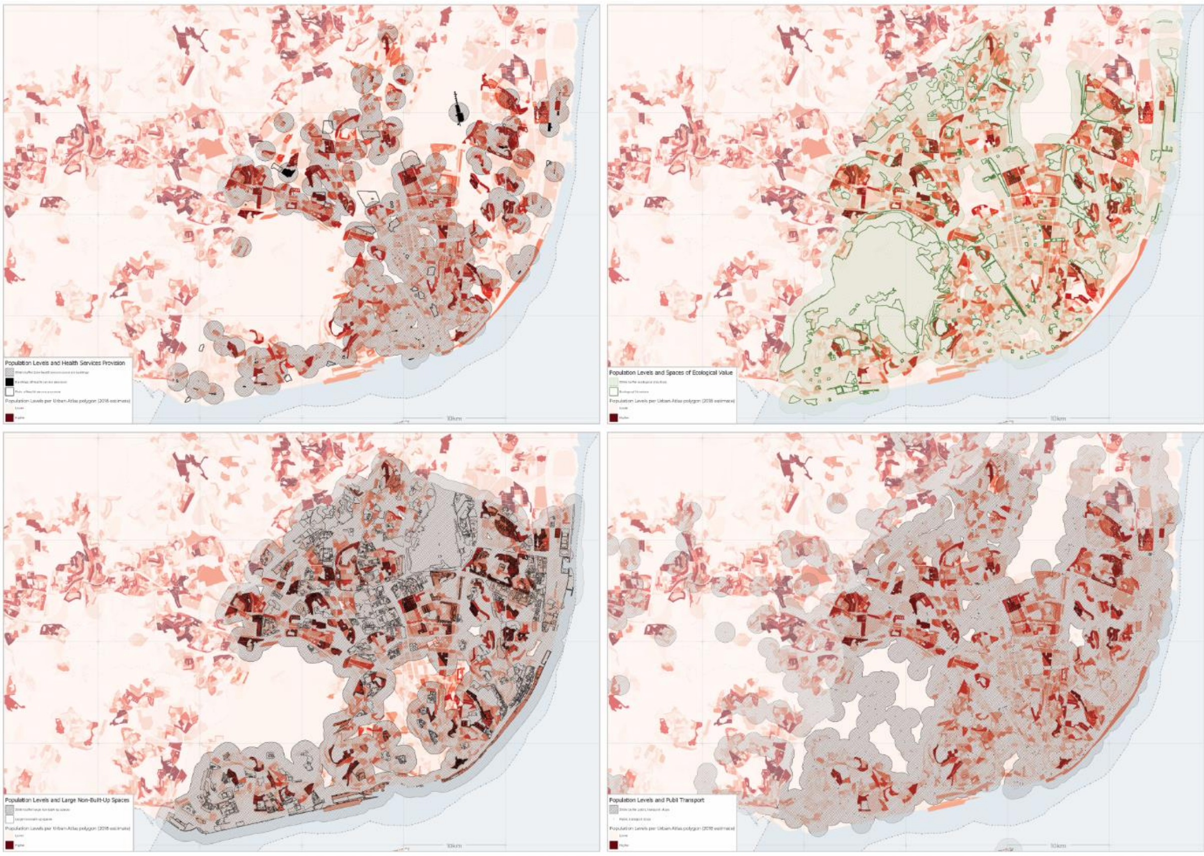


Figure 9.40 Correlation between population levels and (from upper left to lower bottom): 1. health service provision, 2. proximity to the major ecological structure, 3. proximity to large non-built-up spaces, and 4. public transport stops (image by BUUR/PoS 2022 with data from as is in Figure 14, Figure 20 and Figure 25)

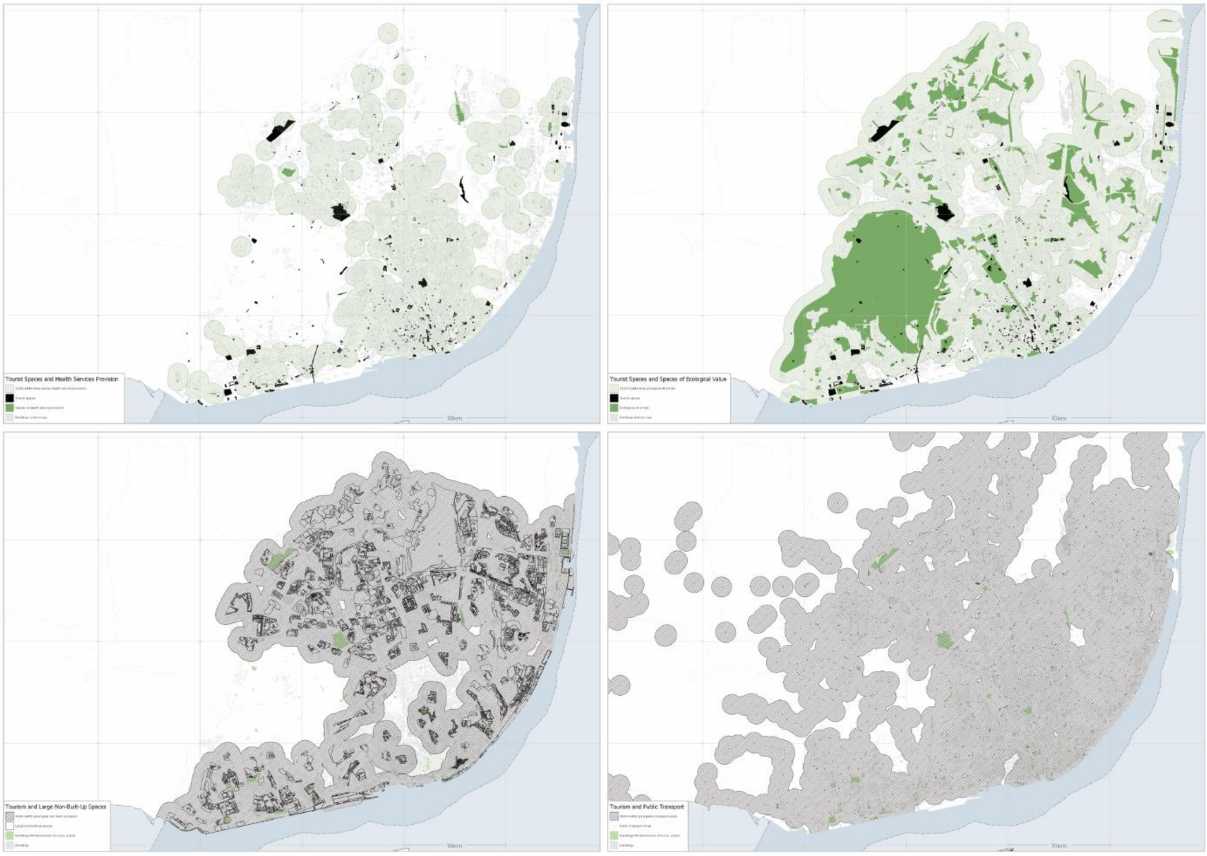


Figure 9.41 Correlation between the position of tourist places and (from upper left to lower bottom): 1. health service provision, 2. proximity to the major ecological structure, 3. proximity to large non-built-up spaces, and 4. public transport stops (image by BUUR/PoS 2022 with data from as is in Figure 14, 20 and 25)

As discussed in Chapter 3 of this report, the experience of heat stress, as well as other aspects that might exacerbate it, are present in the Lisbon Metropolitan Area and the Municipality of Lisbon particularly due to the seasonal and absolute, movement of people from the countryside towards the urban centres, as well the seasonal tourist influx to and around the urban centres. This not only leads to further pressures in e.g., water availability or health service provision but also further pressures to embed within the urbanized landscape heat regulation measures to cater for the increase in population levels. Figure 9.40 highlights the underlying conditions in reference to population levels, while Figure 9.41 does so in reference to tourist spaces.

It has been found and suggested that along quotidian movement, cool spaces should be placed at a maximum of 300 m between them (Nuijten 2008; Kluck et al. 2020). As such, an analysis of proximity levels between the built stock and: 1) the ecological structure, 2) non-built-up spaces, 3) functions/programmes and spaces of public interest and 4) public transport stops are presented in Figure 9.42.

The four maps of Figure 9.42 represent differences between the distinct proximity analyses. As such, an intersection of their results is necessary. This is done by, first, isolating those buildings that are further than 300 m from both the ecological structure, as well as large non-built-up spaces. Subsequently, the buildings that are positioned further than 300 m from amenities and public transport stops are merged. The resulting collection is evaluated on the basis of its own buffer of 300 m and the results are shown in Figure 9.41.

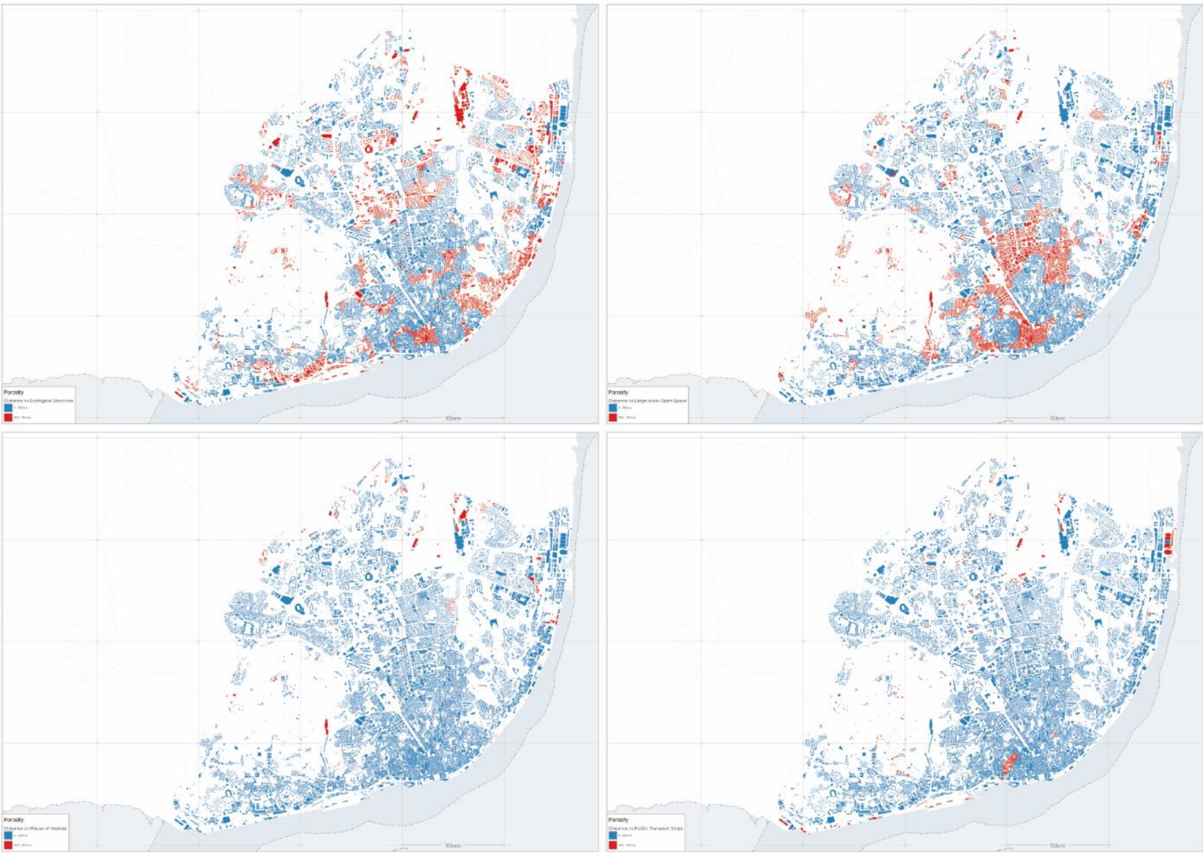


Figure 9.42 Distance between buildings and (from upper left to lower right): 1. spaces of ecological value, 2. non built-up space, 3. functions/programmes and spaces of public interest, and 4. public transport stops and stations (image by BUUR/PoS 2022 with data from "Geofabrik" 2022 (http://download.geofabrik.de/europe/portugal.html))

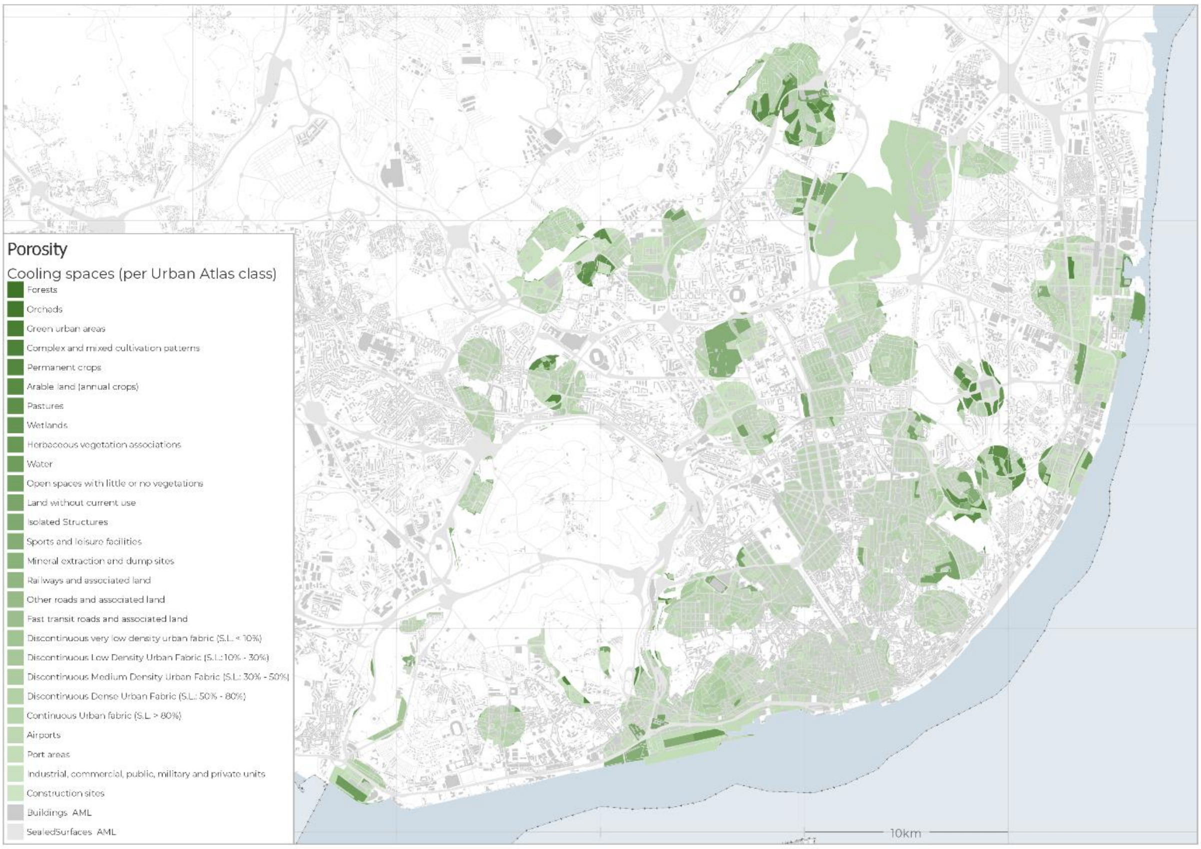


Figure 9.43 Cooling spaces for a porous system for the Metropolitan Area of Lisbon (left) and the municipality of Lisbon (right), image by BUUR/PoS 2022

9.3.2.4. Flexibility

Flexibility signifies the overall potential of a specific space to be transformed to perform a particular function (here: cooling), the degree of said performance, as well as the different possibilities for transformation and use (Kuzniecow Bacchin 2015). Flexibility is a function of land-use and land-cover, size, and ownership. The former follows the logic presented for the previous three dimensions: according to (Bryan Ellis et al. 2012), different land-use/land-cover classes host different potentials at performing specific ecosystem functions and providing associated services. Following this logic, spaces with lower built-up area and higher intensity of vegetation are positioned higher on the corresponding scale, while human activities such as mobility infrastructure, the urban fabric, and industrial/commercial units are positioned at the lower part of the spectrum. Ownership patterns suggest which spaces host greater or lower potential at transformation, due to the governance structure that regulates them. These range from large scale afforestation (in terms of public estates) all the way to private gardens (in terms of private ownership) ("Urban Green-Blue Grids for resilient cities", n.d.). Finally, size, as previously discussed, is an indicator of the scale of heat regulation measures, as well as of the overall possibility for such, since, for example, spaces of less than 200m^2 have significantly lower capacity to perform for heat mitigation and adaptation.

The map of Figure 9.442 illustrates the above three aspects for the Municipality of Lisbon. It is interesting to note that there is a discrepancy between the overlay of public programmes, large patch size and land-use/land-cover-related flexibility, which indicates the importance that the existing ecological structure (and its upgrading) will play, as well as the importance of point-scale measures and their deployment throughout the entire spatial extent.

Figure 9.44 Degree of flexibility of spaces for cooling per Urban Atlas Class, public ownership and size (image by BUUR/PoS 2022 with data from "Copernicus Land Monitoring Service" n.d. (https://land.copernicus.eu/local/urban-atlas/urban-atlas-2018); "Geofabrik" 2022 (http://download.geofabrik.de/europe/portugal.html))

9.3.2.5. Contingency

Contingency signifies the organization of the composition and the configuration of spaces that address a particular issue (here: heat stress regulation) in reference to a particular issue (here: heat stress regulation) according to governance and ownership patterns (Kuzniecow Bacchin 2015). For the purposes of heat stress regulation, this implies the areas thar are classified as protected thanks to their involvement in the ecological performance of the territory, as well as to those spaces of the public estate that are part of the overall network of cool (or with the associated capacity) places. That is, the determination of limits to heat stress mitigation and adaptation is related with the evaluation of the degree to which existing plans and policies for nature conservation and large cool public spaces corresponds to the elaborated upon system of adequate spaces. For this, an overlay of the former over the latter is utilized. The result illustrates possible mismatches, as well correspondences, indicating the need for the introduction of heat regulation to the various strategies and plans for nature conservation.

The maps of Figure 9.45 show the resulting network of cooling spaces and the rate of cooling potential for the Lisbon Metropolitan Area and the Municipality of Lisbon.

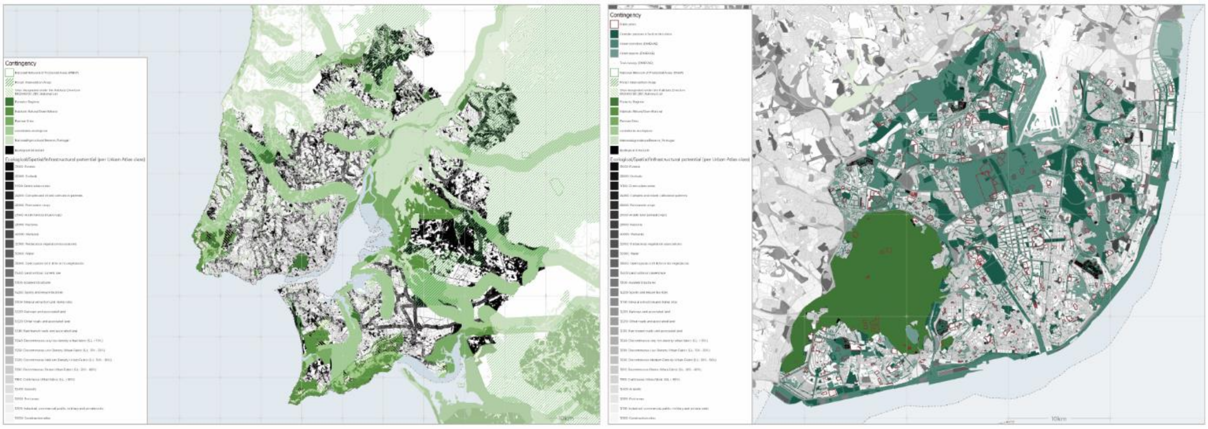


Figure 9.45 Overlay of protected areas of ecological value for the Lisbon Metropolitan Area (left) and the Municipality of Lisbon (right), with indication of plots of public ownership and/or significance for the smaller scale, over the existing ecological structure and the possible networks of cool spaces (image by BUUR/PoS 2022 with data from as in Figure 14, 26 and 41)

9.3.3. Synthesis

The maps in Figure 9.46 and Figure 9.47 represent the synthesis of the Structural Profile for the Lisbon Metropolitan Area and the Municipality of Lisbon after the evaluation of their interrelationship with the regulation systems according to the spatial dimensions for heat regulation as elaborated upon in the previous sub-sections.

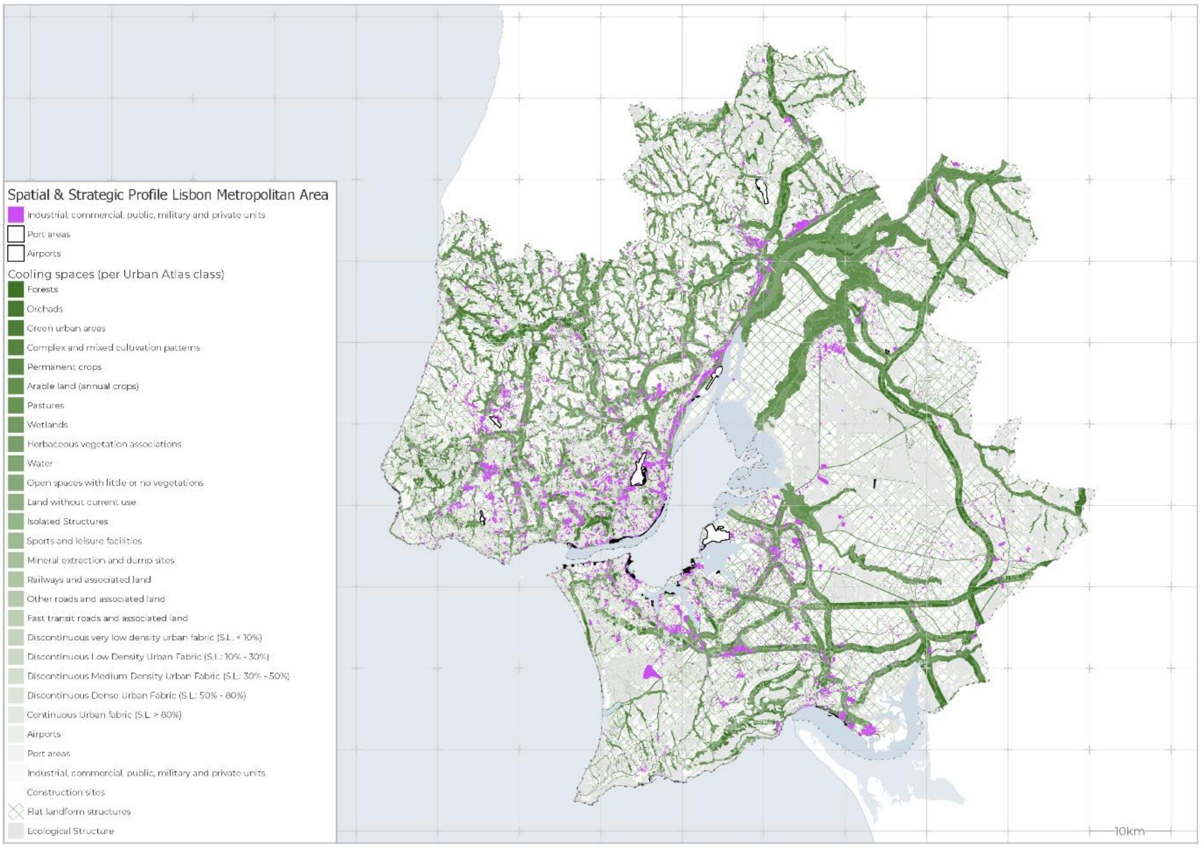


Fig. 9.46 Strategic Profile for the Lisbon Metropolitan Area for heat stress regulation, image BUUR/PoS 2022

Figure 9.47 Strategic Profile for the Municipality of Lisbon for heat stress regulation, image BUUR/PoS 2022

9.4. Conclusion

What stands out for the Lisbon Metropolitan Area is the imperative to reorganize the patterns of existing agricultural (cropland and pasture) land uses and land covers, as well as areas of herbaceous vegetation that primarily rest on flat landform structures (and populate the largest extent of the region), so that they incorporate higher degrees of intense vegetation. As this chapter has made clear, the areas where the agricultural sector is prevalent are facing a demographic reorganization and, consequently, an increase in the risk of desertification and wildfires, exacerbated by and increasing the risk of heat stress. Subsequently, the utilization of the mobility and surface hydrographic systems as carrying structures for a territory-wide cooling project is evident, thanks to their high degree of territorial penetration and their position across areas of ecological value. At the same time, the greening of the valley structures that rest, primarily, at the northern part of the Metropolitan Area presents itself of strategic importance (particularly due to the high presence of settlement patterns). Finally, the significance of the adaptation of the network of industrial and commercial units, transportation nodes, as well as is the infusion and retrofitting of cooling devices within the urbanized landscape (according to the degree of built-up intensity) completes the picture.

For the Municipality of Lisbon, the emphasis is on the correspondence between those spaces that participate in the everyday life of the inhabitants and visitors to the city, and the governance and ownership systems. It has already been argued that the exodus from the countryside towards the urban cores, as well as the influx of tourist populations, increase both the risk of exceeding the capacity of the region to mitigate and adapt to higher temperatures, as well the overall exposure of populations to heat stress. As such, there is a need for embedding cooling measures in proximity to and together with places of public significance, namely, amenities, tourist spots, health service provision buildings, public transport stops, as well as general residential areas. The above are illustrated in the map, as is their correspondence with governance and ownership patterns. While the current system of green spaces exhibits a high degree of adequacy in reference to heat regulation, the network itself needs a higher level of retrofitting along the mobility infrastructural network (that corresponds to that of the entire Lisbon Metropolitan Area). However, filling the gaps that it highlights, while possible due to the existence of large non-built-up spaces, might stumble upon difficulties in management regimes due to private ownership or inflexible uses.

The further mitigation of heat stress and the adaptation of the territory in question to higher surface and air temperatures rests on two interconnected aspects in reference to the work to be carried out within the PROVIDE project: 1) elaboration of scenarios of transformation of ownership, governance and use regimes of particular spaces within the urbanized landscape, and 2) elaboration of contextual (from large-scale to point interventions) strategies and physical solutions according to the spaces indicated in the maps above and their inherent characteristics. These will be evaluated through climate modelling, in terms of their performance in heat regulation, and to current territorial instruments and plans/strategies/policies for climate adaptation in general, and heat stress mitigation in particular.

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10. Structural and strategic profile: Islamabad, Pakistan

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10.1. Introduction

Islamabad is the only planned city of Pakistan built from scratch in the 1960s at the foothills of Margala Hills. It is located in an area which was then seen as a green landscape with a pleasant climate and good water resources. Sixty years later, temperatures across the Islamabad Capital Territory have risen at almost double the average global rate and the hot, humid summers followed by monsoon and severe winters are placing Islamabad in a vulnerable position. In addition to that, the increased variability of rainfall combined with the rapid, unplanned urban growth are resulting in severe urban flooding.

Designed as a linear city with a grid arrangement of sectors and straight, intersecting roads, Islamabad had to cope in the past decades with a rapid population growth, which resulted in an accelerated annual urban expansion and a reduction in vegetation cover. With a current population of more than 2 million people, which is expected to double by 2030, the capital needs sustainable, climate-resilient development strategies. These strategies should address both the problems occurring in the city, such as urban flooding, urban heat islands, fragmentation of native habitats, anthropogenic pollution, epidemic diseases, social inequality, as well as the degradation and conversion of the surrounding green and agricultural areas, influenced by the water table depletion.

The impact of the recent urban growth patterns of Islamabad is to be seen in the larger context of the Islamabad–Rawalpindi metropolitan area. The older and much larger city of Rawalpindi is facing even higher urban expansion rates, which add to the reduction of the amount of barren and agricultural land. These, in turn, influence local ecological processes, including the local climate, and make ever-increasing demands on natural resources.

The objective of this study is to focus mainly on the Islamabad Capital Territory. However, the system atlas will analyse the main characteristics of the whole metropolitan area, trying to understand the climate risks and the larger scale implications for the whole region.

10.2. Structural profile

10.2.1. Soil and topography

The relief of the metropolitan area of Islamabad and Rawalpindi consists of mountains and plains. In the north, the Margala Hills, a part of the lower and outer Himalayas, reach up to 1,600 m altitude near Islamabad. South of the Margala Hills there is a piedmont area with extensive plains. Their altitude ranges between 450 to 600 m above sea level.

The Pothohar Plateau has a sedimentary geology, mainly consisting of limestone, shales, sandstone, and silt. In most of the southern and western parts of the Pothohar Plateau, the soil is thin and infertile. Areas of fertile soil are found in some depressions and sheltered parts of the plateau, there where flood plains or loess plains are located (Iqbal M.Sheikh 2007). The loess and the gravel form most of the foundations of buildings. Many of the ridges and valleys of the piedmont area have been buried by alluvial deposits from the hills.

Urban development is concentrated in the piedmont bench area, which is permeated by smaller streams spread all over Islamabad and by the prominent Soan River in Rawalpindi. Limestone from the mountains is used for construction activities and leads to ecosystem degradation in the Margala Hills National Park. On the other hand, the Pothohar clay that can be found in the region of Islamabad and Rawalpindi is used for the manual fabrication of bricks. The smoke that results from the coals which are burned in brick production is an important factor in degrading the air quality.

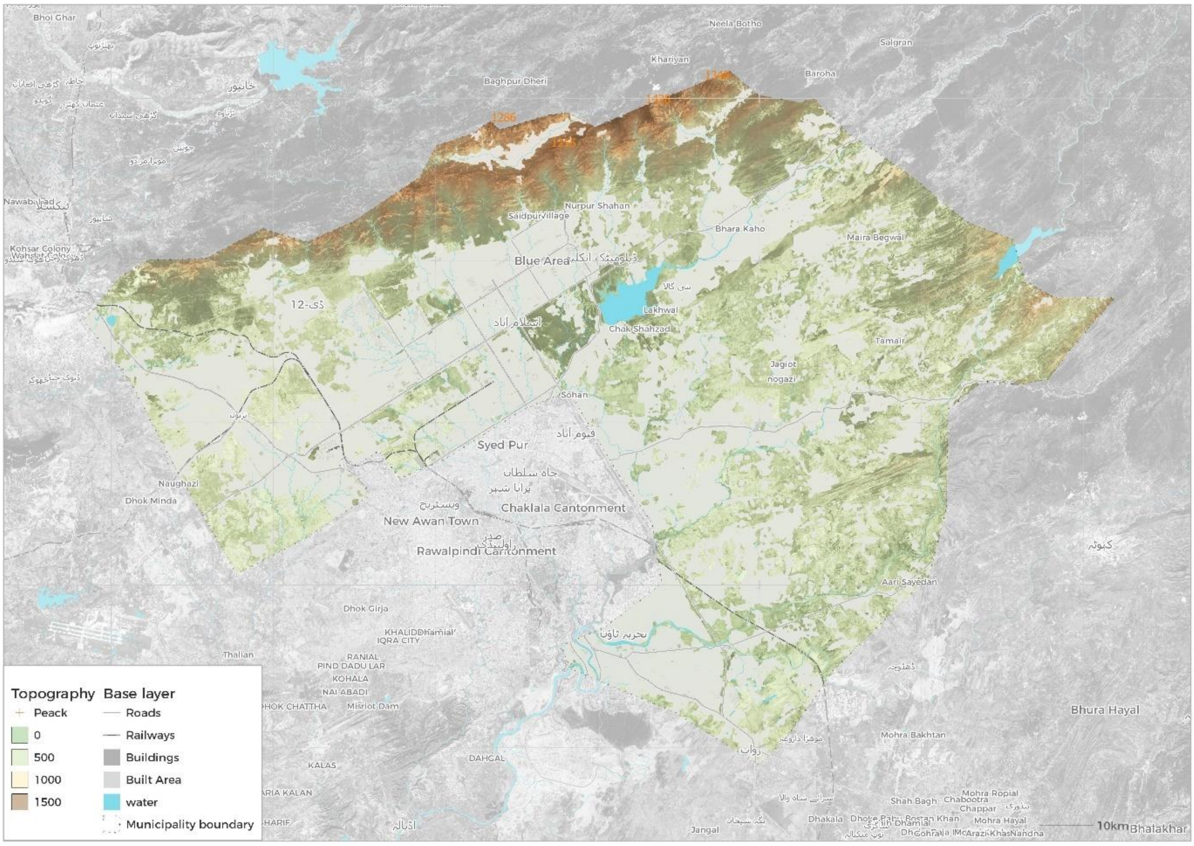

Figure 10.1 Topography, image by BUUR/PoS 2022

10.2.2. Water

The Soan and Kurang Rivers are the main streams crossing the region. The Kurang River runs through the eastern suburbs of Islamabad and Rawalpindi, with Gumreh Kas as its main tributary. The Kurang River joins the Soan River, which passes through the southern periphery of Rawalpindi together with its eastern tributary, the Ling River.

A third system of extensive streams which originate in the Margala Hills - the Nullah Lai – crosses most of the urban area of Islamabad. It enters Rawalpindi at the Khatarian Bridge and passes through the centre of the city before joining the Soan River. The Nullah Lai is collecting many drainage and sewerage channels from Rawalpindi contributing greatly to the pollution of the Soan River below their confluence (Fahad and Wang 2020) (Jawed Ali Khan 2014). The solid-waste disposal practices in the metropolitan area are threatening both the riverbeds and the quality of the ground water.

Both Kurang and Soan Rivers are dammed at Rawal and Sambli Lakes to provide for the water needs of both cities. Extensive forest reserves ensure the water quality (Iqbal M.Sheikh 2007).

The Nullah Lai stream system is, as the name ‘nullah’ suggests, a watercourse that flows through steep narrow valleys (natural ravines). Because the Nullah Lai is often entrenched, floodwaters cannot spread evenly. Therefore, the low-lying areas, especially in Rawalpindi, have often been affected by the depth and the suddenness of the flooding.

More recently, the newly built sectors in western of Islamabad were also affected. In 2021, after extensive heavy rains, Islamabad's sectors E-11, F-10 and D-12 were flooded and three people lost their lives. The urban development that took place there in the past twenty years not only reduced the width of the nullah but also altered its natural watercourse. This example shows clearly how urban flooding can occur as a result of land development. Human interventions that disrupt the natural hydrological flow are a crucial factor in increasing urban climate risks.

Looking at the initial plans drawn by the town planner C.A. Doxiadis (Figure 10.3), one can see the proposed interlocking of urban (public space and mobility) and ecological grids. The focus on the design of an open space structure that shapes and regulates the built form is contrasting to the recent developments.

Another aspect to be taken in consideration is the availability of the ground water. Both Islamabad and Rawalpindi have a network of municipal and private wells reaching as deep as 200 m below surface. However, in recent years the water table seems to run dry and many recently developed areas suffer from water shortage.

Waste disposal in the area of the streams and in the adjacent green areas are also putting pressure on the water sources and decrease water quality.

Overall, the water resources of the metropolitan area seem to be relatively vulnerable, the socio-economic factors enhancing the effects of the climate change.

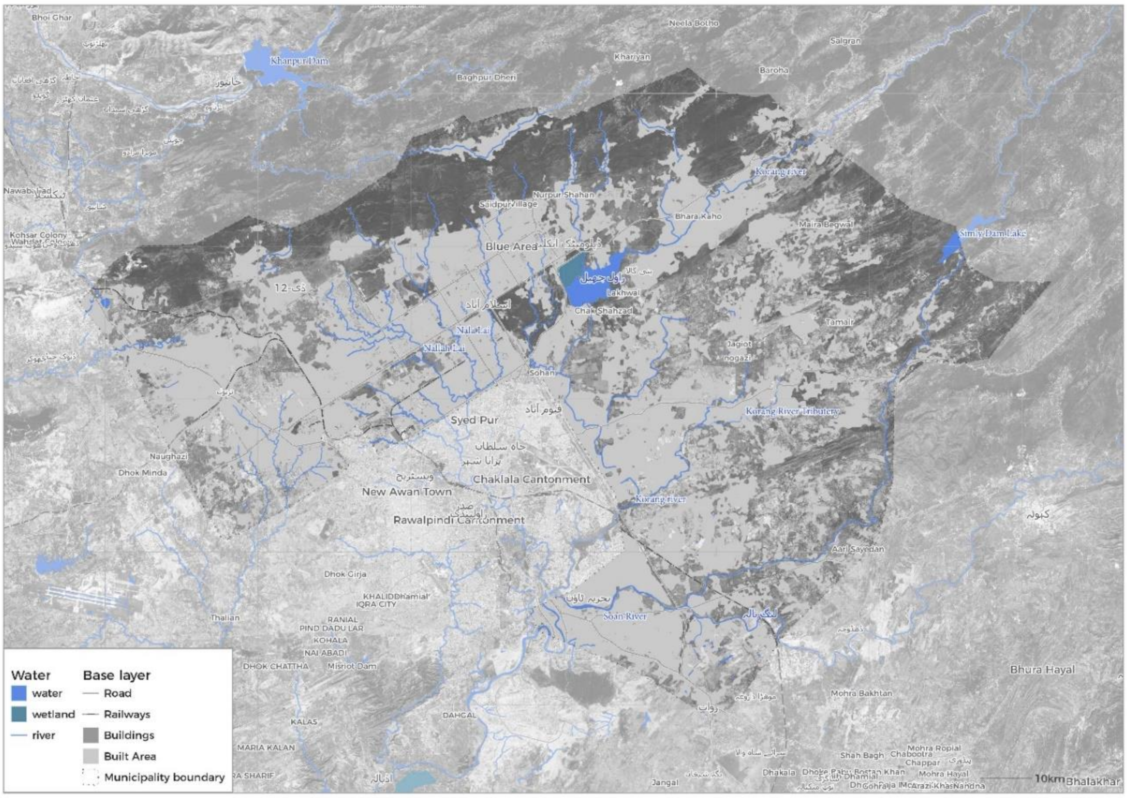

Figure 10.2 Water system, image by BUUR/PoS 2022

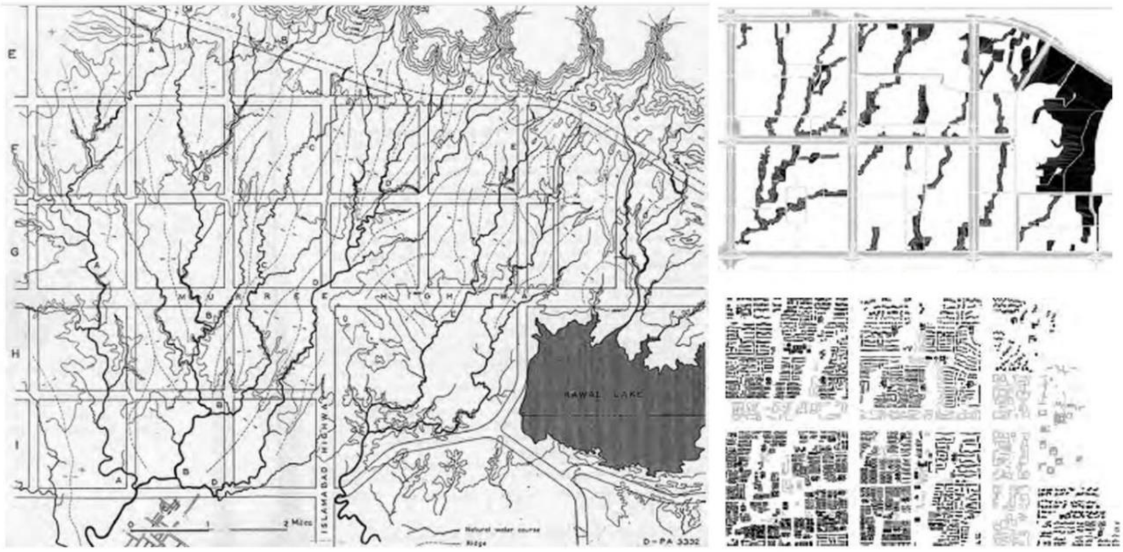

Figure 10.3 Interlocking of formal and natural systems (Images from the paper "Towards sustainable built environment – Understanding sustainability prospects in a metropolitan framework – the case of Islamabad" 2012)

10.2.3. Land cover

Land cover change results mainly from economic and social activities in areas where large populations are migrating to urban regions. Many peri-urban areas are transforming into dense urban areas and urban morphology is directly affecting temperature and thermal stress.

In the past thirty years, the unplanned expansion of Pakistan's metropolitan twin cities has led to the conversion of millions of green areas to grey areas. In Islamabad the amount of barren land and agricultural land was reduced at an annual rate of 2.08% and 2.18%, respectively, while the annual rate of urban expansion measured 16.5% (Liu et al. 2021). In addition, the total stored forest carbon was found to have decreased.

A recent study (Liu et al. 2021) has used Landsat images from four periods between 1990 and 2018 to show the expansion of urban land in the Islamabad Capital Territory. Figure 10.4 shows that cropland, in orange, had an overall downtrend while the woodland, in green, demonstrated an increase due to the plantation campaigns that the Capital District Authority organized in the past decades. Shrub and grassland, in pink, decreased approximately in a half in the past thirty years resulting in a more fragmented landscape. Impervious surface (brown) increased more than three times in surface. These findings are of a high relevance since we know that the change towards impervious surface is irreversible. This aspect can also be linked with an increase in urban flooding events. Bare land (grey) has fluctuated and is today at almost the same values as in 1990. Water bodies (blue) showed a small increase of only 1 km^2 in thirty years.

The visible increase in built surface is definitely one of the leading sources of increasing urban temperatures. There is a high correlation between the amount of green and the lower temperature areas, whereas the densely built areas with a dense infrastructure and high percentage of paved surfaces have higher land surface temperature.

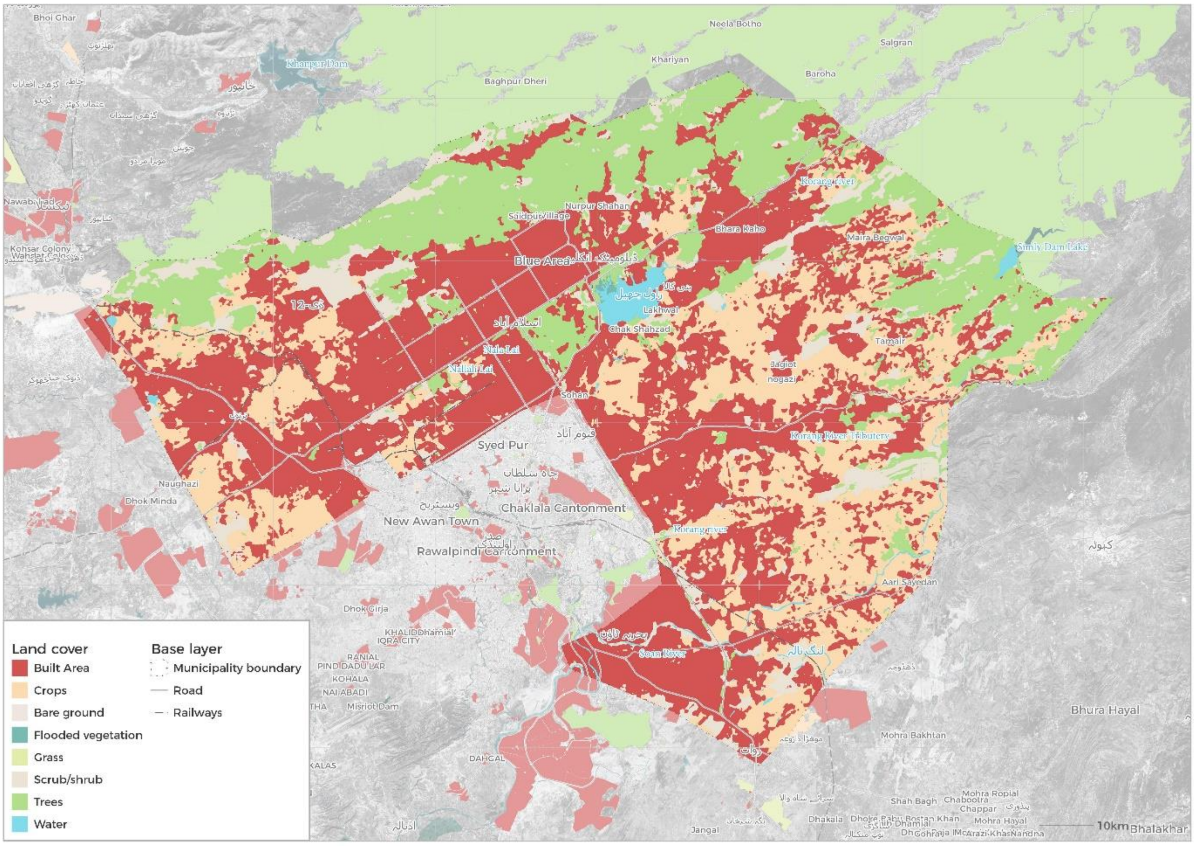

Figure 10.4 Land cover, image by BUUR/PoS 2022

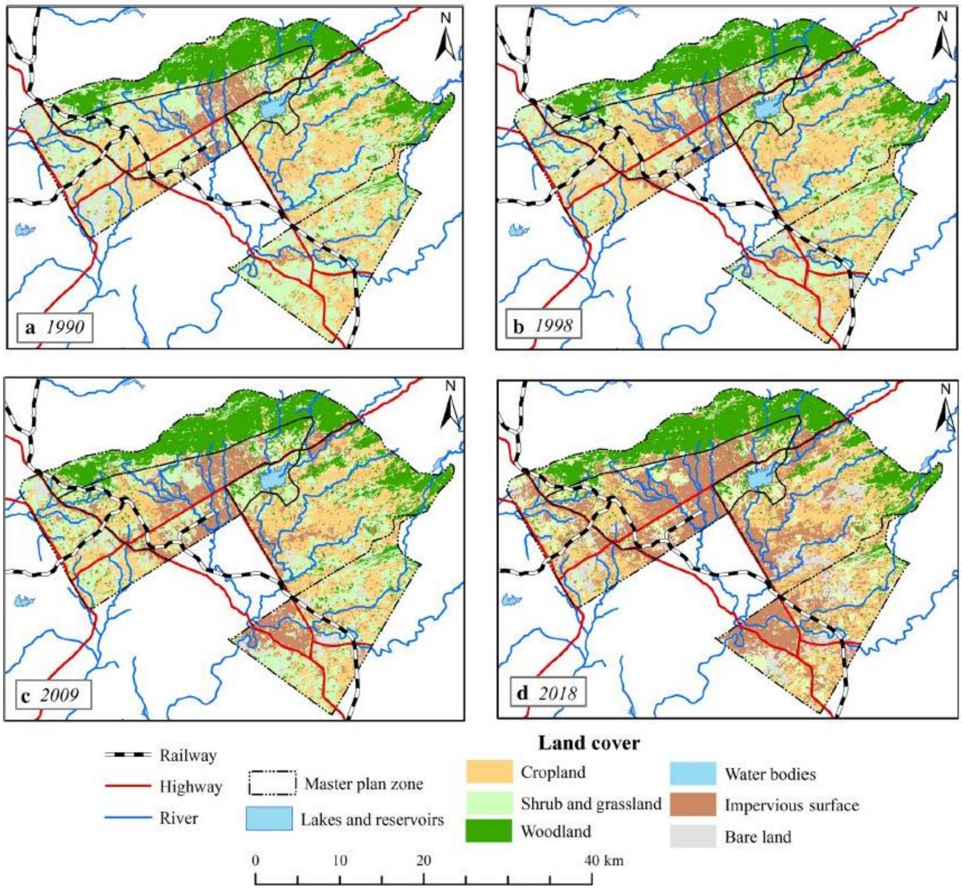

Figure 10.5 Islamabad land cover (Liu and Jiang 2021)

10.2.4. Land use (city functions)

Islamabad was planned as a low-density, administrative city and was managed from the beginning by the Capital Development Authority (CDA). In 1992, CDA adopted a new zoning regulation which divided Islamabad into five zones: Zone 1 was designated as an area where only CDA could acquire land for development (housing, commercial and administrative land use); Zones 2 and 5 were offered to private housing societies for development; Zone 3 was a reserved area including Margalla Hills National Park, while Zone 4 was kept for multiple activities including farming, educational institutions and research and development (Figure 10.6). Recent studies have shown that some areas of the Margalla Hills National Park have been consumed for development purposes. In Zone 1, the grid of 2 km x 2 km divides the city into sectors which are known by letters (from A to I) and numbers (Figure 10.7). Each of these sectors has five sub-sectors – four residential and one with commercial (Markaz) and public functions at its core. The residential developments are supposed to stay low-density, rendering a suburban character.

Unfortunately, no housing facilities were planned for the socially weak people, which in the end led to the development of unplanned settlements in areas which were originally designated for green and blue networks or in peripheral areas.

The masterplan did not foresee initially any city centre. In the recent decades, a CBD (more popularly known as the Blue Area) was attached to the masterplan. It consists of 8 to 12-

story linearly placed, mixed-use buildings which, however, are detached from the urban fabric and therefore not able to generate a true urbanity in their vicinity.

The Islamabad National University and the main administrative functions have been placed out of the city, on the eastern outskirts, not being linked with the city fabric and hence not enriching the liveability of Islamabad.

The International Islamic University was built at a later stage and occupies partly Islamabad's Sector H-10, the rest of it being preserved as a green area. The neighbouring sectors H-9 and H-8 are also hosting other major public functions such as hospitals, research centres and further universities.

Two major green areas in Zone 1, the Kachnar Park and Fatima Jinnah Park (F-9 Park), are functioning as the green lungs of Islamabad. Within the sectors linear strips of green can be found along the Nullah Lai streams. Sports and recreational facilities are also present in many sectors strengthening the initial idea of community facilities in walking distance.

According to a recent document published by the Pakistan Institute of Development Economics (Lubna Hasan 2020) the existing land and building regulations are too rigid and have resulted in over-regulating Islamabad, limiting both the social and economic potential of the city. Urban sprawl and the inefficient use of land should be tackled by allowing more flexibility in zoning regulations.

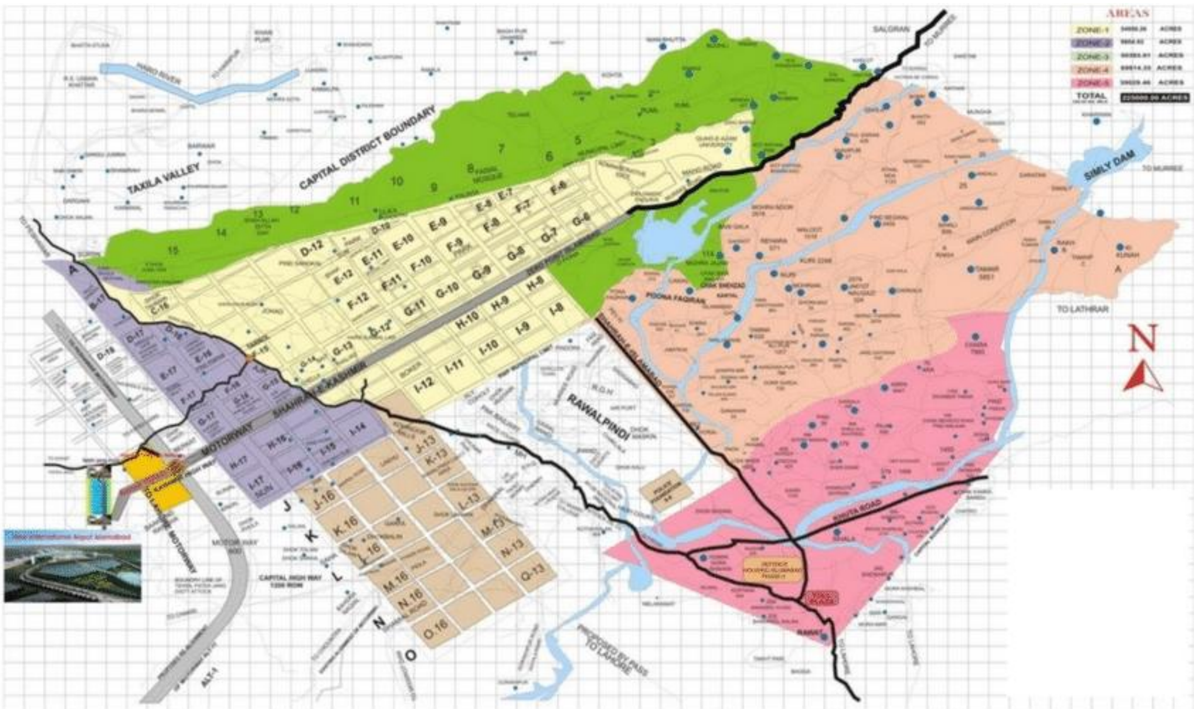

Figure 10.6 Masterplan of Islamabad (Capital Development Authority)

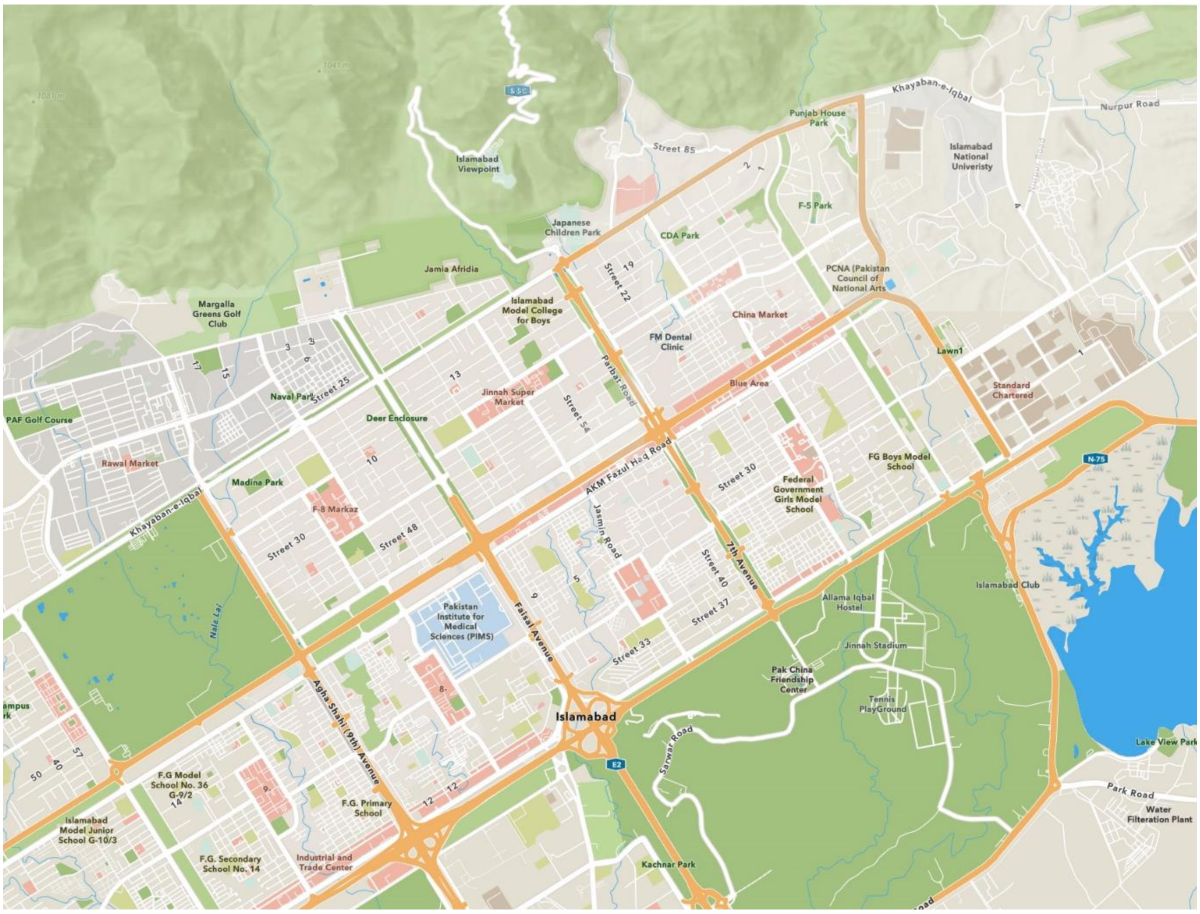

Figure 10.7 Zoom on Islamabad central sectors (Zone 1) (Map based on the data found at: https://gis.cda.gov.pk/isl/)Nature and agriculture)

There are very few capitals in the world that can profit from the proximity of nature as Islamabad does. The Margalla Hills, part of the Himalayan foothills, are a protected area completely covered in green. Its forests ensure an adequate habitat for a variety of animals and birds. However, many of the natural forest areas located in the piedmont landscape have disappeared with the intensification of human activities. Their place has been taken by secondary shrubbery, grass, and crops.

Overall, the unplanned urban expansion of the past decades has led to the conversion of many green areas to grey areas.

Within the urbanized area of Islamabad, a number of green areas, which have important environmental and conservation value, were planned in the initial masterplan. The continuous green areas along the Nullah Lai form natural ecosystems which ensure the survival of species and biodiversity richness. Whenever these corridors are disrupted by newly built infrastructure or housing, extra pressure is added on these ecosystems.

Apart from the linear green structures, Islamabad benefits from one large urban park, the Fatima Jinnah Park, and one national park, the Kachnar Park, located in a hilly area in the close vicinity of Rawal Lake.

The green belts along the main traffic corridors are also contributing to the 'green look' of the capital and serve as habitats for various species.

The agricultural land in the region has a low productivity and in the southern and western parts of the Pothohar Plateau the soil is infertile. The most fertile areas are to be found in the vicinity of the river valleys (flood plains and loess plains). The amount of agricultural land in the metropolitan region has been decreasing over the past three decades (Mannan et al. 2021). Adding to this, the agricultural production was affected by the change in temperature, precipitation and the depletion of the groundwater.

Cultivation in the region is divided in two seasons. Winter crops are sown during October and December and harvested during March and April, while summer crops are grown from February to October.

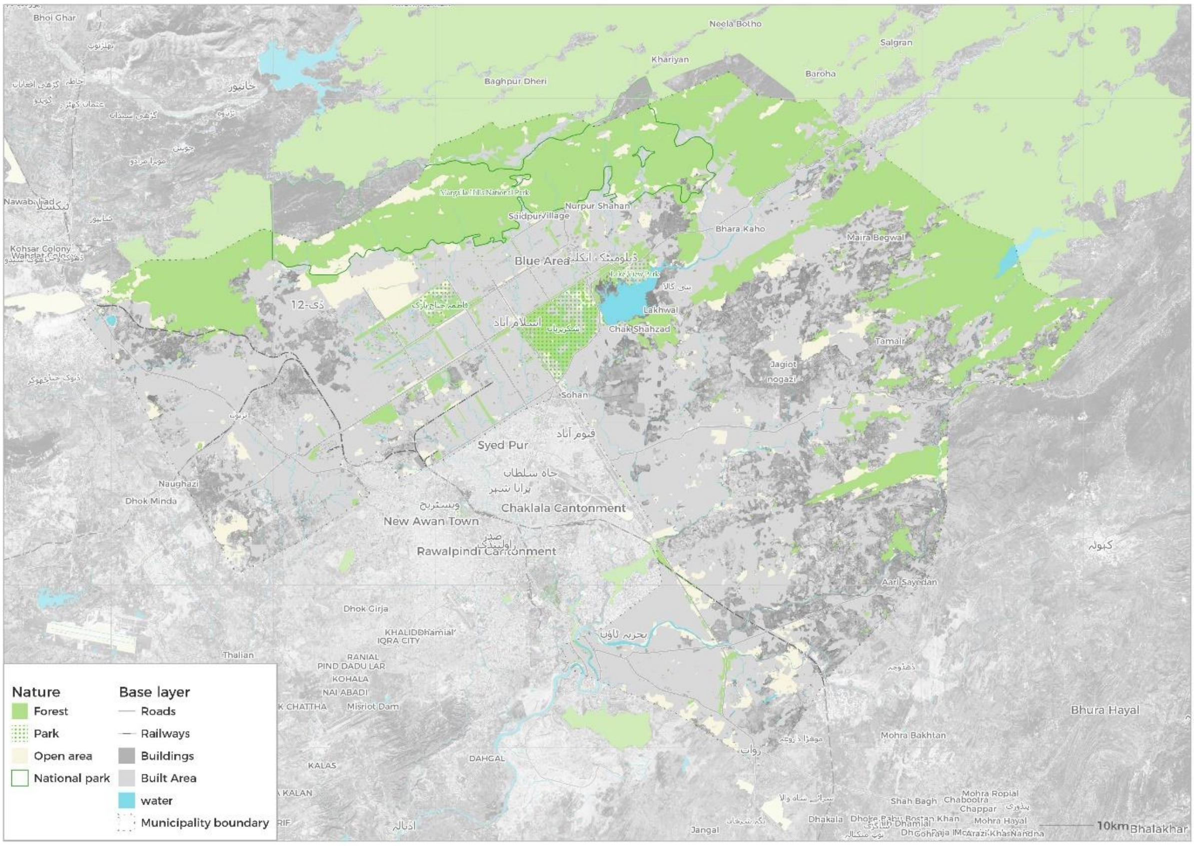

Figure 10.8 Nature in the region, image by BUUR/PoS 2022

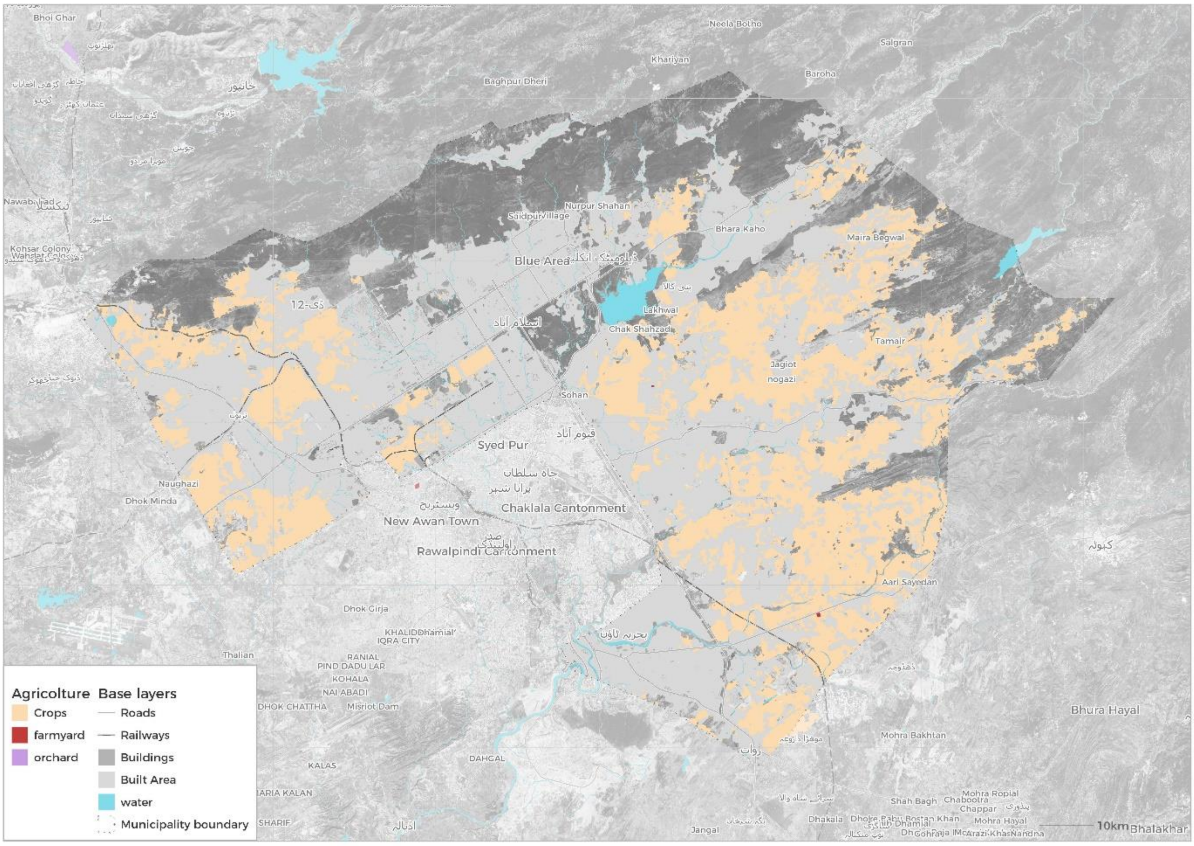

Figure 10.9 Agriculture land, image by BUUR/PoS 2022

10.2.5. Transport networks

The planning paradigm of Islamabad, consisting of a linear structure with relative low building densities and generous spaces for roads, has resulted in a car-oriented culture. Currently, there are almost one million cars registered in Islamabad (Khan 2021) and the road infrastructure is constantly renovated and updated by the Islamabad Traffic Authority. In order to accommodate the exponential increase in vehicles, Islamabad is constantly expanding present highways and roads and creates new flyovers and underpasses to further link different sectors. Many of the main roads crossing the capital have changed in the past decades from wide, four-lanes boulevards into real highways crossing the entire city and acting as strong barriers in the urban structure.

The proximity of Islamabad to Rawalpindi and their strong interdependent relation, adds a high pressure as well on the mobility network of the entire metropolitan region. Even though the number of daily passengers using the Rawalpindi-Islamabad metro bus (BRT) is currently estimated at around 100,000, the majority of people from the middle and upper classes prefers to use private transport in their daily trips through the region.

The constantly increasing number of private vehicles has an important impact on the urban climate and the air quality.

The public transport in the metropolitan region includes the mini-buses and the Bus Rapid Transit (BRT) also known as the Metrobus. The BRT operates around Islamabad along a fixed designed route with specific stations, built exclusively for this mode of transport. It also operates between both Rawalpindi and Islamabad ensuring an important connection in greater metropolitan area. A further connection, which is supposed to connect the airport with the main city, is now under planning.

Bike infrastructure is not very well developed in Islamabad. However, a start-up known as ‘EZ-bike’, has implemented bike stations at major hubs such as metro stations or parking areas of markets.

Islamabad is connected with the larger region through two major highways, the M-1, which connects Islamabad with Peshawar, and the M-2 which links Islamabad with Lahore.

The city has two railway stations, the Islamabad railway station and the historical Golra Sharif Railway Station which is also used for the transportation of goods. Furthermore, the metropolitan area is served by a third station located in Rawalpindi.

An important transport means for longer distances is the newly built Islamabad International Airport located outside of the metropolitan area. The airport caters not only for the international flights but also for domestic flights from all over Pakistan.

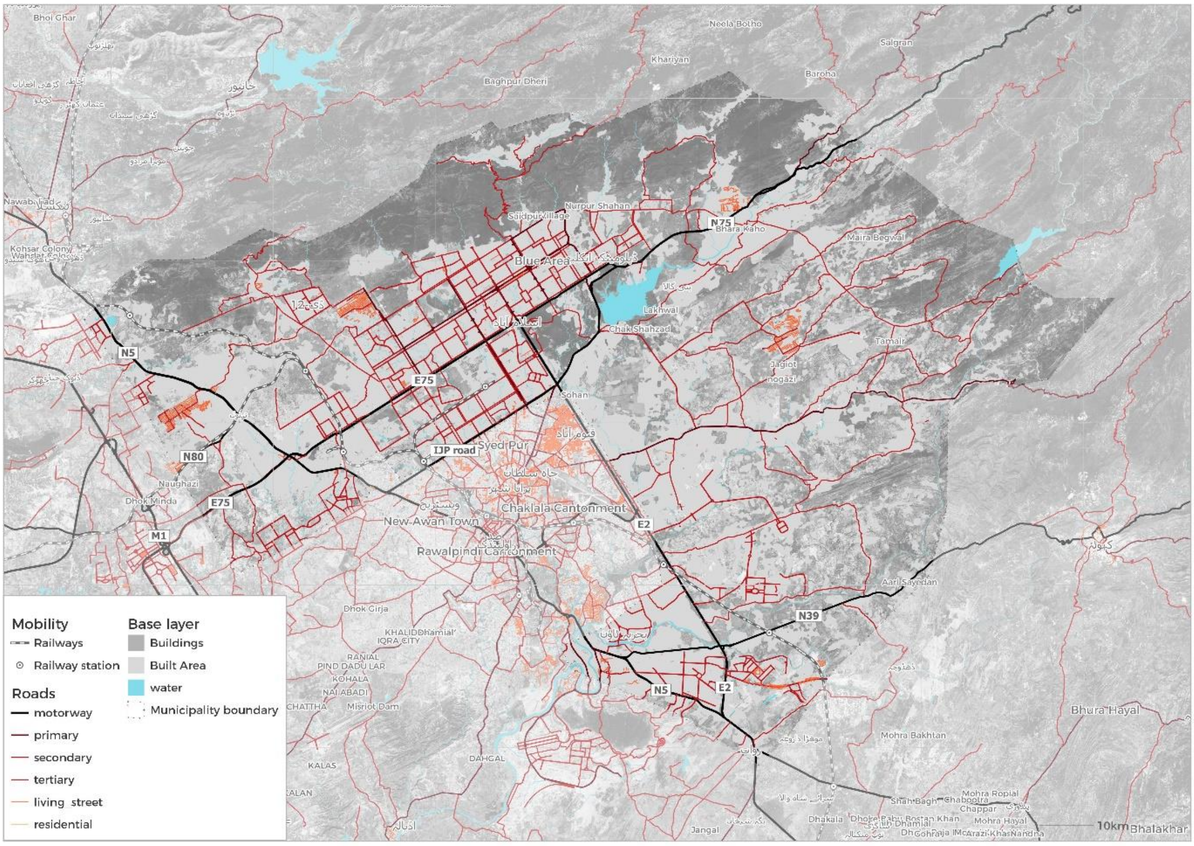

Figure 10.10 Mobility networks, image by BUUR/PoS 2022

10.2.6. Governance and spatial planning

After gaining its independence, the new state of Pakistan decided to create a new capital that had to fulfil a broad array of criteria such as strategic location, adequate climate and natural surroundings, modern built environment, possibility of using existing facilities.

In 1959 the government commissioned Doxiadis Associates, a Greek firm, to assess different locations for the capital and finally entrusted it with the conception of a master plan that would support the harmonious development of the region.

The backbone of the Islamabad Metropolitan Area Master Plan was formed by two highways, Islamabad Highway and Murree Highway, the alignment of which was dictated by the natural landscape pattern. The metropolitan region was divided into three zones: Islamabad itself, the Margalla Hills National Park and Rawalpindi and its surrounding cantonment. Islamabad city itself was then further divided into zones that were described in the previous section (10.2.4 Land use).

The whole metropolitan area was sub-divided into sectors that were expected to become communities with self-sufficient utilities and amenities at the neighbourhood level.

In order to manage the city and implement the masterplan the Capital Development Authority was established in 1960. Twenty years later the Islamabad Capital Territory Administration was created as a provincial government tasked with the administration of the overall Islamabad Capital Territory area, which includes Islamabad.

In 2019 the city went through a process of reviewing its master plan. However, the result is still perceived as a very rigid document as it limits both the social and economic potential of the city and slows down sustainable urban development. In this context, many voices are raised asking to move away from master plans towards guidelines and rules that respond to the needs of the market.

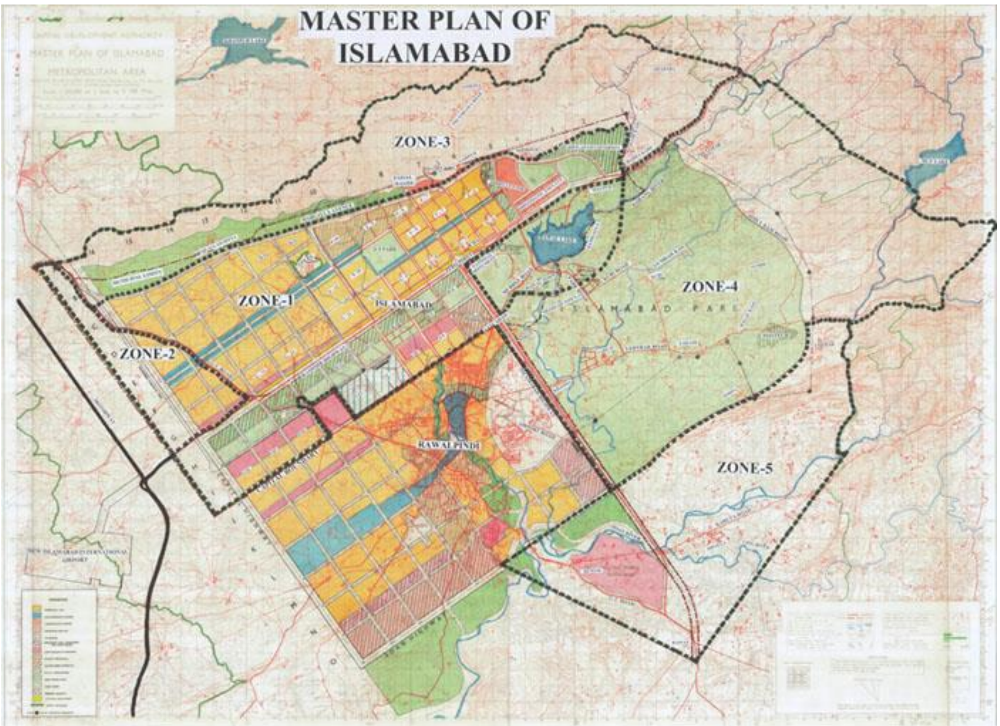

Figure 10.11 Masterplan of Islamabad (CDA)

10.3. Strategic profile

10.3.1. Local climate risks

The vulnerability of Islamabad has been assessed in multiple studies which utilize projected climate scenarios as well as first-hand information from the previous extreme events. The assessment of exposure focuses mainly on changes in temperature and rainfall.

The results of a study from UN-Habitat (Jawed Ali Khan 2014) show that from 1960 to 2010 the average temperature increased by more than 3°C in the region of Islamabad and Rawalpindi.

During the same time period, rainfall increased both in terms of annual average and across almost all seasons. However, in the past twenty years, rainfall has started to decrease slowly, and variability has increased significantly. This means that even though the precipitation amount does not suffer major changes, there could be both extended dry spells, leading to droughts, and more intense rainfall, which can lead to flood.

This chapter will look at two specific climate risks – flooding and heat stress – focusing on the analysis of the spatial regulatory systems which play a major role in the adaptation strategies. In doing so, the study tries to identify how these systems function today and whether they are capable of performing their regulatory function – and where this is less or not the case, what weaknesses cause this and what opportunities there may be to (partially) remedy the weaknesses.

Due to the limited amount of information available at the moment of the preparation of this report, the focus will lie mainly on the analysis of spatial systems. At a later stage, further impacts of climate change on urban drainage systems, urban potable water supply systems, housing, sanitation, or human health could be added..

10.3.2. Pluvial and fluvial floods

10.3.2.1.Adaptation strategies

Floods in the Lai Nullah Basin occur mainly during the monsoon season from July to September reaching a peak in August. The total rainfall during the monsoon rainy season is about 600 mm (Ahmad et al. 2010). Approximately twenty severe flood events occurred in the last forty years, the most recent one in 2021. The expected increase in precipitation amounts during extreme weather events brings an increase in risk of pluvial flooding in Islamabad.

Adaptation strategies for this type of flooding consist of both measures to protect against the floods themselves and strategies that reduce the amount of rainwater runoff, such as buffering and natural infiltration. In certain circumstances, accelerated drainage can also be a solution.

According to the Environmental Resilience Institute (ERIT 2022) the following measures can be taken to adapt:

Flood protection

- protection measures on building scale
- physical protection infrastructure
- temporary (emergency) protection
- warning systems
- insurance

Water buffering

- lakes, ponds & wetlands
- water squares & other urban above ground buffering
- storage sewers & other underground buffering
- rainwater harvesting & storage

Infiltration

- increasing soil permeability (reduction of impermeable surfaces)
- natural buffering systems
- bioswales & infiltration strips
- underground infiltration systems (horizontal/vertical)

Drainage

- improving above ground drainage (deepening rivers)
- above ground drainage systems
- underground reverse drainage (incl. infiltration)
- underground drainage systems

The next subchapter will examine how the water system works today and how the green space could play a role for infiltration as well as for buffering rainwater.

10.3.3. Regulation systems: green-blue network

Perhaps the most defining natural feature in the Islamabad area, besides Margalla Hills, is the Nullah Lai basin with its natural ravines. Approximately 70% of the upper basin (Janjua et al. 2021) falls in Islamabad city while the lower basin falls in Rawalpindi city and its suburbs.

This natural landscape has been fully respected when designing the layout of the new city in the 1960s. The ravines network, on top of which the formal mobility and social grids were imposed, formed a diagonal open space system equally present in all the sectors.

The robust green blue network was intended to bring nature into the close proximity of the residential areas, secure ventilation corridors and ensure ecological continuity. Therefore, the design focus was on the open space structure, as a combination of natural landscape and public space, which shaped and regulated the built form.

Figure 10.12 Comparison between the ecological systems in the sectors F-6-F-7 and G-6-G-7 Left: map of the original structure as designed in the 1960s and Right: current situation, image by BUUR/PoS 2022

Figure 10.12 clearly shows the changes that have occurred in the open space structure over the past sixty years. Many of the watercourses have been buried (blue dotted line) and the green corridors along them have been also partly disappeared. This results in a lower infiltration and water buffering capacity in case of flooding.

At the scale of the city one can see the same problems repeating over again (Figure 10.13). The green symbols point to areas which have been developed along streams and that could be prone to flooding in the future. The pink areas are mapping large unplanned settlements which are severely impacted in case of flood events.

Moreover, diminishing trees and vegetation can also increase stormwater runoff and erosion.

Another possible issue results from the lack of proper integration of newly build infrastructure in ecologically important areas (black symbols).

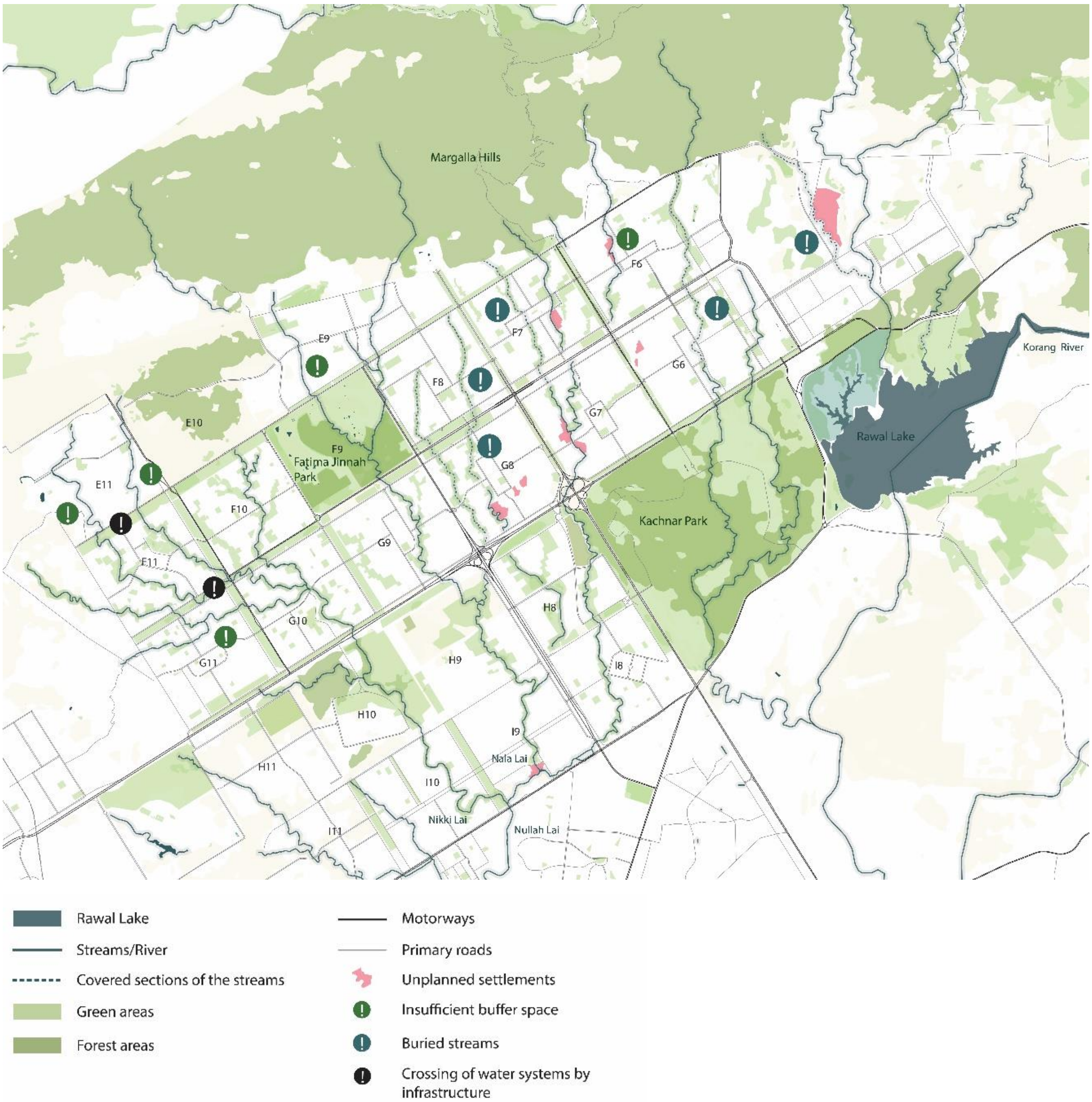

Figure 10.13 Green-blue system of Islamabad, image by BUUR/PoS 2022

10.3.4. Heat stress

10.3.4.1. Adaptation strategies

During the period from 1991 to 2010 temperatures across the Islamabad Capital Territory rose at almost double the average global rate (Jawed Ali Khan 2014). In June, the daily maximum temperature reaches 40°C, while the daily minimum temperature falls near 0°C in December and January. In the monsoon season temperatures are slightly moderate due to humidity.

Figure 10.14 shows the length of heatwaves in the metropolitan region. As global temperatures continue to rise due to climate change, heat wave frequency and severity are expected to continue to increase. In Islamabad, the average heatwaves can last somewhere between twelve to seventeen days, whereas in Rawalpindi the heatwaves can exceed even twenty days. Areas which already suffered from the urban heat island effect (UHI) will likely be the most affected and will bear their associated harmful health and environmental effects.

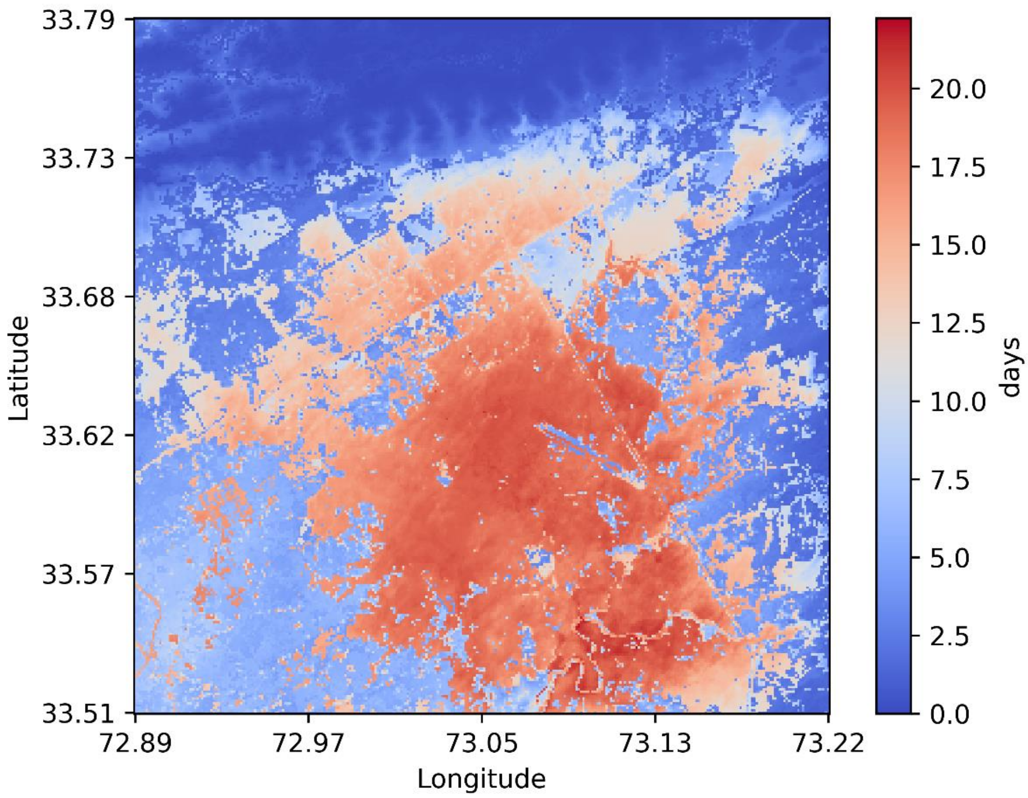

Figure 10.14 Number of heatwave days per year (Vito preliminary study)

According to the Environmental Resilience Institute (US EPA 2014) the following five strategies could be used to reduce heat island effects: 1) increasing tree and vegetative cover, 2) installing green roofs, 3) installing cool roofs, 4) using cool pavements (either reflective or permeable), and 5) utilizing smart growth practices.

Out of these strategies, the first and the fifth are of special interest as planning strategies. Increasing tree and vegetation cover lowers surface and air temperatures by providing shade and cooling through evapotranspiration. Smart growth practices cover a range of development and conservation strategies that help protect the natural environment and at the same time make our communities more attractive, economically stronger, and more liveable.

10.3.4.2. Regulation system: green network

Besides the already well described ravine and stream system, Islamabad benefits from one large urban park situated in sector F-9 – the Fatima Jinnah Park – and one national park, the Kachnar Park. Adding to this, green buffers which can be found along motorways and primary ways contribute to the cooling and ventilation of the urban system.

While comparing Islamabad and Rawalpindi urban morphology (Figure 10.15), it becomes clear that districts with large amounts of vegetation and surface water are cooler than densely built areas with many sealed surfaces. Trees in Islamabad have a positive effect on the microclimate due to their shade and by the fact that the ground below them is heated less.

All types of green and water surfaces have the capacity to cool through evaporation. In Islamabad Rawal Lake is playing an important role in cooling down the surroundings.

Figure 10.15 Left: Islamabad urban tissue ravines and green buffers along the motorways Right: Rawalpindi densely built tissue with only a couple of green areas (urban parks and linear green strips along the river)

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11. Structural and strategic profile: New Providence and Nassau, The Bahamas

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11.1. Introduction

The Bahamas is an island nation located in the northwest corner of the Caribbean Sea. It spread out over 700 islands and 2,400 uninhabited islets. The majority of the population lives on six islands: Abaco, Andros, Eleuthera, Exuma, Grand Bahama, and New Providence, which includes the capital city of Nassau. The island of New Providence sits in an east-west direction on the edge of the Great Bahama Bank opposite Andros (see Chapter 5 for further detail.

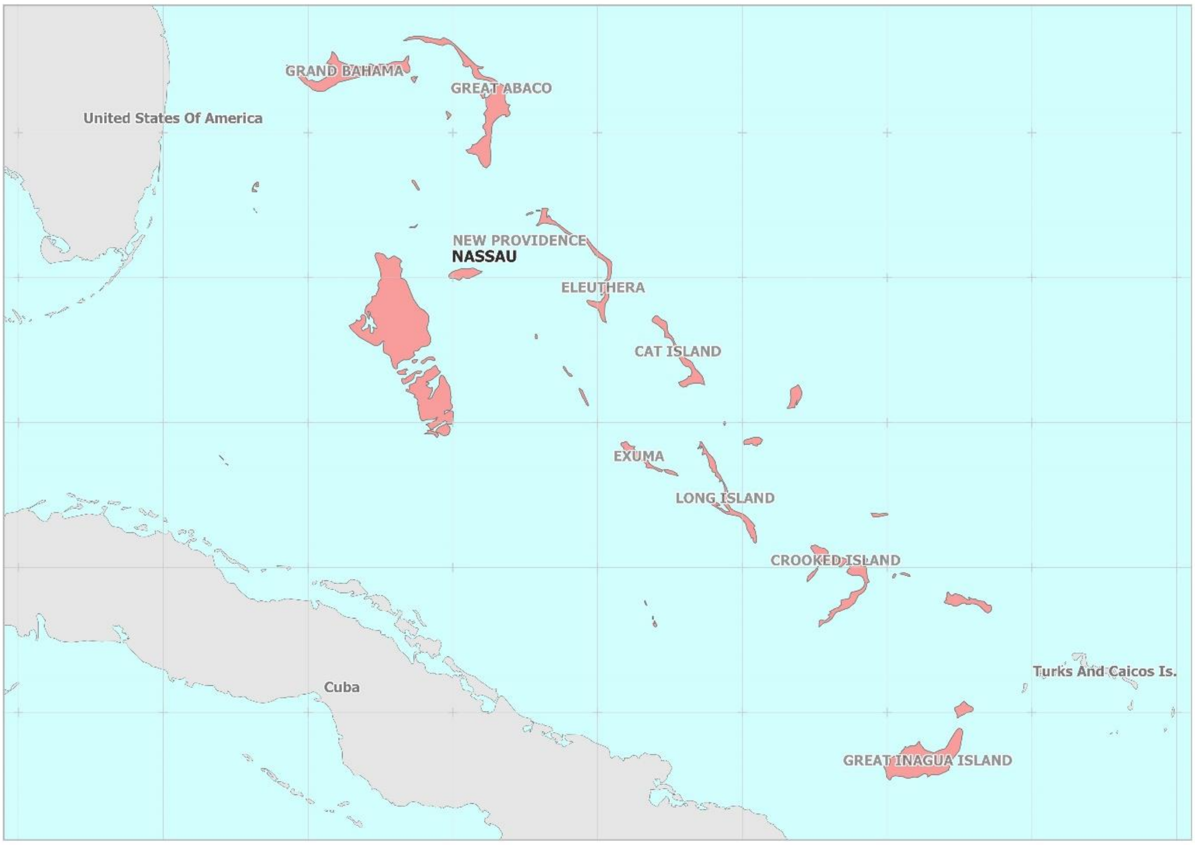


Figure 11.1 Localisation Nassau, image by BUUR/PoS 2022

New Providence is a cay, an island of low altitude (5 meters maximum) mainly composed of sand and coral, 34 km long and 11 km wide, dotted with lakes and ponds, the most important of which is **Lake Killarney** in the centre. The island has a surface area and a population density close to that of the island of Malta (respectively ~200 km² and 1,578.18 inhab./km² in 2007) and is also approximately 50% urbanized. The configuration of the island has allowed the development of marinas around it, such as Sandyport, Old Fort Bay, Lyford Cay, Coral Harbour, Port New Providence or Fox Hill Creek, which are for the most part Gated communities, secure and exclusive communities.

Nassau is the capital and the largest city of the Bahamas. Its low-rise sprawl dominates the eastern half of New Providence.

On the west of Lake Killarney is **Lynden Pindling International Airport**, formerly known as Nassau International Airport, which is the largest airport in the Bahamas and the largest international gateway into the country (Figure 11.2).

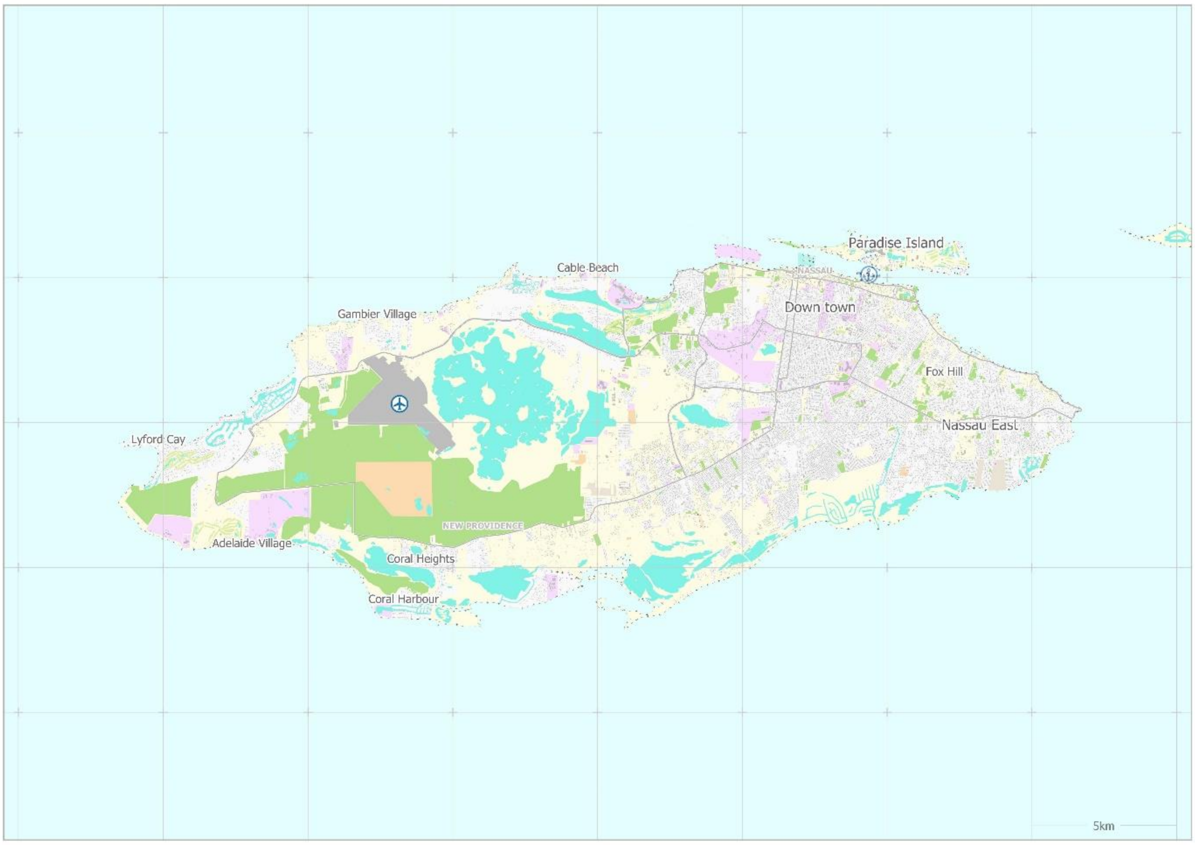


Figure 11.2 Base map New Providence, image by BUUR/PoS 2022

11.1.1. New Providence and Nassau: context & history

The history of Nassau and New Providence is long and complex; thus, we present only a few highlights in this paragraph.

Nassau is the site of the House of Assembly and various judicial departments. The Bahamas and Nassau in particular were a haven for pirate activities in the 17th century, resulting in the city being sacked and burned in 1703 in an attempt to eliminate the problem (Joan Albury 1975). Nassau's modern growth began just over 200 years ago with the migration of American Loyalists and enslaved Africans. As the population of Nassau grew, so did the built-up areas. The city first became overcrowded and then burst its bounds to spread over much of the 207 km^2 (80 square miles) of New Providence. By 1980, Nassau's island officially contained 135,000 people, 65% of the Bahamian total, compared with 46,000 (54%) in 1953 and 12,500 (23%) in 1901. The 1980 figures gave New Providence a population density of 4,400 per km^2 (1,700 per square mile), compared with the Bahamas' overall average of 101 per km^2 (39 per square mile), and the combined average of less than 7,7 per km^2 (3 per square mile) for Andros and Inagua, the two largest islands (Michael Craton 1986). Independence for the Bahamas was celebrated in Nassau on 9 July 1973.

Today the city dominates the entire island and its satellite, Paradise Island with approximately 70% of the population located on the island of New Providence which hosts the capital city of Nassau (Cf. Section 5.1.3). Population levels exploded in New Providence after the Second World War as the tourist economy began to develop (Sealey 1990).

The 1788 heart of Nassau was just a few building blocks (Government House and the harbour), but the town gradually expanded (Figure 11.3). Indeed, the city of Nassau area corresponds historically to the small area where Charles Towne arose in the 18th century. It was a stretch of some 15 blocks along the coast where the harbour and colonial buildings appeared (West and East bay street). The town's fabric was made up of English-style masonry houses aligned to the property line, placed on large plots of land.

The largest concentration of African descent lived in the "Over-the-Hill" suburbs of Grants Town and Bain Town to the south of the city of Nassau, and until about 30 years ago was the most populous part of the city. Most of the European-descent inhabitants lived on the island's northern coastal ridges. During the 20th century, the city spread east to Village Road and west to Fort Charlotte and Oakes Field. This semicircle of residential development (Figure 11.3) was the main area of settlement until after the Second World War and marks a distinct phase in the city's expansion, the outer boundary to this zone being the effective limit of the continuous built-up area. The wealthier residents continued to spread east and West (to Lyford Cay).

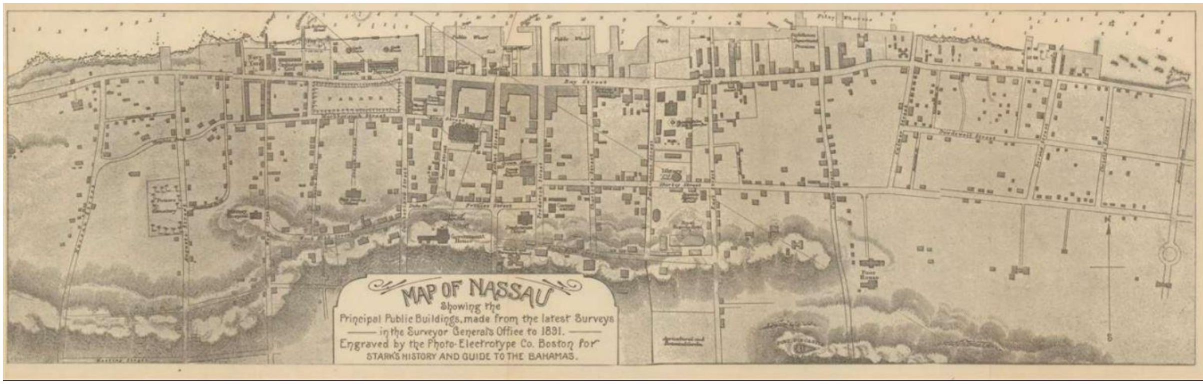


Figure 11.3 Map of Nassau showing the principal public buildings, made from the latest surveys in the Surveyor General's Office to 1891. Source: James Henry Stark 2018

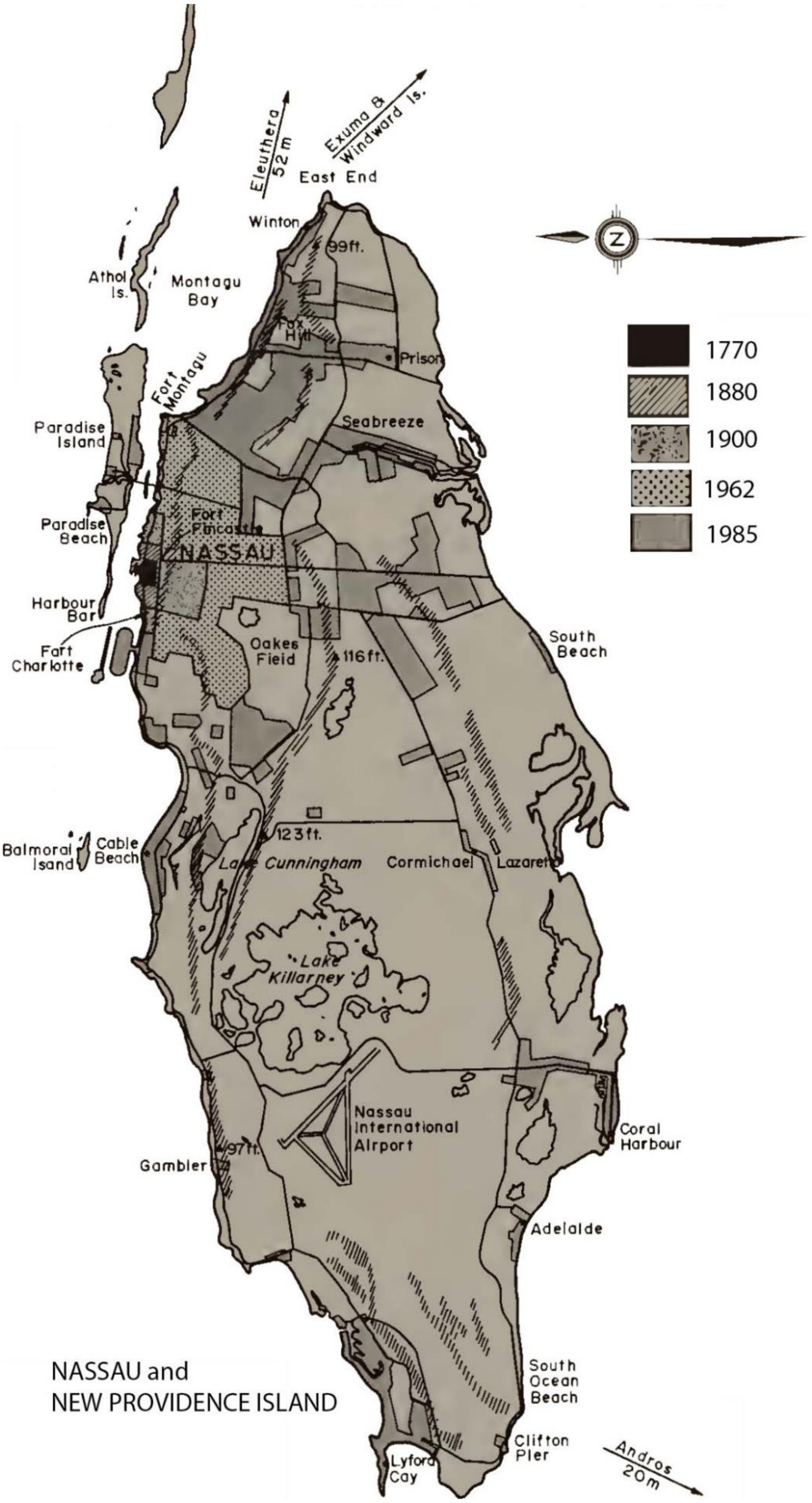


Figure 11.4 Historical map Nassau and New Providence;. Source: Michael Craton 1986

11.2. Structural profile

11.2.1. Soil & topography

New Providence is somewhat unusual when compared to other Bahamian islands, as it contains **a broad expanse of large ridges**. The relief of the ridges on New Providence (Figure 11.5) shows variability and distinct trends both from north to south and from west to east the highest relief ridges (with some peaks > 30 m) are confined to within 2 km of the north-western, northern, and north-eastern coasts of the island, with one exception. This one ridge stretches 12 km along an axis trending NW-SE, with the innermost portion being almost 5 km inland. The southern portion of the island is dominated by low-relief ridges (generally not exceeding 10 m) trending generally east to west or ENE-WSW (Reid 2010).

The majority of New Providence Island's land is composed of young and very pure **limestone**. Both characteristics are of considerable significance to agriculture. The purity means that only calcium carbonate is available to plants from the geology (much in the way of nutrients comes from the air, and via decaying vegetation such as humus). The soils, due to the mix of acid and calcium carbonate produce soils which are alkaline (Little 1977). As acid conditions are generally bad for crops, Bahamian land avoids this growth. Moreover, the Bahamas soils are alkaline, usually in the range of 7.5 to 8.5 on the PH scale brings problems for water drainage, knowing that anything over 7 to 8.3 offers challenges for the ability of a plant to absorb water.

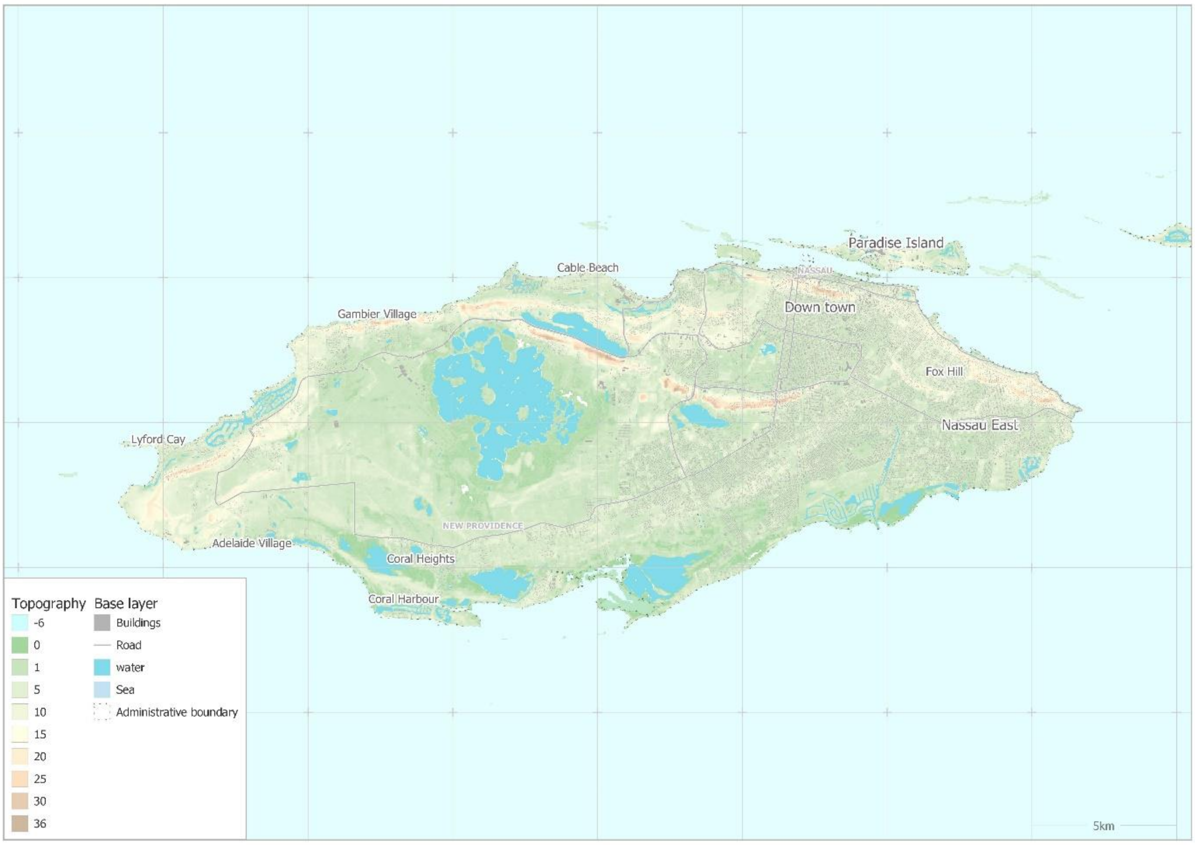


Figure 11.5 Topography Providence Island, image by BUUR/PoS 2022. Data: KPA 2022 https://geo.ngu.no/

11.2.2. Water

Water is a crucial function of the small island ecological system. Like many tropical islands, natural freshwater supplies in the Bahamas consists of freshwater aquifers, sitting in a lens on top of a lower saltwater layer.

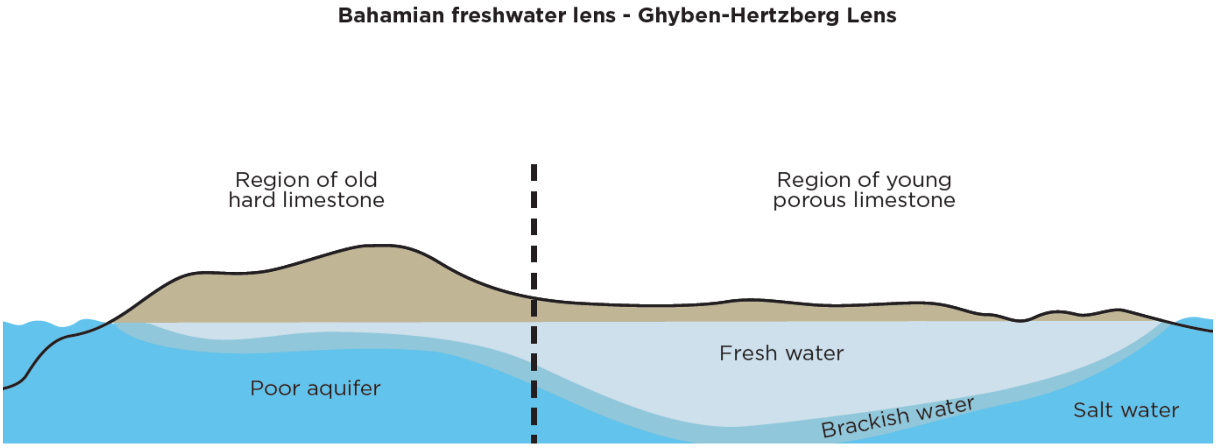


Figure 11.6 Fresh water aquifer location. Source: Wyatt, Alan 2018

This resource is dependent on rainwater and is susceptible to salinization if over-pumped.

The water resource situation is very severe on New Providence (with 70% of the population), water supply is from local groundwater and 30% of water is transported by barge from Andros Island, 75 km to the west. All water is from groundwater except small supplies from roof catchments and desalination of seawater. There are no major surface water sources because of the porous nature of the soil and rock. No major irrigation is carried out (Ekwue 2010).

The island's terrain is low and flat with a few small lakes and mangroves swamps (Figure 11.8). The southern coast of the island between Adelaide and Cay Point is dominated by lagoons and ponds. These areas are brackish or saline throughout the year. The biggest lake on the island, Lake Killarney, located in the centre of New Providence, is surrounded by marshlands. The lake is quite shallow, only a meter or so deep, and is also brackish. These features should not be considered sources of freshwater. Surface water features may be polluted by industrial and urban runoff. The only source of freshwater in the country is rainfall. Thus, inland wetlands fulfil an important function as water catchments, influencing the condition of the island's freshwater lens. With the help of plants growing in these areas, e.g., mangroves, excess nutrients are removed from the water before it reaches the ground water table. During the rainy season, inland wetlands can collect and store water away from homes and roads. Nevertheless, a lot of building was and is still built along these shallow basins. Consequently, the ecosystem's ability to prevent flooding is diminished. Due to low relief and large urban areas, New Providence is often inundated.

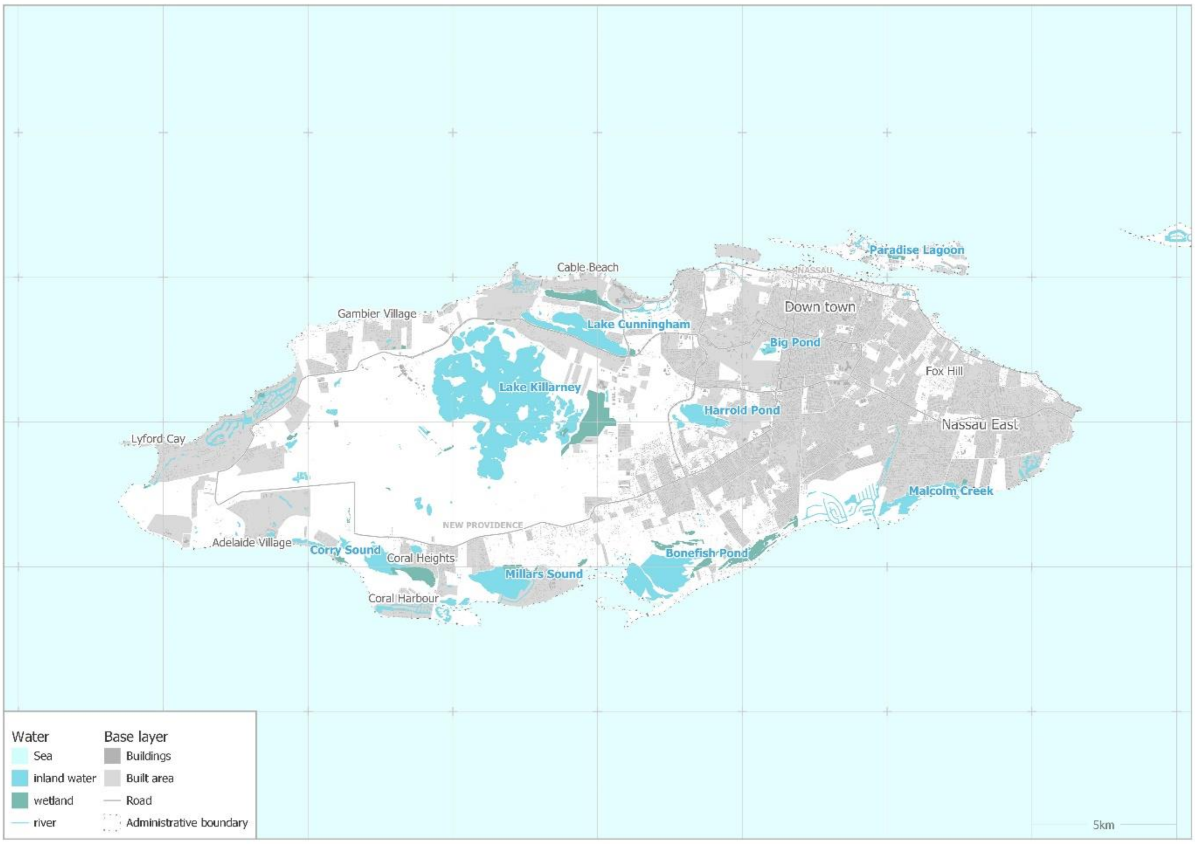
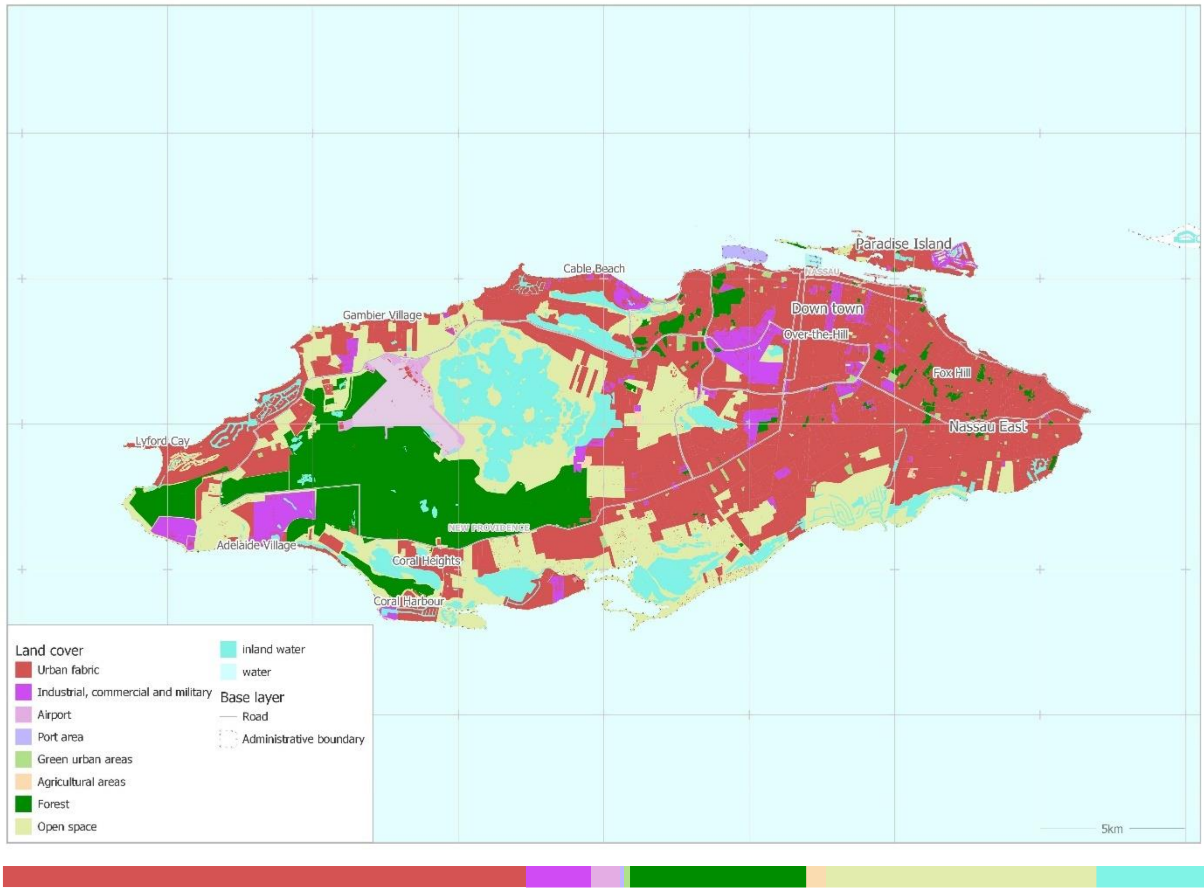


Figure 11.7 Water system New Providence, image by BUUR/PoS 2022. Data: open street map, 2022

11.2.3. Land cover

A large part of the economic activities of the country is concentrated on New Providence. Inland water covers more than 10% of the total surface island areas and forest 15% (Figure 11.8). Thus, almost a quarter of the island is occupied by nature elements. The residential capital stock is concentrated in the populated areas, specifically, in part east of the island and on the north-west coastland. In total, the urbanized area of the island covers more than one-third of the island. However, according to the Sustainable urban Nassau (IDB 2018), 367,500 persons will be living on the island by 2045. The expected housing demand can be met with an additional 6,186 homes while the land use mix could change to include 54% of urbanized space and 46% of natural areas. Due to urbanization and soil quality, agriculture is negligible on New Providence (>2% of total island surfaces).



Urban fabric 43.5%
Industrial, commercial and military 5.5%
Airport 2.4%
Port area 0.3%
Green urban areas 0.5%
Forest 14.7%
Agriculture 1.6%
Open space 20.8%
Inland water 9.1%

Figure 11.8 Land cover map, image by BUUR/PoS 2022. Data: open street map, 2022

11.2.4. Ecology

The Bahamas islands consist of landscapes including vast Caribbean Pine forests, mangrove swamp areas, Blackland coppice, sandy and rocky shores as well as tidal creeks. There are also marine landscapes including blue holes, relatively large coral reef areas, open ocean areas and a huge bank system consisting mainly of the Great and Little Bahama Banks. In total there are 32 national parks in the archipelago of which four are located in New Providence[45] (Figure 11.9).

In the south lies **Bonefish Pond**, a coastal wetland area which is the most visited national park on the island. In the centre South, **Harrold and Wilson Ponds** include two shallow freshwater bodies. The park protects valuable freshwater wetlands, coppice, and pinelands. Located in southwestern New Providence the **Primeval Forest** supports a diverse collection of plants and animals. This old-growth woodland is representative of

[45] Bahamas national trust: https://bnt.bs/explore/new-providence/

the early evergreen tropical hardwood forests of the Bahamas. The last national park on the island lies in the heart of the capital. The **Retreat Garden** is an urban green oasis garden of palms and rare tropical plants. Formerly a private home, the estate was the first national park in New Providence. Next to the national parks, the island contains natural reserves of a different character.

Many are located in the wetlands and are protected habitats for birds like Lake Cunningham or Waterloo. Some are marine reserves, like South West Marine Managed Area. Also, a lot of forests are protected, like Carmichael North and South and Corry Sounds, both with wetlands that are real bird paradises.

Wetlands are important to The Bahamas because they absorb and store water, lessening the impacts of storms and floods, as well as cleanse water of pollutants and recharge groundwater supplies. Wetlands also provide important habitats for a wide variety of wildlife species. They are known as the greatest carbon sinks on the planet. According to the Global Forest Watch (GFW), in 2010, New Providence had 344kha of tree cover, extending over 26% of its land area. In 2021, it lost 1.55kha of tree cover, equivalent to 596kt of CO_2 emissions.

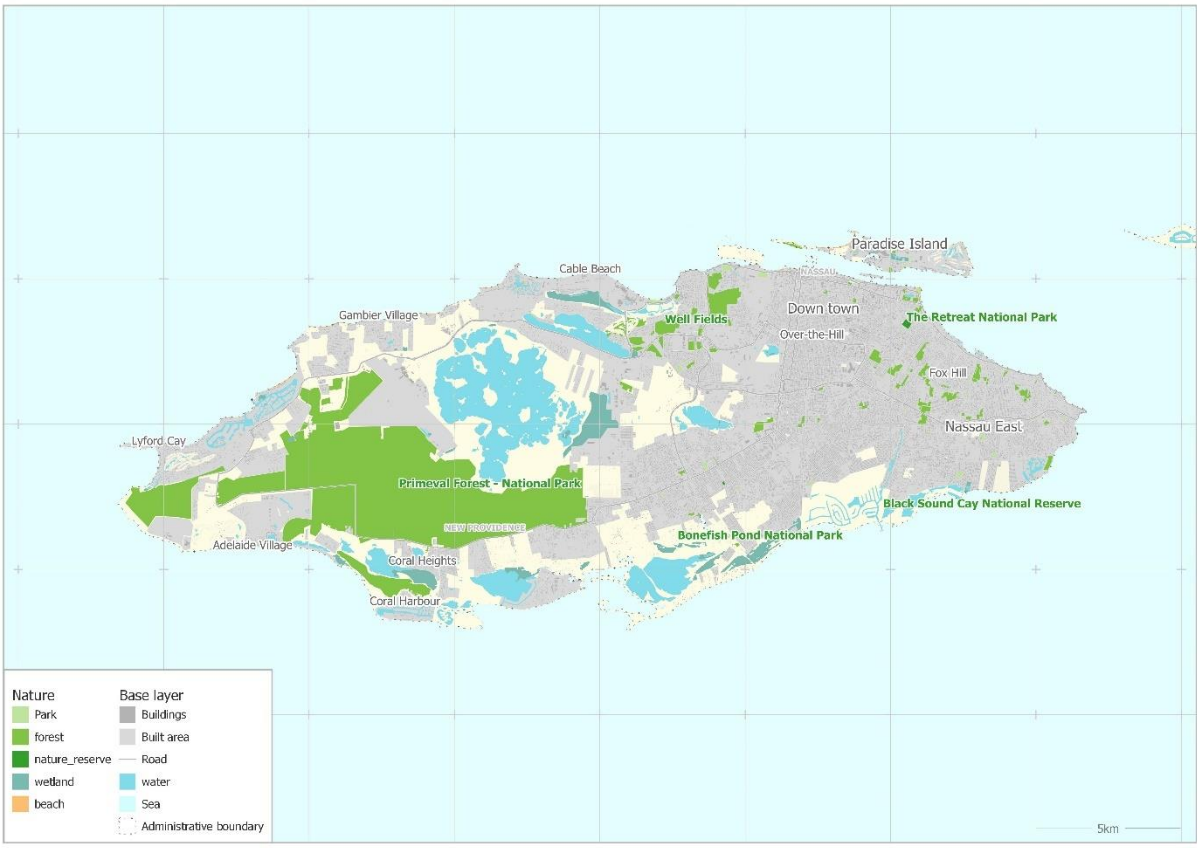


Figure 11.9 Nature map, image by BUUR/PoS 2022.
Data source: open street map, 2022

11.2.5. Transport and networks

According to the Sustainable Nassau plan, the current mobility and transport system in New Providence does not appear to be supporting the island's economic, social, or environmental well-being. The ongoing increase in private vehicle ownership and use continues to harm citizen safety, air quality, overall quality of life and citizen mobility. The existing road network (Figure 11.10) is challenged by a lack of room to expand, and traffic is often congested and chaotic. Congestion is a serious problem in that many intersections exceed their design capacity (Transportation Public Policy and Change in New Providence). Public transportation routes have remained essentially unchanged since 2000 despite new growth areas throughout the island. There are currently 23 bus routes. While routes extend to most parts of the island, their orientation is towards downtown Nassau. As such, there are no cross-island routes to allow users to travel directly from one side to another. Thus, users who want to travel across a need to transfer through downtown and take a second bus.

Despite the island's relatively flat topography, bicycle use is very low in New Providence. There are no facilities for bicycles. The narrow roads of Nassau do not encourage the use of bicycles and can make their use dangerous. Thus, without specific accommodation for bicycles and light motorized vehicles, there is a continued dominant reliance on the car.

Figure 11.10 Mobility New Providence, image by BUUR/PoS 2022

11.2.6. Land use

New Providence mimics the global trend in urbanization with its proportion of the population increasing from 54% in 1953 to 70% in 2010. The total island population is expected to grow by approximately 27% between 2015 and 2040 (IDB 2018). Such a high concentration of the population in the capital begets a natural accrual of public, economic, and infrastructure resources. Yet, despite the perceived employment opportunities, poor planning has exacerbated the woes accompanying urbanization, namely crime and social stratification. Land use on New Providence is directly related to the primacy of the city of Nassau as the major Bahamian urban area. The specific island uses are the port activities of Nassau and, the airport sites near Nassau. As a popular cruise ship destination, Nassau is known for its beaches, coral reefs, shallow waters, tropical climate, and other amenities of tourism. It retains many of its characteristic pastel-coloured British colonial buildings, such as the pink-hued Government House (Figure 11.11) and the Public Library Building.

Figure 11.11 Government House © 2022 worldatlas.com

The Historical centre of Nassau effectively represents two distinct communities (Figure 11.12) that at one time formed the centre of city life: Downtown Nassau and Over-the-Hill. Despite the rapid urban growth of the city, Nassau's downtown today remains empty and disconnected from the rest of the city. This area is almost entirely commercial without homes and living spaces. This area was built mostly using the local limestone deposits of New Providence's natural ridge. Beyond the ridge is Over-the-Hill.

The Over-the-Hill community was originally established as freed-slave settlements in the 1800s. Today several areas of the community are deteriorated with dilapidated building structures, lack of basic infrastructure and have a shortage of clean, safe public spaces.

On the east and central south of the island, the urban fabric is characterised as low to medium density in comparison to the two previous communities, which are the highest densely built areas of New Providence.

The build-up area of the island is also organised around several gated community. New Providence hosts in its coastal areas some of the most luxurious and prestigious gated communities as a form of a residential community working as islands inside the island as Port New Providence waterway and Lyford Cay.

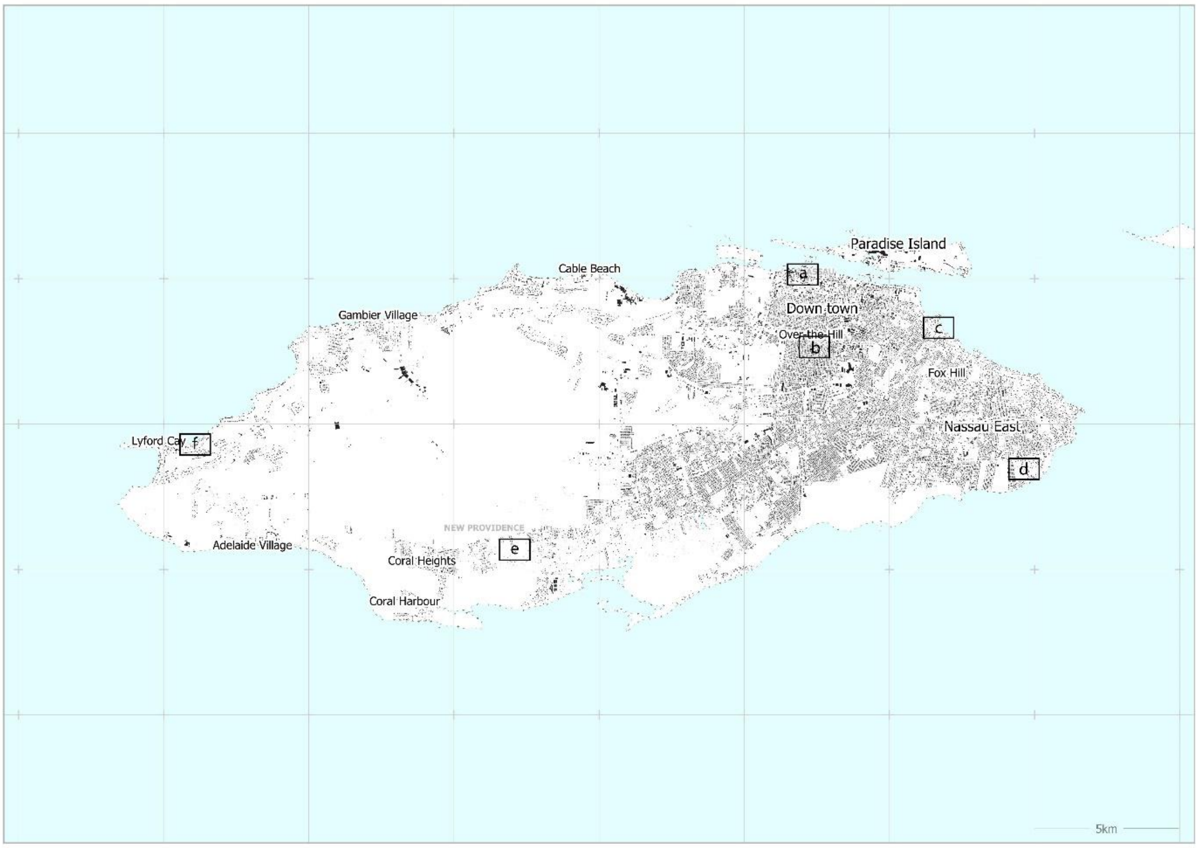


Figure 11.12 Building morphology, image by BUUR/PoS 2022

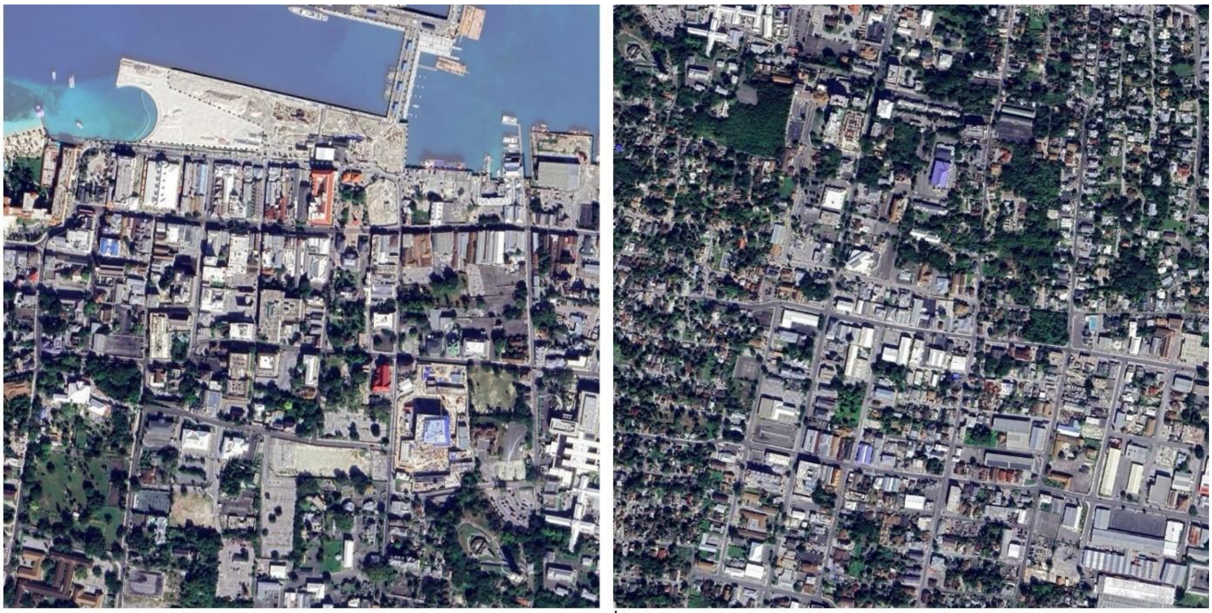
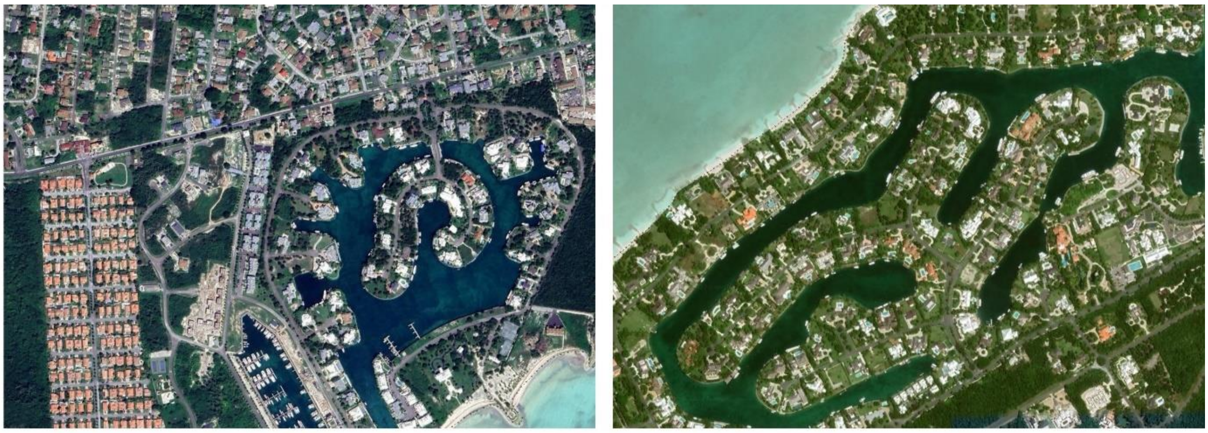


Figure 11.13 a. Downtown Nassau; b. Over-the-Hill (google earth images)

c. e.

Figure 11.14 c. East Nassau ; e. South-Centre New Providence



d. f.

Figure 11.15 d. Port New Providence waterway; f. Lyford Cay

From the building analysis, it appears that there are few qualitative open spaces, and the disconnection of public space in the centre of Nassau decreases the attractivity for walking or using another way of transportation than private transport. The presence of private development all around the coastland makes the disconnection from the waterfront more predominant for the citizen who doesn't have the opportunity to live in the gated community.

11.3. Strategic profile

11.3.1. Local climate risks

Climate change is exacerbating the vulnerability of the island, with temperatures steadily rising, sea level rising, and average annual rainfall decreasing and becoming increasingly erratic.

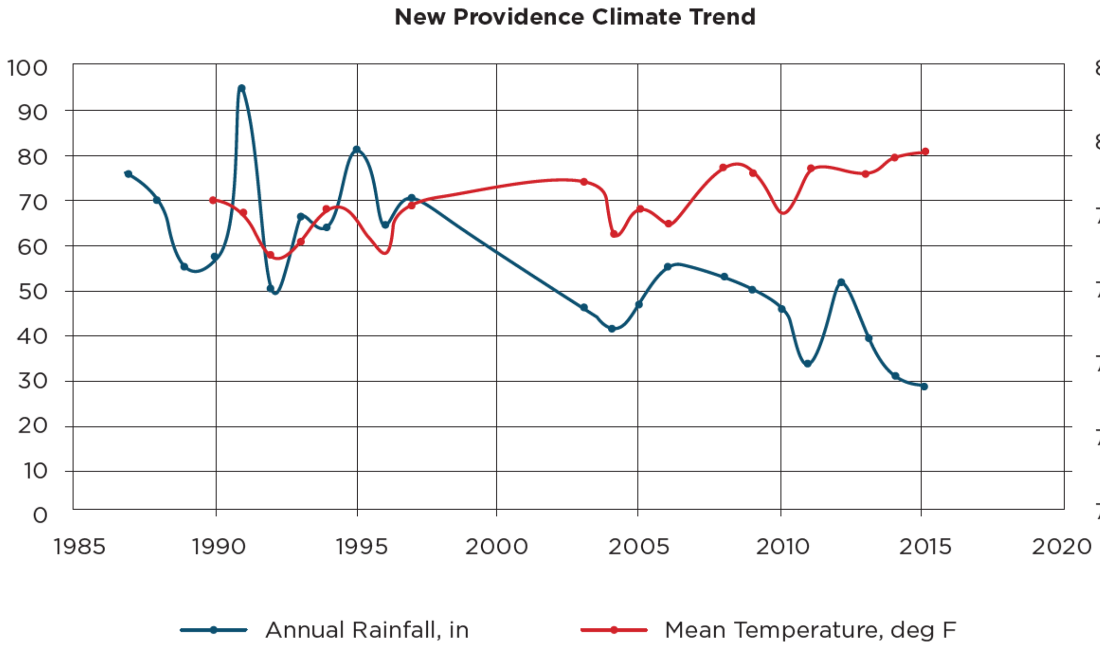


Figure 11.16 Recent changes in rainfall and temperature - New Providence. Source: Wyatt, Alan 2018

11.3.2. Sea level rise

Island such as New Providence are obviously sensitive to sea level rise. In general, three broad groups of adaptation strategies can be distinguished: (physical) protection measures, risk avoidance through changing land use, and disaster management.

- (Physical) protection measures
  - construction of new infrastructure
  - adaptations to buildings
  - natural buffers such as wetlands
- Risk avoidance through land use change
  - new developments only outside risk zones
  - relocation of activities and infrastructure away from risk zones
- Disaster management
  - modelling & risk analysis
  - warning systems
  - emergency plans
  - insurance

New Providence is the seat of the capital city Nassau and the most densely populated island in the Bahamas. It is also the most exposed island in the country, to be impacted by hurricane winds, with nearly a tenth of its total shoreline currently highly exposed. The most exposed areas on New Providence are primarily along the southern coast of the island where it is positioned on a shallow tongue of the Great Bahama Bank (Figure 11.17).

The adaptation strategies are structured around restructuring coral reefs and underwater plants, beach restoration mangrove protection, and infrastructure adjustments.

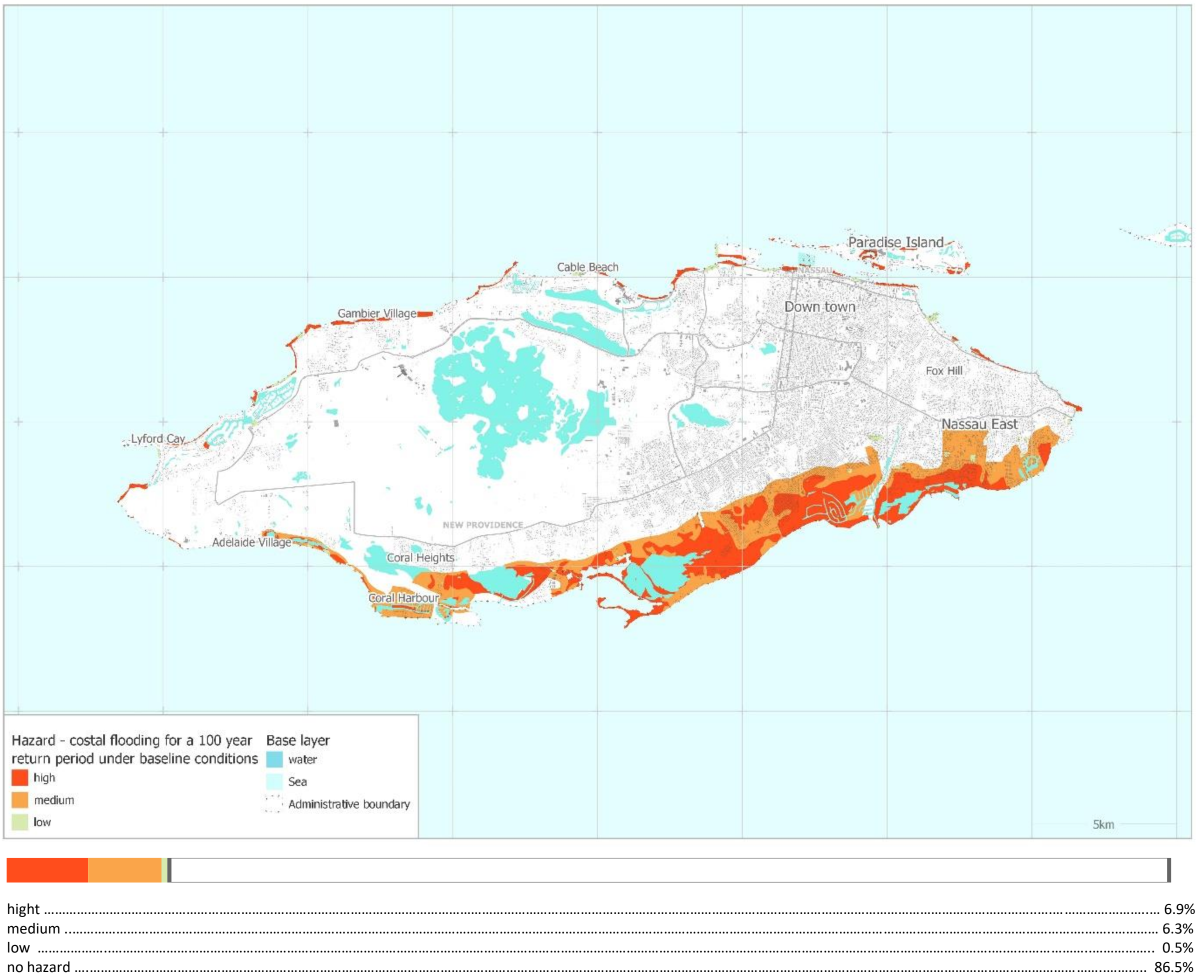


Figure 11.17 Costal flooding, image by BUUR/PoS 2022
Source: IDB 2018 and open street map

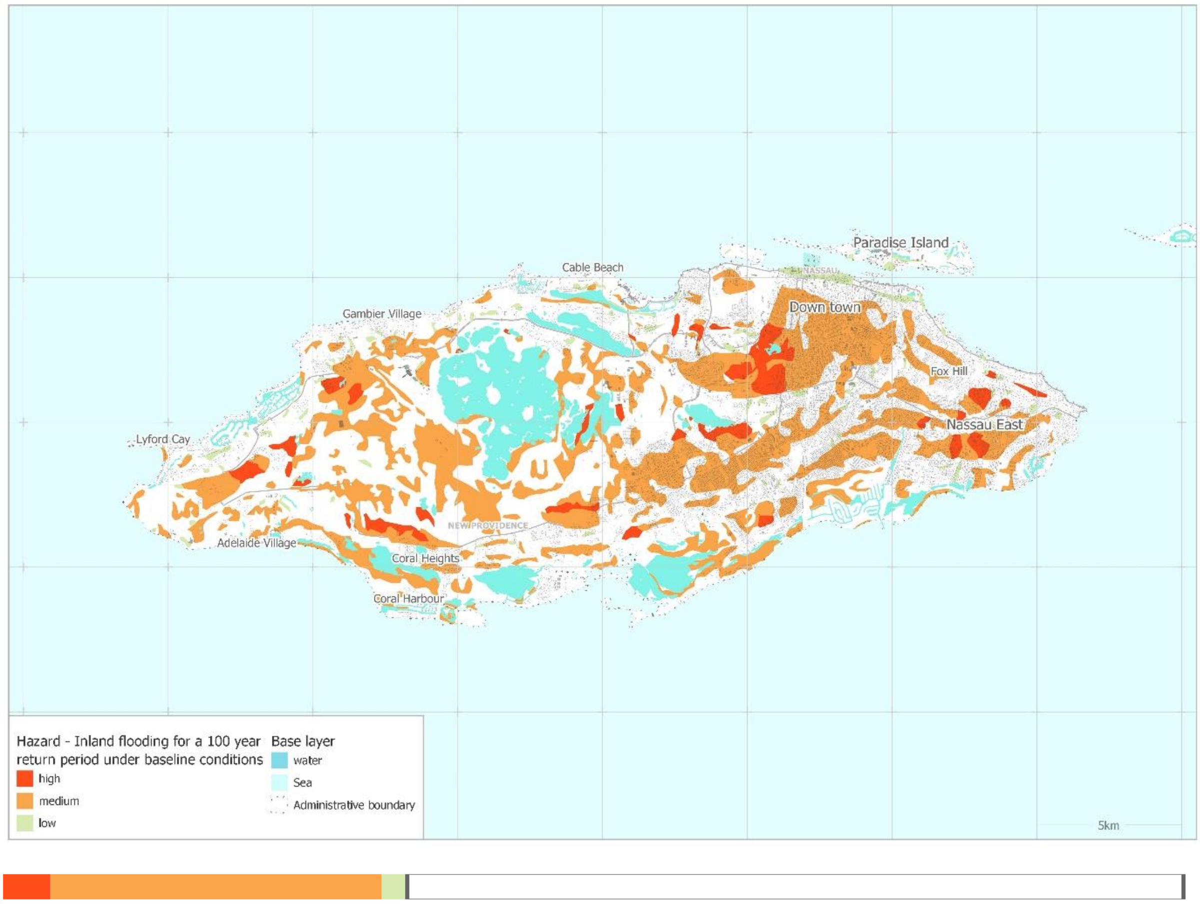
11.3.3. Pluvial and fluvial flooding

The expected increase in precipitation amounts, both average and during extreme weather events, also brings an increase in the risk of inland flooding in New Providence, especially in the urban area of Nassau. Here, runoff precipitation from the city's paved surfaces meets precipitation water discharged through open or channelled waterways. Despite the calcareous characteristics of the soils of New Providence (which are highly permeable), they rapidly become saturated due to the high-water table and the slow seepage process.

According to the sustainable Nassau plan, New Providence is considered highly vulnerable to groundwater salinization, both because the freshwater lenses are being overexploited and due to contamination.

Adaptation strategies for this type of flooding, consist of both measures to protect against the floods themselves, and strategies that reduce the amount of rainwater runoff, such as buffering and natural infiltration. In certain circumstances, accelerated drainage can also be a solution.

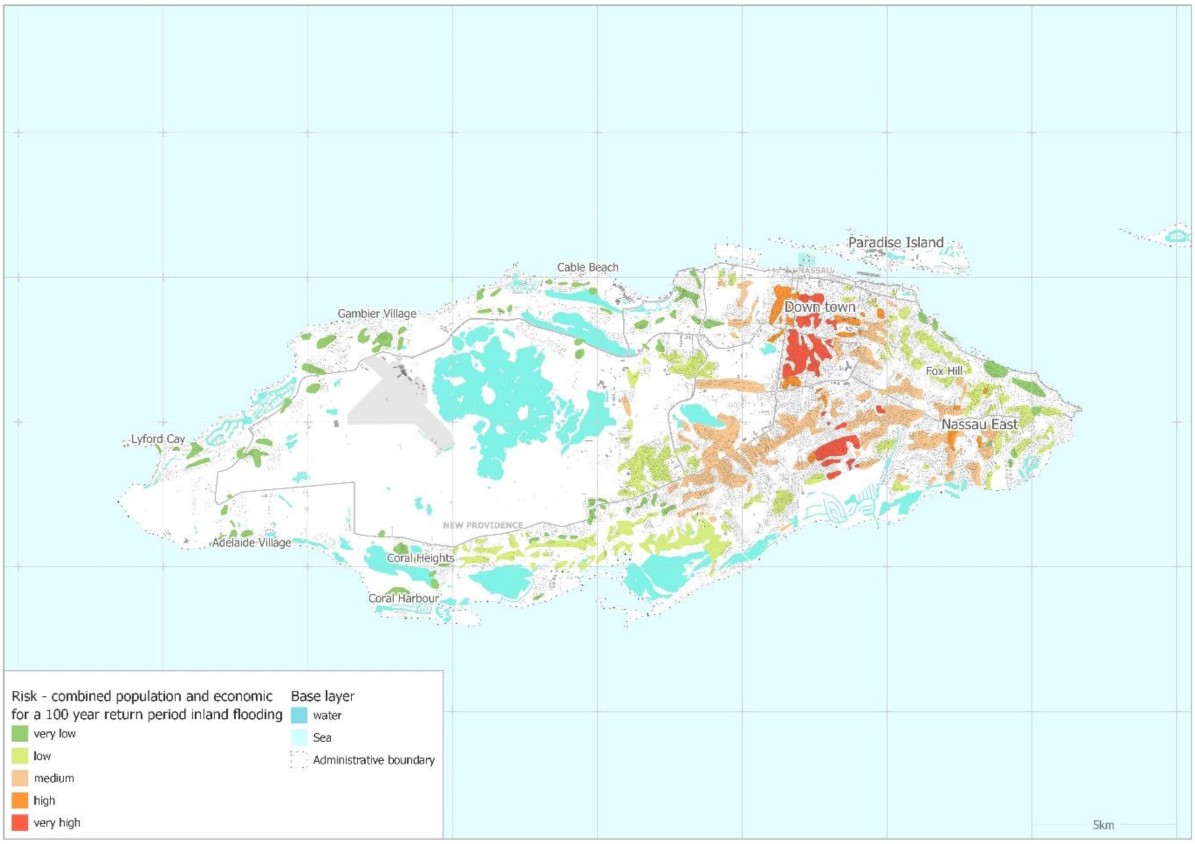
- Flood protection
    - protection measures on a building scale
    - physical protection infrastructure
    - temporary (emergency) protection
    - warning systems
    - insurance
- Water buffering
    - lakes, ponds & wetlands
    - water squares & other urban above-ground buffering
    - storage sewers & other underground buffering
    - rainwater harvesting & storage
- Infiltration
    - increasing soil permeability (reduction of impermeable surfaces)
    - natural buffering systems
    - bioswales & infiltration strips
    - underground infiltration systems (horizontal/vertical)
- Drainage
    - improving above-ground drainage
    - above ground drainage systems
    - underground reverse drainage (including infiltration)
    - underground drainage systems



high 4%
medium 28%
low 2%
no hazard 66%

Figure 11.18 Inland flooding, image by BUUR/PoS 2022
Source: IDB 2018 and open street map

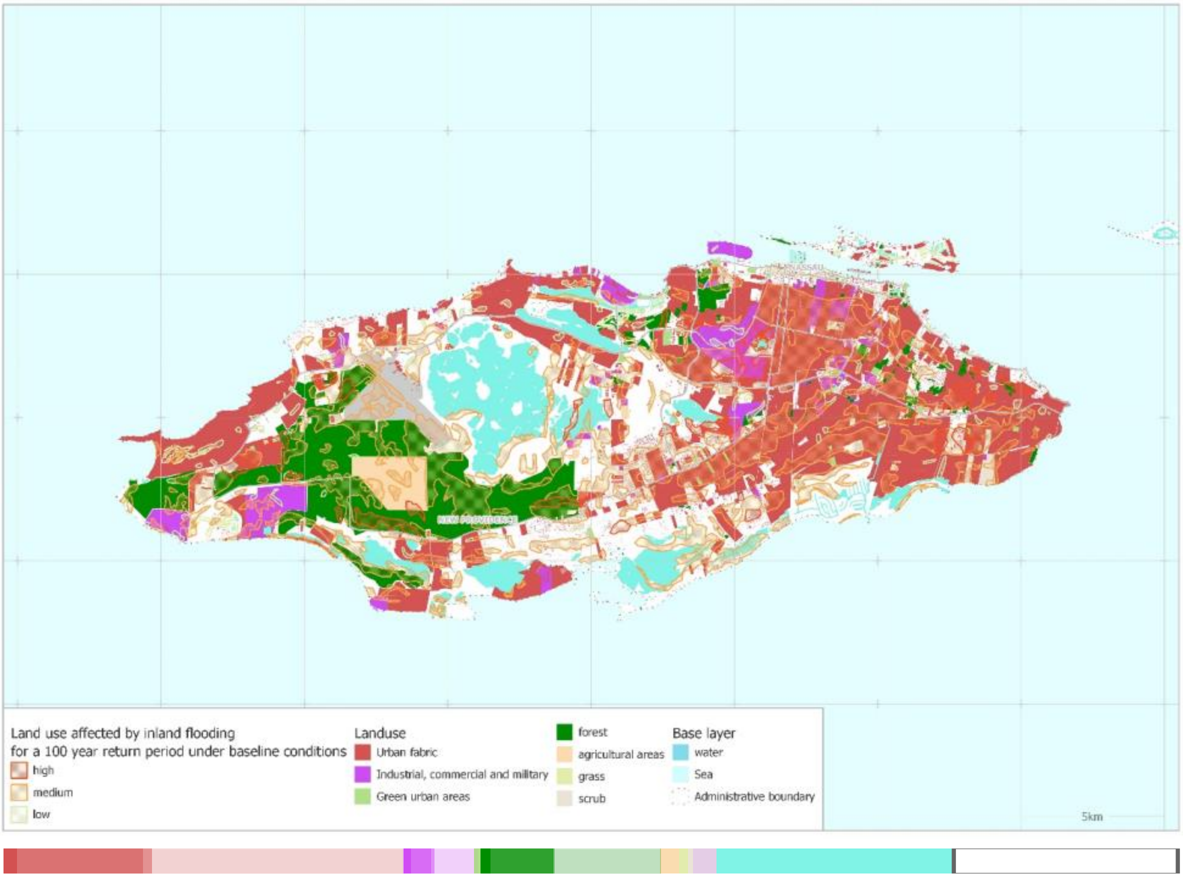
The vulnerable people in the centre of Nassau are the first impacted by the floods (cf. Figure 11.19). In this area of the island, there is a high density of population and a large number of buildings exacerbating the risk. In addition, the IDB estimated an increase of 8-13% in economic losses due to flooding.



very high 1.5%
high 1%
medium 5%
medium 5%
low 2.5%
no risk 85%

Figure 11.19 Risk – Combined population and economic (BUURpos 2022)
Source: IDB 2018 and open street map

The land use and flood analysis (Figure 11.20) shows a need to reinforce the planning of coastal zones and regulate residential construction along beaches of New Providence.



Urban fabric .... 37% (3.3% H,31.5% M, 2.2% L)
Industrial, commercial and military .... 43.8% (10.2% H, 28.1% M,5.5% L)
Green urban areas .... 40.8% (3.2% H, 35.9% M, 1.7% L)
Forest .... 41.3% (5.7% H, 34.7% M, 1.0% L)
Agriculture .... 24.3% (2.8% H, 20.6% M, 0.9% L)
Grass........ 22.0% (14.5% , H7.5% M, 73.6% L)
Scrub........ 43.2% (0.0% H, 43.2% M, 0.0% L)
Airport........ 40.1% (0.0% H, 39.6%M, 0.5% L)

Figure 11.20 Land use affected by inland flooding (BUURpos, 2022)

In May 2022, the Ministry of Works and Utilities adopted a “comprehensive Disaster Management” strategy to mitigate the issue of flooding in New Providence. Drainage cleaning, a pilot drilling project, an aggressive maintenance program, conventional wells, and installation of new systems in open spaces are among the mitigation measures that the Ministry is using and/or proposing.

11.4. Bibliography

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12. Summary part II

12.1. Adaptation challenges across the Iconic Cities

There are significant similarities between the adaptation challenges faced by the four Iconic Cities in the PROVIDE project in their respective spatial structural and strategic profiles. All four places showcase vulnerability to various climatic risks by the effects of anthropogenic activity, such as the urbanization of coastal areas, the covering of water streams and the discontinuity of green-blue structures in Bodø, the sealing of valley and stream landforms, the intensity of the built-up space and the organization of economic activities in the Lisbon Metropolitan Area, the urbanization occurring along ecological corridors in Islamabad, and the urbanization occurring along the coastal coast in New Providence. All four place are also faced with the paradox of the existence of corresponding spatial potential to address their respective climatic risks, but with a high degree of private ownership and absence of sufficient governance regimes, as well as with a decrease in its network configuration, resulting in fragmented organizations without coherence with their context and associated needs for climate adaptation and mitigation.

Table 12.1. Summary of adaptation challenges the Iconic Cities

Bodø	**Lisbon**
Multiple spatial claims in vulnerable zones, anthropogenic impacts (covering of water streams), limited spatial (green-blue) potential, limited network connectivity (limited adequate system configuration), private ownership VS public demands	Organization of industrial and commercial units along vulnerable zones and/or spatial opportunities of adaptation (need for their respective transformation and sectoral organization), built-up-space intensity (need for retrofitting of green-blue devices), reorganization of agricultural regimes and protection of natural vegetation, conflicts between spaces of opportunity and ownership and management regimes (public VS private ownership and absence of suggested spaces from the current planning objective system).
Islamabad	**New Providence**
Urbanization pressures on ecological corridors	The urbanisation of the vulnerable coastal zones (need for restructuring coral reefs and underwater plants, beach restoration mangrove protection, infrastructure adjustments)

12.2. Knowledge gaps

Two interconnected issues present themselves as gaps in current planning practice as regards the adaptation and mitigation challenges of the four Iconic Cities.

Firstly, there is a need for spatially explicit information on the interrelationship between urbanization patterns (patterns of land use and land cover) and their exposure to climatic risks. This is to ascertain that spatial planning policies and practices have an adequate view of the possibilities and restrictions brought forth and posed by current urbanization patterns to address the vulnerability of the regions and their cities to heat stress, sea level rise, coastal, fluvial, and pluvial flooding. It is also necessary for the introduction of particular instruments and objectives within future climate adaptation plans and strategies; without an explicit assessment of how space affects climatic vulnerability, the absence of the vocabulary of climatic risk and adaptation cannot be sufficiently remedied, nor can its abstractness be transformed into concrete planning and policy.

Secondly, it will be necessary to elaborate appropriate and relevant future scenarios and projections for the dynamics of the development of these spatial systems and their governance. .

12.3. Implications for PROVIDE's Overshoot Proofing Methodology

The Overshoot Proofing Methodology needs to take the spatially explicit nature of the interrelationship between spatial patterns, climatic risk, and climate adaptation into account. Specifically, this requires 1) the embeddedness of the assessment of the existence of adequate spatial potential (and its organization) to be a part of associated planning, 2) the conceptual and practical connection between said potential and connectedness and patterns of spatial governance, and 3) the introduction of spatial dynamics in the development of relevant adaptation scenarios.

12.4. Implications for PROVIDE's Climate Services Dashboard

The emphasis on the effects of the spatial structure on climatic vulnerability and climate adaptation and mitigation suggests an imperative (and opportunity) for climate services to incorporate illustrative insights on the contextuality of the organization and use of space. This signifies the expansion of climate services from numerical tools to guide policy objective-setting too include physical/spatial and institutional (scenario-based) aspects of possible impacts and adaptation narratives as illustrative negotiation tools, thus increasing the target end-user base of the Dashboard.

12.5. Implications for further work in WP4 and regional stakeholder engagement

As regards the subsequent work to be carried out within PROVIDE about the Spatial and Strategic Structure of the Iconic Regions and Cities, this pertains to two interconnected aspects:

- The elaboration of scenarios of transformation of ownership, governance and use regimes of spaces within the urbanized landscape (according to the scenarios elaborated by WP1 as well as the impact chains elaborated by WP2); and
- The elaboration of contextual (from large-scale to point interventions) strategies and physical solutions according to the Structural and Strategic profiles elaborated in WP4.

These will be evaluated through climate modelling, in terms of their performance in heat regulation, as well as in contrast to current territorial instruments and plans/strategies/policies for climate adaptation in general, and heat stress risk mitigation in particular (according to the overshoot proofing methodology elaborated in WP3). The above necessitates a more robust identification of relevant regional and local stakeholders and the input of existing adaptation strategies and plans as baselines upon which to conduct such an evaluation.