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THE EFFECT OF URBANIZATION ON CLIMATE CHANGE, THE VULNERABILITY OF URBAN AREAS TO CLIMATE CHANGE AND THEIR CUMULATIVE IMPACT ON STORMWATER

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Abstract

Water is an essential factor of the population existence and health and a primordial condition for the evolution of the society. In the context of climate change that determines the reduction of resources, the sustainable use of water, are key factors of sustainable development. The spatial and temporal distribution of water is determined not only by economic activities and the degree of urbanization, but also by natural variations in climate as a result of climate change. In recent decades, there has been a growing awareness of the value of stormwater as a resource that must be considered in urban development. In the context of the deterioration of the ecological conditions of water sources, due to pollution on the one hand, population growth and the influx of people into urban areas, on the other hand, the challenge for cities is to balance the limited supply and the growing demand for water. In recent years, migration is an additional challenge for the urban development strategy. At the same time, water as a resource and related infrastructure are among the most vulnerable sectors during armed conflicts.

Key words: *climate change, rainwater, urbanization.*

INTRODUCTION

The world is becoming more and more urbanized. Today, more than half of the world's population lives in urban areas, up from about one-third in 1950 and projected to rise to about two-thirds in 2050. In many parts of the world, water resources are declining or depleted, they are contaminated with pollutants and the natural reserves currently in use can no longer meet the growing demands on water supplies. With a steadily growing world population, the consumption of resources, intensive agriculture and climate change, water is becoming a limited resource. These factors can hinder economic development and growth the geographical distribution, density and movement of the population.

Unlike conventional collection/drainage approaches, which treat stormwater as a burden/ product to be removed from the urban area as quickly as possible, sustainable stormwater management considers it a multifunctional resource (Mitchell, 2006) with many benefits' potential for society and the environment (Barbosa et al., 2012; Fletcher et al., 2015; Makropoulos et al., 2008; Mitchell, 2006).

A growing awareness of the value of stormwater as a resource to be considered in urban development was determined by various socio-economic aspects, such as:

- population growth and implicitly the demand for water;
- the growth of urban areas and related impervious surfaces;
- increasing awareness of the need for environmental protection;
- the risk/consequences/damage caused by heavy precipitation and storms exacerbated by climate change.

The World Meteorological Organization (WMO) report confirmed that 2023 was the warmest year on record, with the global average near-surface temperature at 1.45°C (with a margin of uncertainty of ± 0.12°C) above the pre-industrial baseline. It was the warmest ten-year period on record.

In 2023, the impacts of climate change continued to be seen across Europe, with millions of people impacted by extreme weather events, making the development of mitigation and adaptation measurements a priority.

Climate change leads to an increase in the intensity and amount of precipitation, thus having a direct impact on the behaviour of the sewage system, which, through overloading, can ultimately lead to flooding and material damage in urban areas.

Precipitation is one of the most difficult meteorological elements to forecast. This is because of complex micro-physical processes taking place in clouds, the effect of external factors and geographic conditions and hard to parameterize cloud-forming processes.

Despite these doubts and assuming proper selection of climate change scenario, obtained results may serve as an advisory material supporting long-term development strategy.

For cities, some aspects of climate change may be amplified, including heat, flooding from heavy precipitation events and sea level rise in coastal cities.

The implementation of sustainable stormwater management involves measures at different scales, from urban and regional planning, where different land uses can be determined according to topographic and hydrological conditions, to the construction of individual facilities or the application of best management practices (BMP) (Carmon & Shamir, 2010).

MATERIALS AND METHODS

As part of a scientific research program, the article offers a review of analysis and interpretation of the existing published literature, correlated with the existing worldwide statistical information regarding demographic and climatological data in order to evaluate the cumulative impact of urbanisation, industrialization and climate change on urban area.

Statistical data were taken from United nation - World Social Report 2023, IPCC Reports on Climate Change: Impacts, Adaptation and Vulnerability and also climate change indicators reached record levels in 2023 according to Word Meteorological report.

RESULTS AND DISCUSSIONS

Currently, there is no universal definition of what "urban" means. The oldest cities, which are still inhabited today, testimonies of human and cultural history are considered: Jericho - Palestine (8000 BC), Byblos - Lebanon (6000 BC), Damascus - Syria (5000 BC), Jerusalem, Israel (4500 BC).

In the history of humanity, the development of cities had opposite effects. On the one hand, urbanization brings a positive impact on society as it helps/contributes to improving the social and economic aspects of people's lives. During the development there was a demographic explosion, which generated disruptive phenomena for normal activity: lack of housing and their crowding, lack of food and unemployment.

Urbanization processes dominate not only the history of the last century and a half, but are currently associated with the notion of development, urban equipment indicators being used in any argumentation regarding the quality of life on a national, regional or local scale.

By concentrating the population in big cities following human activity in industry, agriculture, transport, tourism, etc., the elements of biocenosis and biotope in the urban ecosystem fell prey to pollution.

The European Environment Agency declares that "for the first time in human history, more people live in cities than in rural areas. Europe is one of the most urbanized continents. Consequently, the demand for land in and around cities becomes acute, urban expansion reshapes the landscapes and affects people's life quality and the environment. According to the 2022 United Nations World Cities Report, it is predicted that approximately 70% of the world's estimated population will live in urban areas in 2050.

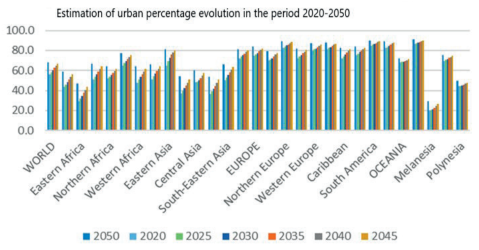

Figure 1. Estimation of urban percentage evolution in the period 2020-2050
https://ourworldindata.org/urbanization

The growth rate of the urban population is higher than the population growth rate, both worldwide and at the European level. 80% of the population lives in cities, which therefore generate the majority of greenhouse gas emissions.

Low-density housing, a single family, is preferred rather than multi-family housing even though compact land development is arguably environmentally more sustainable particularly in the face of climate change and demographic shift (immigration) that increase demand for housing and ancillary urban services-water, sewer, and road.

The impact of cities on the environment is not limited to the space within their inner city, the increased needs of such a settlement also require the exploitation of resources from the neighbouring areas and beyond (waste storage, collection of raw materials, etc.).

The high urban density of modern cities and the reduced openings to the sky of the streets contribute to the shading of the canyon surfaces and the decrease in the absorption of solar radiation. On the other hand, the compactness of cities and increased building densities can lead to trapping of long-wave radiation emitted by the ground and building surfaces at night, thus inhibiting urban cooling. In parallel, high surface roughness due to increased building density considerably attenuates the wind flow inside street canyons and the consequent convective heat transfer from urban surfaces to the atmosphere.

Moreover, land and building surfaces in modern cities generally have low values for the relative amount of light that surface reflects compared to the total incoming sunlight (albedo < 0.31), high infrared emissivity, and increased thermal conductivity and specific heat capacity.

Given their thermal and optical characteristics, urban elements absorb and store an important part of the direct solar radiation that reaches their surface, from early morning to late afternoon. The accumulated heat is then dissipated by convective and radiative phenomena during the evening and late night, cooling urban surfaces but increasing the ambient air temperature of adjacent air layers.

Rainwater falling in the atmosphere always contains impurities, even in the absence of human influence.

The results of studies conducted over the past decades, regarding the impact of global climate to changes in albedo showed that increases in albedo cause: decreased land evaporation, decreased land precipitation and increased precipitation over the sea, in the global change cases (Garratt, 1993).

Other related studies support the statement that increased surface albedo leads to local/regional climatic changes in the direction of greater aridity. Another consequence of urbanisation and industrialisation is acid rain, caused by air pollution, that contributes to climate warming.

Acid rain was identified in the 19th century by Robert Angus Smith, a pharmacist from Manchester (England), who measured high levels of acidity in rain falling over industrial regions of England and compared them to the much lower levels he observed in less polluted areas near the coast.

Little attention was paid to his work until the 1950s. Acid rain is one of the consequences of air pollution. The emission of sulphur dioxide, nitrogen dioxide, and carbon dioxide causes acid rain. Carbon dioxide is a primary gas that also leads to the greenhouse effect. Human activities produce these chemicals of acid rain which reach the atmosphere, when their concentration becomes high then the temperature of the atmosphere increases and results in climate warming.

The assessment of the cumulative impact on water, associated with climate change in urban areas, especially the way in which climate systems and urban systems interact, is presented following the study of scientific articles, of which the following aspects are considered representative:

- Globally, increased frequencies and intensities of extreme precipitation from global warming will likely expand the global land area affected by flood hazards (Alfieri et al., 2018; Alfieri et al., 2017; Hoegh-Guldberg et al., 2018);
- Future urban flooding risks increase with the continued increase in surface temperature (IPCC, 2019b; Winsemius et al., 2015; Hoegh-Guldberg et al., 2018);
- Urban flood risks are also increased by urban expansion and their land use due to the increase of the impervious surface, impacting the drainage of flood waters with consecutive sewer overflows (Arnbjerg-Nielsen et al., 2013; Aroua, 2016; Kundzewicz et al., 2014);
- These risks are also determined by the increasing complexity of society, long-term

urban and economic development policy (Berndtsson et al., 2019);

- The economic risks associated with future surface water flooding in cities are considerable. For example, in the UK, annual damage from surface water flooding is predicted to increase by £60-200 million for an estimated warming of 2-4°C scenarios; improved adaptation actions could manage flooding up to 2°C, but will be insufficient beyond this (Sayers et al., 2015);
- The impact of urban flooding can exacerbate the activity of hospital facilities (including the potential occurrence of epidemics, outbreaks of malaria and cholera), which are aggravated by damage to medical facilities (for example, damage to hospitals and disruption of drug supply chains) (Gough et al., 2019);
- Rising sea levels and increased storm surge from tropical cyclones and increased rainfall will increase the likelihood of coastal cities flooding;
- Risks of urban water scarcity and security are compounded by vulnerabilities such as service availability and infrastructure quality (Ahmadalipour et al., 2019; Dong et al., 2020; Reynolds et al., 2019; Thomas et al., 2017; Mullin, 2020);
- Droughts interact and manifest in complex ways in interconnected urban areas by increasing the risk of urban water scarcity (Tapia et al., 2017; Rushforth & Ruddell, 2015);
- Urban interdependencies mean that droughts in one region can limit the availability of water resources in another region (Chuah, Ho, & Chow, 2018; Gober et al., 2016; Srinivasan, Konar, & Sivapalan, 2017; Zhang et al., 2019; Zhao et al., 2020).

Climate change is bringing multiple different changes to different regions – which will all increase with further warming.

These include changes to wetness and dryness, to winds, snow and ice, coastal areas and oceans, like:

- intensifying the water cycle;
- climate change is affecting rainfall patterns. In high latitudes, precipitation is likely to increase, while it is projected to decrease over large parts of the subtropics;
- coastal areas will see continued sea level rise throughout the 21st century contributing to more frequent and severe coastal flooding in low-lying areas and coastal erosion;
- further warming will amplify permafrost thawing, and the loss of seasonal snow cover, melting of glaciers and ice sheets, and loss of summer Arctic Sea ice;
- changes to the ocean, including warming, more frequent marine heatwaves, ocean acidification, and reduced oxygen levels have been clearly linked to human influence.

During 2023, the majority of Europe was wetter than average; around 7% wetter than average for the continent. The majority of Europe saw wetter-than-average conditions. Drier-than-average conditions were experienced in countries to the west of the Black Sea, and across the southern Iberian Peninsula, where dry conditions occurred from February to April.

A region between western Europe and Ukraine was wetter than average from October to December, whereas most of Fennoscandia was drier than average in November and December.

Figure 2 presents the anomalies expressed as a percentage of the annual average over European land from 1950 to 2023.

Perspectives

As climate change intensifies, the European Union faces more rainfall, stronger storms and rising sea levels. According to the European Environment Agency (EEA), the consequences of fluvial, rainwater and coastal flooding in Europe will worsen overall as a result of the increase, both locally and regionally, in the intensity and frequency of flooding.

Observed climate trends and future climate projections indicate significant regional variations in precipitation across Europe (Figure 3). Forecasts indicate an increase in the amount of annual precipitation in northern Europe. Winter precipitation could increase by more than 25% in the last 20 years of this century in some parts of Europe.

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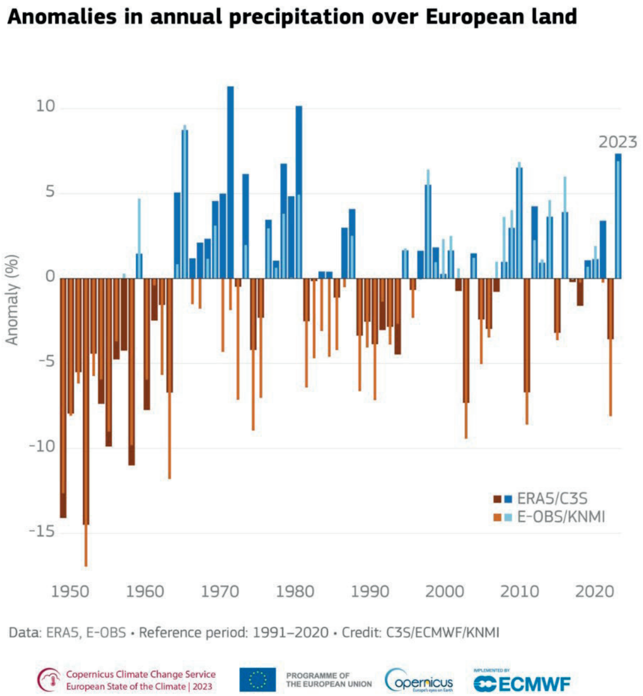

Figure 2. Anomalies (%) in annual precipitation over European land from 1950 to 2023
Data source: E-OBS (light blue and light brown) and ERA5 (dark blue and dark brown)
https://climate.copernicus.eu/esotc/2023/precipitation

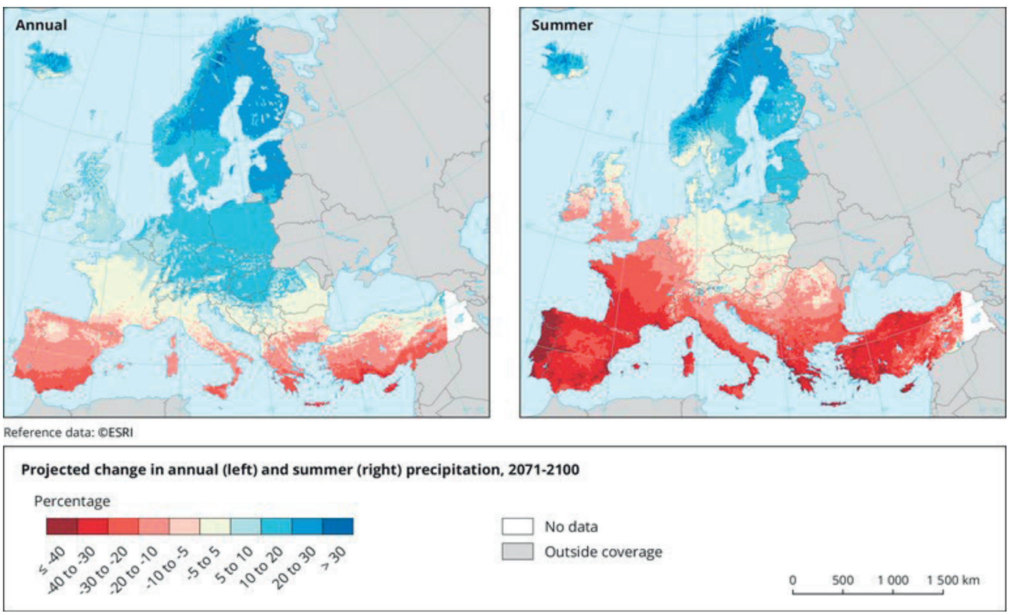

Figure 3. Project change in winter (left) and summer (right), precipitation, in 2071-2100 period (scenario based on a 2°C increase in global temperature), %
https://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-annual-and-6

Urbanization is one of the main changes, which has been observed to substantially alter the local environment, especially the soil-atmosphere interaction, resulting in significant diurnal temperature differences (Kalnay, 2003), which could partially contribute to the projected 2°C temperature increase under conditions of potential climate change (Georgescu et al., 2014).

The following changes can be expected in an urbanized watershed:

- The frequency of flood peaks is predicted to increase;
- Increased values of maximum flood flows (by two to five times);
- Increased volume of discharged rainwater;
- Increasing the frequency of summer floods and the severity of floods;
- Reduction of minimum runoff and groundwater levels, because of rapid water drainage;
- Increasing the speed of water flowing on the streets and in the drainage systems and, as a result, increasing the speed of the flow in the emissary during the rain.

Any of the mentioned changes can lead to an increase in the concentration of pollutants in the water discharged into the outfall. At the same time, along with the increase in the maximum flood flows, erosion phenomena and the modification of the emissary bed also occur. Thus, the problems related to pollution are multiplied with the increase of urbanization.

Flood risks are increasing due to the following factors:

- Change of land use destination – excessive cutting of forests and intensive agricultural practices, urbanization and economic activities reduce water retention capacity (natural drainage) during and after rainfall.
- Urbanization and real estate developments in flood risk areas.
- The regularization of natural rivers and the disconnection of the naturally flooded meadows of the watercourses, which increase the flow speeds and reduce the natural retention of water (reducing the time in which the flood propagates in a sector – faster floods.
- The accentuation of extreme hydrometeorological phenomena because of climate change correlated with uncontrolled urban development.

Implementing sustainable stormwater management involves measures at different scales, from urban and regional planning.

In the context of the deterioration/degradation of the ecological conditions of water sources, due to pollution on the one hand, population growth and the influx of people into urban areas, on the other hand, the challenge for cities is to balance the limited supply and the growing demand for water.

Both the infrastructure and the public services, respectively the degree of urbanity that they have tend to measure the suitability or inadequacy of a population to a contemporary way of life.

Increasing urban temperatures will also have a strong influence on evapotranspiration that is largely limited by precipitation.

Thus, there might be increased evapotranspiration in areas with more precipitation but also increased durations of drought in areas with reduced precipitation.

In northern regions there is also an expected seasonal change in precipitation with more winter precipitation falling as rain and higher spring temperatures, leading to increased winter runoff and a reduction in late season snowmelt.

Climate change will influence several factors of importance to habitat quality and development of urban biodiversity.

The projected change in temperatures, rainfall, extreme events and enhanced C02 concentrations will influence a range of factors related to single species (e.g. physiology), population dynamics, species distribution patterns, species interactions and ecosystem services, as a result of spatial or temporal reorganisation (Bellard et al., 2012).

The perceptivity that both nature and society are at risk drives scientific research to focus on adaptation strategies, to develop mitigation plans, to inspire sustainable solutions and to (re)invent practices how locals and communities, stakeholders and economies, can deal with changing settings and pressures (Walker et al., 2014).

CONCLUSIONS

Extremely dynamic today, contemporary society is increasingly feeling the combined impact of current pressures: urbanization, climate change and the globalization of the economy.
The spatial and temporal distribution of water is determined not only by economic activities and the degree of urbanization, but also by natural variations in climate as a result of climate changes.
Our understanding of the role that urbanization plays in the processes and evolution of the climate system is incomplete.
Adaptation to actual or expected climate change effects involves a range of measures or actions that can be taken to reduce the vulnerability of society and to improve the resilience capacity against expected changing climate.
Due to the climate crisis, the phenomenon of rapid urbanization and the insecurity regarding food and energy, the sustainable management of water resources remains a critical issue. The path towards adaptation and societies' resilience to overcome risks and threats to a more sustainable future entails attentiveness and place-tailored measures and actions (Das et al., 2021).
In recent years, migration is an additional challenge for the urban development strategy. At the same time, water as a resource and related infrastructure are among the most vulnerable sectors during armed conflicts.
Climate change leads to an increase in the intensity and amount of precipitation, thus having a direct impact on the behavior of the sewage system, which, through overloading, can ultimately lead to flooding and material damage in urban areas.
The explosive growth of metropolises and cities, in general, affects territorial structures, impoverishes primary resources and makes it increasingly difficult to manage adaptation processes to current climate conditions.
Change in urban precipitation may be due to interactions of urban heat islands, urban roughness effects, and aerosols, each of which may have a positive, negative, or synergistic impact. Building cities that "work" – green, resilient and inclusive – requires intensive policy coordination and optimal investment choices.
Increasing urban temperatures and changed precipitation dynamics will influence species community development through limiting water availability during the growing season as well as changing the nutrient dynamics.
All these phenomena lead to a chain degradation of the natural balances in an urbanized watershed and to a sharp degradation of the aquatic resources of fauna and flora.
These changes have profound economic and societal implications due to the reduction of significant natural resources and the degradation of their quality.
Acid rain should be considered as one of the important problems derived from the climate change and must be addressed with the importance it has.
Possible adaptation measures to handle climate change can take many forms and be effective at a range of spatial and temporal scales, proactively planned or as a result of socio-political drivers such as new planning regulations, market demand or even social pressure.
With the increasing frequency of human activities and climate change, how to reveal the response of ecosystem water conservation function the changing environment, is a scientific problem that needs to be urgently addressed in ecological hydrology research.
In the context of the deterioration/deterioration of the ecological conditions of water sources, due to pollution on the one hand, population growth and the influx of people into urban areas, on the other hand, the challenge for cities is to balance the limited supply and the growing demand for water. In recent years, migration is an additional challenge for the urban development strategy. At the same time, water as a resource and related infrastructure are among the most vulnerable sectors during armed conflicts.

REFERENCES

Aguiar, F.C., Bentza, J., Joao, M.N., Ana, S., Fonsecaa, L., Swarta, R., Duarte Santosa, F., Penha-Lopes, G. (2018). Adaptation to climate change at local level in Europe: An overview. *Environ. Sci. Policy, 86*, 38–63.
Alfieri, L., Bisselink, B., Dottori, F., Naumann, G., De Roo, A., Salamon, P., Wyser, K., Feyen, L. (2016). Global projections of river flood risk in a warmer world. *Earth's Future, 5*(2), 171–182.

Alfieri, L., Dottori, F., Betts, R., Salamon, P., Feyen, L. (2018). Multi-Model Projections of River Flood Risk in Europe under Global Warming. *Climate, 6*(1), ISSN 2225-1154, JRC108760.

Barbosa, A.E., Fernandes, J.N., David, L.M. (2012). Key issues for sustainable urban stormwater management. *Water Research, Special Issue on Stormwater in urban areas, 46*, 6787–6798.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W., Courchamp, F. (2012). Impacts of climate change on the future of biodiversity. *Ecology Letters, 15*(4), 365–377.

Carmon, N., Shamir, U. (2010). Water-sensitive planning: integrating water considerations into urban and regional planning. *Water and Environment Journal, 24*, 181–191.

Das, J., Goyal, M., Nanduri, U., Eslamian, S. (2021). Water Harvesting, Climate Change, and Variability. In Handbook of Water Harvesting and Conservation: Basic Concepts and Fundamentals; Eslamian, S., Ed.; John Wiley & Sons Ltd.: Hoboken, NJ, USA, pp. 427–446.

Garratt, J.R. (1993). Sensitivity of climate simulations to land-surface and atmospheric boundary-layer treatments. - a review. *J. Climate, 6*, 419-449.

Georgescu, M., Morefield, P.E., Bierwagen, B.G., & Weaver, C.P. (2014). Urban adaptation can roll back warming of emerging megapolitan regions. *Proceedings of the National Academy of Sciences, 111*(8), 2909–2914.

Hoegh-Guldberg, O., Poloczanska, E.S., Skirving, W., Dove, S. (2017). Coral Reef Ecosystems under Climate Change and Ocean Acidification. *Frontiers in Marine Science, 4,* 158,

Makropoulos, C.K., Natsis, K., Liu, S., Mittas, K., Butler, D. (2008). Decision support for sustainable option selection in integrated urban water management. *Environmental Modelling & Software, 23*, 1448–1460.

Marsalek, J. (2001). Review of Stormwater Source Controls in Urban Drainage, in Advances in Urban Stormwater and Agricultural Runoff Source Controls, NATO Science Series, Marsalek, Jiri, Watt, E., Zeman, E., Sieker, H. (eds.). Netherlands, Dordrecht: Springer. p. 1

Mitchell, V.G. (2006). Applying Integrated Urban Water Management Concepts: A Review of Australian Experience. *Environmental Management, 37*, 589–605.

Walker, B.J., Adger, W.N., & Russel, D. (2015). Institutional barriers to limate change adaptation in decentralised governance structures: Transport planning in England. *Urban Studies, 52*(12), 2250-2266. https://doi.org/10.1177/0042098014544759

Winsemius, H., Aerts, J., van Beek, L. et al. (2016). Global drivers of future river flood risk. *Nature Climate Change, 6*(4), 381–385.

https://ourworldindata.org/urbanization

https://www.oecd.org/climate-action/ipac/the-climate-action-monitor-2023-60e338a2/chapter-d1e1621#section-d1e1882

https://climate.copernicus.eu/esotc/2023/precipitation

https://www.eea.europa.eu/data-and-maps/figures/projected-changes-in-annual-and-6