POLITECNICO DI TORINO

Corso di Laurea Magistrale

in Pianificazione Territoriale,
Urbanistica e Paesaggistico-Ambientale

Tesi di Laurea Magistrale

Water and Resilient Cities
Theories and practices to foster urban adaptation
to water-related climate effects

Relatori
Prof.ssa Grazia Brunetta
Prof. Nicola Tollin

Candidata
Margherita Nardi

Anno Accademico 2020/2021

Master's degree programme in

Territorial, Urban, Environmental and Landscape Planning

Curriculum: Urban and Regional Planning

Master Thesis

Water and Resilient cities

Theories and practices to foster urban adaptation
to water-related climate effects

Supervisors
Prof. Grazia Brunetta
Prof. Nicola Tollin

Candidate
Margherita Nardi

Academic Year 2020/2021

A chi vede la bellezza di ciò che ci circonda,
e ne ha cura.

Grazie alle mie colonne,
sempre salde e amorevoli,
e ai miei cuori,
sempre vicini seppur lontani.

Grazie alla mia spalla Maria e agli amici di BloxHub per i giorni ordinari quanto straordinari passati insieme.

E un sentito ringraziamento alle Professoresse Brunetta e Caldarice e al Professor Nicola, senza i quali nulla di tutto ciò sarebbe stato possibile.

TABLE OF CONTENTS

Abstract
The number of disasters related to climate change is steadily rising, and the concept of urban resilience as a city's response is gaining popularity.

The present research aims to analyse the climate change effects on our cities and to investigate the solutions adopted so fare. Climate change is global, and global must be the responses to reduce risk and ensure liveability.
This research focuses on water resources management in the urban context, both theoretical and practical, in different geographical contexts. The theoretical investigation will represent a structuring part of the study, deepening the urban resilience paradigm applied to water management and conducting a comparative analysis of Urban Metabolism and Water Sensitive Cities approaches. A practical part will follow, in which theoretical methods and tools will be used as a guide for the collection and classification of the best practices adopted worldwide in water management under climatic stress conditions. The preliminary theoretical research is also be applied, in a third phase, to the evaluation of the above-mentioned best practices through a multi-criteria matrix that will give qualitative assessments about the efficiency and replicability of the analysed practices. The ultimate goal that the present thesis wishes to achieve is to encourage and enhance the sharing of ideas and practices, towards more secure and liveable cities, in harmony with the ecosystem to which we belong.

Keywords: Urban resilience; climate change adaptation; water management; urban metabolism; water sensitive cities; best practices.

Abstract

Il numero di disastri legati al cambiamento climatico è in costante aumento, e il concetto di resilienza urbana come risposta sta acquisendo popolarità.

La presente ricerca mira ad analizzare gli effetti che il cambiamento climatico ha sulle nostre città e vuole approfondire le soluzioni adottate finora in tutto il mondo. Il cambiamento climatico è globale, e globale deve essere la risposta per ridurre il rischio a cui siamo esposti, e garantire così una buona ed equa qualità di vita.

Questa ricerca si concentra sulla gestione delle risorse idriche nel contesto urbano, sia da un punto di vista teorico che pratico, in diversi contesti geografici. L'indagine teorica rappresenterà una parte strutturale dello studio, con l'approfondimento del paradigma della resilienza urbana applicato alla gestione dell'acqua e un'analisi comparativa degli approcci Urban Metabolism e Water Sensitive Cities. Seguirà una parte pratica, in cui i metodi e gli strumenti teorici saranno utilizzati come guida per la raccolta e la classificazione delle buone pratiche adottate nella gestione dell'acqua in condizioni di stress climatico. La ricerca teorica sarà anche applicata, in una terza fase, alla valutazione delle suddette buone pratiche attraverso una matrice multicriteriale, che darà valutazioni qualitative sull'efficienza e la replicabilità delle pratiche analizzate. L'obiettivo finale che la presente tesi vuole raggiungere è quello di spronare e implementare la condivisione di idee e pratiche, verso città più sicure e vivibili, in armonia con l'ecosistema di cui facciamo parte.Keywords: Resilienza urbana; adattamento al cambiamento climatico; gestione dell'acqua; metabolism urbano; water sensitive cities; best practices; casi studio

List of abbreviations and symbols

WSP: Water Sensitive Planning

UM: Urban Metabolism

CUM: Circular Urban Metabolism

CE: Circular Economy

WUM: Water Urban Metabolism[1]

WME: Urban metabolism efficiency

MFA: Material flow analysis

PWP: Potable Water Production

GDP: Gross domestic product

DRR: Disaster Risk Reduction

NBS: Nature-Based Solution

Glossary:

Megaregions: Ensemble of several big metropolitan areas with over 20 million people, active economy and technology development (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

City-regions: clusters of different sizes cities, semi-urban areas and rural hinterlands (Ibid).

Urban corridors: linear systems of urban spaces extending beyond administrative boundaries. Cities of various sizes are connected along transportation routes (Ibid).

Megacities: Continuous urban areas with more than 10 million people (Ibid).

Disaster Risk Reduction (DRR): The concept and practise of reducing the risk through analsying and managing the disaters factors. It includes the reduction of exposure to hazards and the vulnerability of human and physical capital, strategic land and environment management, and improved preparedness for adverse events.

Hazard: A dangerous factor, that can be a substance, human action, or condition, that can be responsible for loss of life, or other health consequences, property damage, social and economic disruption, or environmental damage.

Risk: The probability that a negative event happens and its consequences.

Vulnerability: The susceptibility of a human society to damage.

Equation of Risk: R=HxV

[1] Depending on authors, can also be found in the form: "Urban Water Metabolism"

Resilience: Resilience is a process of continuous evolution, not only the result of action-reaction to unexpected inputs. It should be the spinal cord of the urban system's character, fostering the spatial development through policies, planning, self-organisation and creativity (Brunetta et al., 2019).

Adaptation: The tentative of anticipating adverse effects of climate change with appropriate actions to prevent or minimise the potential damage, or of taking advantage of opportunities that may arise. From the experience, it has been proved that well planned and in advance adaptation actions have social, economical and environmental benefits.

Preparedness: The knowledge and preparatory actions developed by Decision-makers, research groups, technicians, stakeholders and citizen to effectively avoid the negative impacts of some events, and to recover the system's functions.

Mitigation: The action of lessening or limitate climate change and its related disasters.

Prevention: Avoiding altogether the negative impacts of hazards and related disasters.

Hydrology: "which treats all phases of the earth's water, is a subject of great importance for people and their environment. Practical applications of hydrology are found in such tasks as the design and operation of hydraulic structures, water supply, wastewater treatment and disposal, irrigation, drainage, hydropower generation, flood control, navigation, erosion and sediment control, salinity control, pollution abatement, recreational use of water, and fish and wildlife protection. The role of applied hydrology is to help analyse the problems involved in these tasks and to provide guidance for the planning and management of water resources" (Chow et al. 1998).

Urban corridors: Linear systems of urban spaces extending beyond administrative boundaries. Cities of various sizes are connected along transportation routes (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019)

Watershed: A watershed refers to the area that is drained by an interconnected system of lakes, rivers, streams, and groundwater to a particular point. Also rain and snow contribute to the watershed.

Nature Based Solutions: The use natural processes to increase water availability, enhance water quality, and reduce water-related risks, and climate change.

INTRODUCTION TO THE RESEARCH

The present research took birth from the internship at Southern University of Denmark (SDU), in collaboration and under the supervision of the Responsible Risk Resilience Centre (R3C) of Polytechnic of Turin, focused on urban resilience. Beginning with a study trip to Copenhagen in September 2019 and developing through the internships in autumn 2020, we started to approach adaptation to climate change.

Climate change and its effect are happening now, and it will be increasingly affecting the planet over this century and beyond. Responding effectively to the climate change effects requires urgently to reduce the causes of the imbalance and adapting to its impacts, trying to cut the damages. The topics of adaptation and resilience-building have been investigated throughout these theses.

Specifically, Maria Pizzorni's research investigates the urban content in National Adaptation Plan (NAP) submitted by 20 countries of the Global South under the Cancun Adaptation Framework (COP 16, Cancun, 2010). This analysis will be compared with the urban content of Nationally Determined Contributions (NDCs) established under the Paris Agreement (COP 21, Paris, 2015) and of National Urban Policy (NUP) established by Habitat III (Quito, 2016). Therefore, results will show how the urban dimension has been approached and how to implement those contents.

Margherita Nardi's research deepens the topic of climate change from the perspective of water management. Based on the research that is being fostered by UNESCO-IHP (international Hydrological Programme), the current investigation examines the water-related effects of climate change on urban systems, the theoretical state of the art, and the practical responses that have been adopted worldwide to face and reduce the impacts of water-related challenges.

The guiding question of the two theses is how the practices can support the implementation and operationalisation of the adaptation to climate change, moving from policies to actions, and how the policies can play a leading role in that.

To face climate change and minimise its effects, urban systems need to undertake a transition process towards more resilient systems.

The NAP is aimed to guide and propel this transition with national policies and shared strategies. Indeed, the NAP is a process aimed at enabling countries to address their priorities for adapting to climate change, identifying challenges and measures to climate change adaptation.

To reach that goal, the process is structured in planning, implementation, monitoring and evaluation. Throughout this process, the vulnerabilities, the priorities, and the following strategies should be identified and addressed. Moreover, the capacity development, the financing, the appropriate institutional arrangement, and information sharing are part of the NAP's investigation ground.

Within this framework, the potential of practices should be taken into consideration in particular for the role that they can play in operationalising the transition. Indeed, the practices can not only participate in the capacity building giving applied examples of how to face any challenges but can also help in identifying or even preventing the challenge. This can lead more swiftly to priorities and therefore to strategies.

Furthermore, the consultation of practices might support in creating the linkage between national and sub-national level, essential for the NAP's effectiveness.

Local actors and their solutions are the directly concerned stakeholders and the national and international policies should always make contact with them, as well as looking at the big picture. The vertical and horizontal integration shall be the foundation of this change.

National policies, in their turn, are indispensable for the efficacy of practices. They must guide the transition towards a safer, fairer, and more sustainable urban systems. The protection of the population and the environment, the risk reduction, and the creation of favourable conditions for green initiatives are some of the starting points whereby policies can operationalising the adaptation to climate change.

In conclusion, the research could continue creating a catalogue of good practices to be included in the future UN-Habitat guidelines. The catalogue aims to suggest countries some practical solutions to implement adaptation to climate change in urban contexts through planning, building a resilient pathway for urban systems. The catalogue could be structured in a table containing: type of climate change effect (e.g., flooding, droughts, sea-level rise); possible impact on the urban and settled system (e.g., loss of human lives, reduction of agricultural production, etc.); possible practical solutions (e.g., green infrastructures, nature-based solutions, etc.).

Follow-ups and Outcomes of the Master Thesis Research

Internship aboard

- March-September 2020 | Southern University of Denmark (SDU), Copenhagen and Odense. Supervisor: prof Nicola Tollin. **(Margherita)**
- July-November 2020 | Southern University of Denmark (SDU), Copenhagen and Odense. Supervisor: prof Nicola Tollin. **(Maria)**

- *Research activities*
    - BloxHub Summer School
      Assistant to the coordinator coordination of the Summer School. Online, March-June 2020 **(Margherita)**
    - Member group of the research project for UNESCO IHP "Water and human settlements of the future". Researcher on Urban Metabolism, case studies and best practices. **(Margherita)**
    - Member group of the research project "Co-Design for Urban Resilience Education and Capacity Building" to strengthen peer-to-peer learning through co-design and co-design of teaching/learning experiences, as part of the International Urban Resilience Academy (IURA, SDU). **(Maria and Margherita)**
    - Member of the secretary of SDU Summer School on Urban Resilience. Copenhagen, 3-14 August 2020. Urban resilience, international policies, state-of-the-art research, multi-level governance, appropriate technology, Urban metabolism, Nature Based Solutions, planning & design, participatory process & stakeholders' involvement, co-benefits, finance, process design methodology, systems approach. **(Maria and Margherita)**
    - Course – "Hydraulic Modelling for Water-Loss", On-line, 10 September 2020 **(Margherita).**
    - Course – "The Wow and the How - Public speaking Training for Researchers". Odense, October 2020- January 2021. **(Maria and Margherita)**

- Course – "Unconventional Water Resources", United Nations University, Institute for Water, Environment and Health", January 2020. **(Margherita).**

Other experiences abroad

- Selected participant of the field trip “Pianificazione Strategica per la Città Resiliente. Approcci, progetti e innovazioni nella Città di Copenaghen”, organised by Politecnico di Torino (DIST, R3C – coordinator: prof Grazia Brunetta) and supported by the University of Southern Denmark (SDU) and the City of Copenhagen. Torino-Copenhagen, 11-13 September 2019. **(Maria and Margherita)**
- Enrolled in the Itinerant Master's Degree Program titled *Architecture and Museum Design for archeology. Strategic Design and Innovative Management for Archaeological Heritage. XIV Edition*. Proponent: Accademia Adrianea di Architettura e Archeologia. Master programme carried out: Piranesi Prix de Rome (Villa Adriana Tivoli (RM), August 2019); Magna Grecia (Selinunte, Segesta e Mozia, September 2020); Rome Caput Voluta, partner Roma Metropolitane, (Rome, November 2020). **(Maria)**

Publications

- Tollin, N., Caldarice, O., **Pizzorni, M.** (submitted), *Urban Content of the National Adaptation Plans: A review of the National Adaptation Plans submitted to UNFCCC*. In: X. Wan and S. Cui (Eds.) "Development of Climate Adaptation Policies for Resilient Cities" Springer (2021).
- Caldarice, O., Tollin, N., **Pizzorni, M.** (submitted), *Strengthening the science-policy-practice dialogue for urban resilience: Implementation insights from Italian cities.* Environment and Planning C: Government and Policy
- Wieszczeczynska, K.A., **Pizzorni, M.** (submitted) *Traditional Knowledge and Intangible Cultural Heritage for adapting to climate change.* In Morató, J. Wieszczeczynska, K.A., Moreno A., Prado, R., Diaz, L., **Pizzorni, M.,** Tollin, N (Eds.) "The contribution of intangible cultural heritage (ICH) and traditional knowledge to urban resilience" Springer (2021).

- Tollin, N., Morato, J., Brunetta, G., Savino, M., Innocenti, A., **Nardi, M.**, Quevedo, P., Zadra, M., Diaz, L. "*Water Research, Policies and Practices",* Internal Report UNESCO IHP-VIII "Water and human settlements of the future", part of IHP-VIII program. Publisher SDU, November 2020.
- **Nardi, M.,** Zadra, M., Quevedo, P., Innocenti, A., Brunetta, G., Tollin, N. "*Urban Water Metabolism, a systematic literature review".* Invited contribution for UNESCO-IHP (IHP-VIII), on its Theme 4 "Water for Human Settlements of the future", Journal Water, expected publication date June 2020.
- Zadra, M., **Nardi, M.,** Quevedo, P., Innocenti, A., Brunetta, G., Tollin, N. "*Water Sensitive Cities, a systematic literature review".* Invited contribution for UNESCO-IHP (IHP-VIII), on its Theme 4 "Water for Human Settlements of the future", Journal Water, expected publication date June 2020.
- Quevedo, P., **Nardi, M.**, Zadra, M., Innocenti, A., Brunetta, G., Tollin, N. "*Integrated Water Management, a systematic literature review".* Invited contribution for UNESCO-IHP (IHP-VIII), on its Theme 4 "Water for Human Settlements of the future", Journal Water, expected publication date June 2020.

- Tollin, N., Morato, J., Brunetta, G., Savino, M., Innocenti, A., **Nardi, M.**, Quevedo, P., Zadra, M., Diaz, L. "*Best practices on Circular Water Management*". Tollin, N., Morato, J., Makarigakis, A. (Eds.)". Invited contribution for UNESCO i-WSSM, International Centre for Water Security and Sustainable Management, UNESCO i-WSSM, expected publication date September 2020.

Conferences and Webinars

- Participation at the webinar "Talking about Urban Resilience: What changes for cities during a global crisis? ", organised by prof Ombretta Caldarice (Politecnico di Torino, DIST, R3C), Turin (on-line), 4 May 2020. **(Maria and Margherita)**
- Participation at the Webinar Series "Urban resilience. Facing global crisis at the time of pandemic", organised by International Urban Resilience Academy Webinar Series, SDU. 10 webinars (on-line), 28 May-26 June 2020. **(Maria and Margherita)**
- Participation at the UNESCO webinar "COVID-19 Implication on Water Management in Megacities", (on-line), 23 July 2020. **(Margherita and Maria)**
- Participation at the WNA's Urban Water Management Plan (UWMP) 101, (on-line) 15 October 2020. **(Margherita)**
- Participation at the webinar "IWA – Nature-based solutions for wastewater treatment", organised by IWA, (on-line), 27 October 2020. **(Margherita and Maria)**
- Selected speaker at the Italian Congress "Vent'anni di Convenzione Europea del Paesaggio. Sfide – risultati – prospettive', SESSIONE IV - Il paesaggio tra conoscenza, patrimonio culturale e politiche dei territori". Title of the presentation: "Paesaggi Urbani e Cambiamento Climatico. La Convenzione Europea del Paesaggio e la sfida dell'adattamento" (with M. Nardi), Venice (on-line), 29-31 October 2020. **(Maria and Margherita)**
- Participation at the webinar "New research on climate change risks and adaptation in Africa", organised by African Climate & Development Initiative (ACDI) and Climate Risk Laboratory, 3 December 2020. **(Maria)**

INTRODUCTION TO THE THESIS

> *"The city grew old and the inhabitats that were in it were old (…) In those days the world teemed, the people multiplied, the world bellowed like a wild bullm and the great god was bothered by their noise. So the gods agreed to send the flood."*
>
> *The Epic of Gilgamesh (2150-1400 BCE)*

This research has been developed in the frame of the UNESCO's researches made by the Intergovernmental Hydrological Programme (IHP), in the areas of "Water and human settlements of the future". The IHP-VIII, the eighth phase of the International Hydrological Programme, collected the priorities and needs of the Member States in the Nairobi meeting and identified six thematic areas within the Member Stats should direct their endeavours to "*better manage and secure water and to ensure the necessary human and institutional capacities*" (UNESCO IHP, 2014).

What prompted the realisation of this thesis was the thought of cities as executioners, victims and, at the same time, possible solutions to the imbalances caused by humans to nature. In particular, the research will investigate the possibilities that cities have to transform and adapt to climate change, leaving a positive imprint on the resources that pass through them.

Even though it wasn't explored in this contest, the concept of biomimicry has the merit of having inspired the perspective through which the above-mentioned topic was investigated. With biomimicry, we mean the practice of looking to nature for ideas to solve problems in a regenerative way. For instance, the marine sponge, a complex system house of a rich micro-ecosystem, has the function of filtering the water it receives, retaining and metabolising foreign molecules. It is easy to think about theories as Urban Metabolism, Sponge Cities or Water Sensitive Cities. The same goes for Nature Based Solutions, which use vegetation, soil and ecosystems to restore the balance that our activities have altered. Nature has about 3.5 billion years of experience of imbalances, selection, adaptations and new balances. It would be foolish and arrogant of us not to look to it for answers to our problems.

The present research, therefore, investigates the relation between city and climate change. A methodology has been developed to make both theoretical and practical research as systematic and replicable as possible. Indeed, the systematic literature review has a structure made for been reproduced in further researchers and it has already been used and enhanced with colleagues. The effects of climate change on cities were explored, in particular the relationship between cities and water. It was discussed in depth how planning, urban resilience, cooperation and synergy between theories and practices could and should address the problem. Literature reviews have been carried out more specifically on the theories of Urban Water Metabolis, Water Sensitive Cities and Water Sensitive Urban Design.

The practical research, for its part, was also set up based on replicability. Practical solutions that cities can adopt to counteract the effects of climate change were investigated.

In the following phase, thirty-five case studies were collected, from all over the world, to report how did they react to a crisis situation with efficient, sustainable and operational solutions. Then, they were collected and evaluated trough a matrix set up to classify the practices according to their context, the problem faced and the characteristics of the solution. An abacus was created for the representation and sharing of these case studies. In conclusion, a database is proposed to encourage and facilitate the sharing of all the ideas and solutions adopted around the world.

This database is planned to be developed in the following semesters in collaboration with UNESCO-VIII, R3C and SDU.

The ultimate aim is to accelerate and enhance the cities' response to the water-related effects of climate change.

The ark must be built as soon as possible, and urban resilience can provide the tools for it.

1. METHODOLOGY

1.1 Topic and Objectives

The topic of the research is the resilient management of water resource in urban contexts. The resilience concept and few water management approaches will be analysed from a theoretical point of view to reduce the water disaster risk and the infrastructure impacts.

1.1.1 Topic of the research

The topic of the research is how climate change has influenced cities regarding water management. Primarily, it will delve deeper into how cities react to water stress, either excess or shortage, overflying measures experienced so far. As a first step, it will be necessary to define the concepts of resilience and urban system, understanding the latter's relationship with water and the role of resilience in this regard. The analysis will explore some approaches that can be useful to optimise water management, such as the Metabolic approach and Water sensitive planning, and a comparative analysis will be performed between these two approaches.

The scale of the research: The scale of this research is the urban context, without straight limitation related to the size of the city or demographic numbers, but referring more to the urbanism concept and giving priority to the quality of the practices adopted, considering different contexts in order especially for the practical analysis. The objective is, therefore, to start from a local scale to reflect on a global scale.

It will be spoken about the water system, meaning a river and all its tributaries, including reservoirs and mains, to store and supply water for use by a community.

Main water-related issues:
A well-planned urban water system can avoid some of the issues that more cities have to face every year, for instance, catastrophic events like floodings, seawater rise, heatwaves, droughts, and the correlated problematics.

Due to the recent and always more frequent global crises, handling the urban water management closely related to the resilience concept is even more urgent.

Re-thinking the water management
Water sensitive cities: the cities based on holistic management of the water cycle to deliver primary supply and sanitation services while mitigating flood risk and protecting and improving the environmental quality.

Urban metabolism: the urban metabolism is a model to facilitate the analysis and the evaluation of inputs and outputs passing through cities and their relation with urban infrastructure.

Resilience:
Resilience, according to Tollin (2020), is the ability of urban systems to address systemically and dynamically the causes and effects of major global challenges and crises: environmental, biological, geological and human-made hazards; un-just development patterns; unsustainable use of resources and negative externalities; rapid and unplanned urbanisation, climate change mitigation and adaptation.

We can define a city resilient if it can, together with all its socio-technical and ecological networks, resist and assimilate the changes and rapidly restore the required functions. An urban system can reach it, recovering from the effects of a hazard and quickly transforming its constituents that limit the present or future adaptive capacity (Meerow et al., 2016).

From research to action:
The thesis will collect the best practices, good policies, best solutions, and their effects. Eventually, through both theoretical and practical research, we will have the tools to arrive at action recommendations for cities in different geographic contexts.

1.1.2 Aim and objectives of the research

The research aims to investigate water management with resilient approaches in urban contexts. Approaching the topic, it appears necessary to examine the level of knowledge developed in the area, particularly to identify any in-depth fields or new issues that need to be explored in the field of water sensitive planning and urban metabolism.

The general objective is to contribute to cities' adaptation to global crises, water-related, theoretical skeletons, and a practical perspective.
The research wants to investigate and identify knowledge gaps in water management for urban resilience, specifically climate change, bridging theory and practice.

Specific objectives are:
Theory:

To advance in understanding how to re-think water management in the broad frame of urban resilience, through the comparative analysis of two main theoretical approaches: water sensitive cities and urban metabolism.

Practice:

There are numerous examples of resilient ways of managing water in the urban context. Therefore, another objective of the research will be to analyse and evaluate them according to a matrix built considering the city's characteristics, the country, the geography, and the features of the solution taken into analysis.

Evaluation analysis:

To transit from a theoretical to a practical level, the best solutions adopted worldwide to reduce the risk water-related will be collected, guaranteeing a higher quality of life to the citizen, in respect of nature. Indeed, the best practices of some cities can foster the sensibility and determination of others to follow the example, perhaps even expanding it.

Recommend to further integrate theoretical and practical knowledge to support urban resilience transition through integrated water management, defining key enabling/disabling factors (e.g. scale-up replication, integration).

1.1.3 Hypothesis and research questions

Theory:
The close relationship existing between water and the city has so far led to a positive balance only in favour of the city, with the result of immense quantities of water consumed and polluted every day. With the aggravation of problematics related to climate change, however, we now understand that not only do cities urgently need more and more water, but that water can also need cities.
It is in this delicate balance that urban resilience takes part. Through a strategic transition into resilient cities, urban systems can be the solution for this fundamental resource. Many theories postulate the recirculation

of water, cities planned in a water sensitive way, as if they were circuits from which water does not come out polluted by industrial towns and cleaner than it has entered. However, between these theories and the practice, there would seem to be a problematic gap.

Among these theories, there are two that can potentially fill the gap between theory and practice, thanks to their practical applications. These two theories are Urban Metabolism and Water Sensitive Planning, that this research will investigate.

Practice:
On the other hand, most of the world's practices do not seem to have a robust theoretical skeleton, but they seem to be born mainly to solve punctual problems without considering the general system. We believe that practices would be more effective and durable if built together with theory.

Evaluation:
The well-conducted water management planning can help to reduce the impact that cities have on our planet, think of water pollution and wastewater for instance, and at the same time can reduce the effects that climate change has on cities, as flooding or droughts. Furthermore, with the recent experience of pandemics, it is even more evident the importance of turning our cities in systems as resilient as possible not to be paralysed by unforeseen events. Indeed, trying to ensure each urban system with local solutions, as if it were an organism itself, would guarantee efficiency and sustainability more independent from external dynamics. Moreover, coordination between cities and encourage sharing their experiences can reduce the cost in terms of lives, quality of the environment and economy, and save time. This coordination and exchange of knowledge can be encouraged and facilitated with the systematisation of collecting best practices, through an evaluating matrix and a simplified database.

Research questions:

Theory:

- Cities are the main factors of problematics for water, but do they can also be the solution?
- Which role do resilience and planning play in all this?
- Is there a gap between theories and practice? Is there any theory that has the potential to fill this gap?
- Why can UM and WSP be considered with the right potential to do that?

Practice:

- How could practices be strengthened through theories?
- From the comparative analysis of WSP and UM, what can be applied to a practical level?
- Why choose Urban Metabolism?

Evaluation:

- What advantages does a city have from resilient management of the water resource? (With especial regard to the approaches of WSP and UM)
- What are the key enabling/disabling factors for best practices?
- What should we learn from other cities' examples?

This research is targeted to a mixed group of readership, from individual ,students to engineers, to decision-makers. In other words, to anyone interested in the topic.

1.2 Plan and phases

The present thesis is structured in the following phases: a theoretic phase, with literature review and analysis of theories; a practical phase, where the best practices will be collected and analysed; an evaluation phase, with the evaluation of the collected data.

The latter phase will see the conveyance of the previous stages in recommendations points.

1.2.1 Theoretic search

Using the defined keywords, assure to search for recent articles and peer-reviewed, and selecting 5 or 10 according to the number of citations and visibility. Through these articles' references, the network of sources will widen; however, it is crucial to do not deviate from the topic. From this data, it will be possible to start writing state of the art, and if it is necessary to review the methodology.
a) Expand the research to specific keywords and combination key words search on Scopus and select the most cited articles, or most recent
b) read and catalogue the articles and check the most relevant references within the article
c) read the articles reference in articles in b)
d) continue to write the state of the art
e) review the methodology, only if needed
(Does the research plan, developed in the previous phase, work well or need to be adapted?) (The previously defined categories and subcategories are appropriate? Do they need to be adapted?)

Water management

a) Literature review and state of the art
    i. Urban metabolism
        State of the art and literature review
    ii. Water sensitive planning
        State of the art and literature review

b) Comparative analysis
    i. Differences (features, objectives, methodology, approaches, and so on)
    ii. Similarities
    iii. Result of the comparative analysis

    Or (depending on the part a. of the research)
    i. Features (D&S)
    ii. Objectives (D&S)
    iii. Methodology (D&S)
    iv. Approaches (D&S)
    v. Result of the comparative analysis

Which information is missing and should be included in the research?
Have the results been presented and clearly explained?
Is the contribution of the research clearly communicated?
The analysis may include graphic representations to communicate the results better.
Are the graphic representations of the results incisive?

1.2.2 Practical search

(matrix, collection, and analysis of practices)

In this phase, a practical research of the best practices worldwide in water management will be conducted. Beyond the literature research previously conducted, to collect the required data, grey literature will be utilised, such as government reports, policy statements and issues papers, white papers, and so on.

a) The practices will be selected through the following criteria and features:
   i. water management intervention
   ii. the previous situation of risk or shock
   iii. involved a public space or at least with community effects
   iv. medium-long term practice

b) The best practices collected will be singularly analysed
   (What, where, why, how, who, when and how long is it expected to last, SWOT) (description, localisation, peculiarity, management, and maintenance)

c) The best practices will be stored in a matrix, to order them according to certain criteria.

Feature of the practice:

i. Size of intervention
ii. Level of integration with the context
iii. Level of multifunctionality of the project
iv. Type of "water" intervention
   (reduction of use, management of excess, management of scarcity, pollution, distribution and so on)

Features of the context:

v. Key enabling factors
   (technology, finance, governance, institution….)
vi. Climate change related
   (mitigation, adaptation, resilience (both))
vii. Size of urban system
   (small, medium, large…and so on ref OECD)
viii. Type of Climate change challenges
   (sub cluster in mitigation and adaptation, sustainable urbanisation Paris agreement)
ix. Type of DRR
   (vulnerability, risk exposure, hazards), (natural, climatic, human made)
x. Type of exposed elements
   (human capital, natural capital, physical capital, financial capital, social capital)
xi. Type of economy
   (developed, developing, transition), (ref GINI), ref "appropriate" technologies
xii. Type of related sector
   (transport, planning, housing, energy, industry…)
xiii. Type of "water" intervention
   (reduction of use, management of excess, management of scarcity, pollution, distribution and so on)

1.2.3 Evaluation analysis

(evaluation and/or comparative analysis of practices through theoretical frameworks)

At this stage of the research, it would be possible to evaluate the best practices collected through the developed matrix. Thanks to the theoretical framework, and in the light of the analysis of urban metabolism and water sensitive planning, a comparative analysis of all the practices will be conducted.

What are the most versatile practices?
Which are the most efficient practices in specific contexts?
Which have the least environmental impact?
Which practices have the best social impact?
Which have the lowest economic impact a high efficiency and therefore the most replicable in the South of the world?
Which practices guarantee total risk avoidance?

What is the key information we extracted from the search?
Which practices could be considered for our context?

1.2.4 Recommendations

- Consider the previous studies' contributions to the development of the present research.
- Analyses the theories and tools to be applied in practice.
- Collect best practices and understand what can be learnt from the cities example.
- Keep updated the methodology

1.3 Method and strategy

1.3.1 Theoretic search's method

For the purpose explained above, the research will be developed in two different stages.
For the first stage, describing the state of the art, the scientific research method is the most appropriate. Through a search in targeted databases, such as ScienceDirect, Scopus, Web of Science, it is possible to search for articles that meet previously established requirements.

Keywords

The keywords related to the topic, and found from a preliminary search, are "urban resilience", "water sensitive planning", "urban system and water", "sustainable urbanisation". To carry out coherent research and ensure that all the listed topics will be covered, the information obtained throughout the analysis will be divided into categories and sub-categories.

Boolean operators

The terms used for the first survey are "Urban resilience" and "Water sensitive planning" and "climate change adaptation" combined in the following way:
"Urban resilience" AND "water";
"Urban planning" AND "cities" AND "water";
"City planning" AND "water" AND "sustainability";
"Water sensitive planning" AND "Climate Change Adaptation".
From this cross-analysis will be selected only peer-reviewed articles, journal articles and of the last 10 years. Moreover, it is possible to apply a further selection among the articles excluding the disciplines not related to the research.
Concerning these sorting criteria, it is necessary to make sure that the citation categorisation system is reliable.
Through the abstracts and keywords of the selected articles, it is possible to sort the articles strictly related

to water sensitive planning.
Once selected the articles with more citations, found through keywords and verified by a quick skimming with keywords and abstracts, it's the time to read them.
Other topics, related to water sensitive planning, will be identified, and the collected data are stored with the categories and sub-categories listed in point 2.
In this way, it will be making sure that the analysis is covering the prefixed topics.

Tools and software

To search the articles, the most reliable and effective platform are:

-Scopus
-ResearchGate
-ScienceDirect
-Access Science
-ProQuest
-Web of Science

For collecting, cataloguing, and evaluating the references has been used Mendeley. The articles are added on the software from Scopus or ScienceDirect, and they have stored the different references in groups.

(Graphic elaboration, Data evaluations, GIS)

1.3.2 Practical search's method

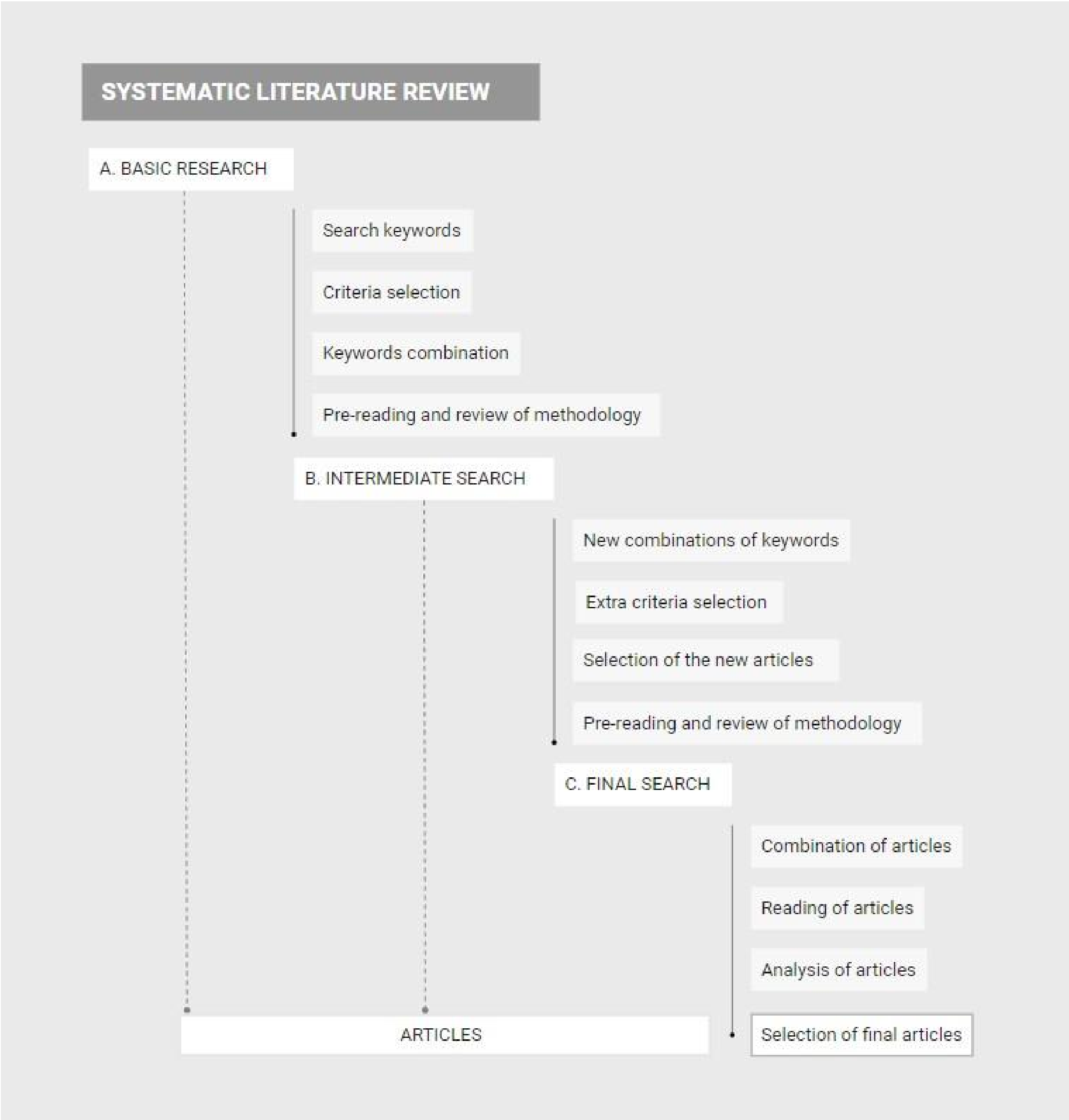
- Matrix
- Database and Abacus

The second stage of the research, passing from a theoretical to a practical level, foresees the collection of best practices worldwide regarding what explained above. These examples of best practices will be analysed and evaluated through a matrix, considering the many characteristics of the city and the solution adopted.

This second stage of the research, to arrive to a practical level, includes investigations through grey literature and different sources to collect information regarding the worldwide policies and good practices. Furthermore, case studies from all over the world are going to be collected.
Part of the research will focus on Copenhagen to analyse a local application of good practices in water management.
For this stage of the research, it will be necessary also to take 5 or 10 interviews to stakeholders and policy makers who have taken part in Copenhagen's transition and, if it is possible, field analysis will also represent a consistent part of this stage's study.

1.4 Methodology for Urban Metabolism

A preliminary reading of sources will define the topic, Urban Metabolism.
The definition of the research's aim will take place at this initial stage, although it is necessary to review it throughout the process, being cautious to remain faithful to the topic.



1.4.1 Topic and context of the research

I. Topic

The present paper will examine the concept of Urban Metabolism in the sense of an urban system as living organisms. Like an organism, the urban system needs the input of resources to stay alive and these resources, passing through the system, are transformed, and then discarded as different types of waste.

The flows into and out of an urban system need to be accounted and assessed to analyse the interactions of human systems with nature. According to the definition given by Kennedy in 2007, Urban Metabolism is "the sum total of the technical and socio-economic process that occur in cities, resulting in growth, production of energy and elimination of waste", to be analysed "in terms of four fundamental flows or cycles – those of water, materials, energy, and nutrients". (Kennedy, Cuddihy et al. 2007)

The urban metabolism's analysis can thereby be an effective way to obtain information regarding the quality and the dynamics of a urban ecosystems. Indeed, the problems of large metabolic throughput, low metabolic efficiency, and disordered metabolic processes are a major cause of unhealthy urban systems. Furthermore, there are different methods to account for and evaluating material and energy flows in urban metabolic processes. An attempt will be made to shed light also on the different methodologies and practical applications of urban metabolism analysis.

Hence, Urban Metabolism is a concept that helps to analyse and optimise urban efficiency.
The state of the art will provide the knowledge on the subsequent categories: the flows metabolism, the social-economic metabolism, urban planning and policies. The first, flows metabolism, comprises water metabolism, energy metabolism, materials and food stocks. Social-economic metabolism constitutes the dynamics that regard/constitute human health, social needs, circular economy, and so on. The urban planning and policies regard the measures, policies and dynamics that make a transition possible.

II. Frame of the researchThis research has been stimulated in the frame of the UNESCO's researches made by the Intergovernmental Hydrological Programme (IHP), in the areas of "Water and human settlements of the future".

The overall objective is to investigate integrated management approaches that can help in the urban transition. This comprises five activities: integrated urban water management, urban metabolism, flexible and adaptive approaches, water sensitive urban design and transitioning (UNESCO, 2019).

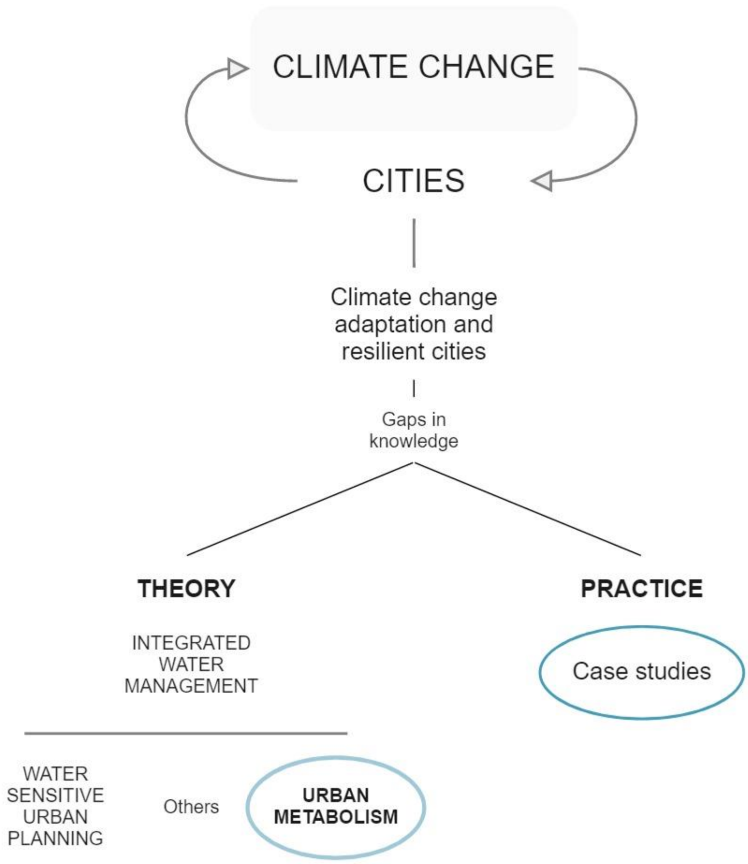


Figure 1 Frame of the research

1.4.2 Aim and purpose of the research

I. Hypothesis

The urban metabolism can provide an effective way of optimising an urban system, meaning water management, energy efficiency, waste management, recycling of materials, and so on. Indeed, accounting the inputs of water, energy, food, and other materials, and accounting the system's outputs helps to scan and understand the characteristic of the system. The hypothesis of this research is that increasing the level of knowledge on the metabolic dynamics of cities might prepare the base for a better climate change adaptation. In addition, the standardisation of the investigation method and approach on urban metabolism can facilitate the comparison between cities' analysis, favouring the collaborative network.

II. Research questions

- How can urban metabolism contribute to optimising a urban system, with all the inherent dynamics?
- Which are the gaps in knowledge and potential field to
- Case studies (Where What What's relevant)
- How urban water metabolism approach can be useful to cope with global challenges

III. Goals

The specific objective is to conduct comparative studies of urban metabolism models with significance to urban water management and potential applicability.
Approaching the urban metabolism's topic, it appears necessary to examine the level of knowledge that has been developed in this area, to identify any in-depth fields or new issues that need be explored.
The purpose of this analysis is to obtain, through the search and review of articles in scientific databases, a comprehensive state of the art about the urban metabolism.
Further ambition is to understand how the urban metabolism approach can be useful to cope with the global challenges and to help cities in climate change adaptation.
The effort of this study is also to provide useful information and knowledge for subsequent state-of-the-art investigations or further studies.

IV. Boundaries and limits

This research will focus on urban metabolism from the water management point of view.
Consequently, the topics related to urban metabolism in general will be discussed introducing the application to water, but they will not be addressed individually.
Thus, there may occur references to circular economy, urban metabolism about energy, society, food, and others. Specific literary references will be indicated to facilitate eventual insights in those regards.
We may talk about urban metabolism as means to spot urban inequalities in the access to resources and services, but we will not go into detail.

1.4.3 Method design

I. Methodology

For the purpose explained above, the scientific method of research is the most appropriate. Through a search in targeted databases, such as ScienceDirect, Scopus, Web of Science, it is possible to search for articles that meet previously established requirements.
The keywords related to the topic, and found from a preliminary search, are "urban metabolism", "circular urban metabolism", "urban water flows", "input-output analysis". In order to carry out a coherent search and to ensure that all the listed topics will be covered, the information obtained throughout the analysis will be divided in categories and sub-categories.

The terms used for the first survey are "Urban metabolism", "Circular urban metabolism", combined in the following way: "circular" AND "urban" AND "metabolism"; "circular" AND "urban metabolism"; "water" AND "urban metabolism". From this cross-analysis will be selected only peer-reviewed articles, journal articles and of the last 10 years. Moreover, it is possible to apply a further selection among the articles excluding the disciplines not related to the research.
Concerning this sorting criteria, attention will be paid that the citation categorisation system is reliable.
Through the abstracts and keywords of the first survey articles, will be sorted the articles strictly related to the topic of urban metabolism.
The articles on relevant topics, but overly general, will be discarded, such as climate change,

sustainability, resilience. Once selected the articles with more citations, found through keywords and verified by a quick evaluation with keywords and abstracts, it will be proceed reading and studying them. Other topics related to urban metabolism will be identified, and the information will be collected with the categories and sub-categories listed in point 2.
As such, it will be ensured all topics will be addressed.

II. Tools/software

For collecting, cataloguing, and evaluating the references has been used Endnote, Mendeley, New RefWorks (...). To search the articles the most reliable and effective platform are:
-Scopus
-ResearchGate
-ScienceDirect
-Access Science
-ProQuest
-Web of Science

1.4.4 Plan and phases

I. Basic search

Using the defined keywords, assure to search for recent articles and peer reviewed, and selecting 5 or 10 according to the number of citations and visibility. Through the references of these articles, the network of sources will widen, however it is important to do not deviate from the topic. With this base of sources, it will be possible to start writing the state of the art, and if it is necessary to keep update the methodology.

II. Full search

The reading, data extraction and analysis will lead to the drafting of the state of the art on Urban Metabolism. The comparison between the articles will allow to develop a critical opinion, required to build the next analysis.
Through the definitions and information obtained, the previously defined categories will be reviewed, and the methodology will be updated.

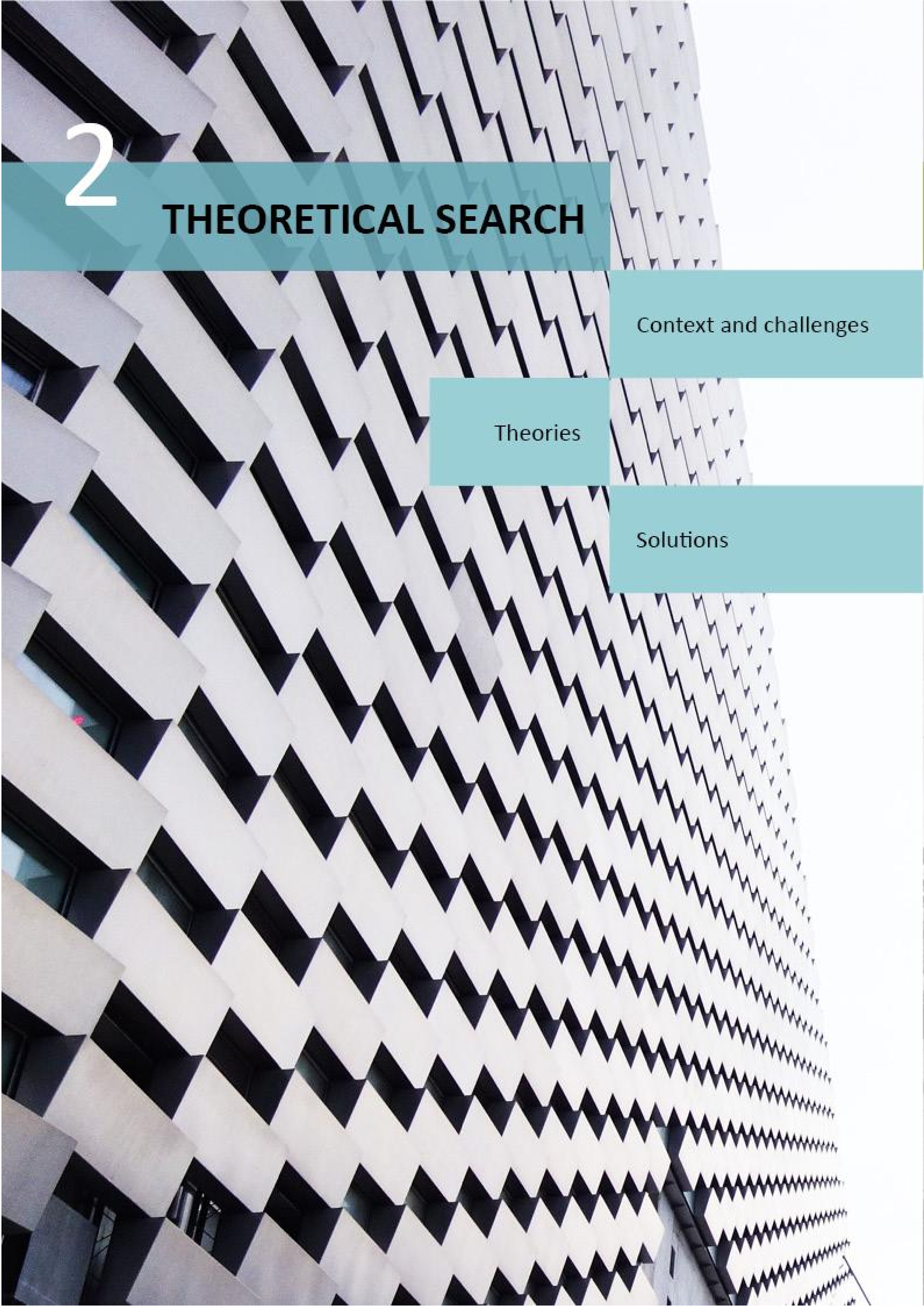
III. Full analysis

Deepen the topics on which the research is intended to focus through a more focused investigation.
At this point, the results of both the more general and the more systematic survey will be systematised. The graphic representation of the results is equally important. It will be necessary to give importance to the connection between the topics addressed, giving importance to the hierarchies and the influences between them. Categories and sub-categories should be clearly defined and should help in the comprehension. The graphic representation of the relations between theoretical and practical concepts is fundamental.

1.5 Conclusions

Check questions

What is the key information and how this fit the purpose of the state of the art?
Which information are missing and should be included in the review?
Have the results been presented and clearly defined?
Is the contribution of the review clearly exposed?
Are the graphic representations of the results communicative and incisive?



2 THEORETICAL SEARCH

Context and challenges

Theories

Solutions

WATER MANAGEMENT IN RESILIENT CITIES

2.1 State of the Art

Human activities have caused, in the last few centuries and especially in the last one, considerable environmental imbalances all over the planet, the consequences of which we see today with increasing frequency. Since the Brundtland Report *Our Common Future* in 1987, studies and research in the field of climate change have increased exponentially. Experts agree that climate change, scientifically proven to be linked to human activities, is responsible for considerable damages worldwide.

Moreover, special Report of the Intergovernmental Panel on Climate Change reports that the frequency of heavy rainfall is likely to increase in the 21st century in many areas of the globe (Field, 2012).

Climate change's effects on the planet are nowadays widely investigated from all points of view. Several studies are going on from the biological, economic and social perspective. The investigation on the health impact has been extensively developed in the last years, and considerable funds are being invested in sustainable energy and industry as well.

From the urban studies perspective, though, even if the material and data are increasing, there are still many items to investigate, especially considering that half of the population lives nowadays in urban realities. Indeed, even if cities are the main responsible for climate change, for this they can also represent the solution, or at least the best compromise for the moment, to the consequences that climate change brings.

As Voskamp and Van de Ven (2015) have highlighted, urban systems are highly susceptible to climate change consequences, as extreme precipitation events, heatwaves and drought, both because of the demographic concentration they have, more than 50%, both because of the related physical concentration of buildings and socio-economic activities related.

The particularity and main complexity of the challenge is that problematic to face is rarely only one: more commonly the extreme events are different and can often also be unexpectedly close in time.

Few studies have been investigating solutions and strategies for adaptation and preparedness to multiple climatic risks (Voskamp and Van de Ven, 2015). An integrated and interdisciplinary perspective is essential to address this kind of multiple hazards, and to develop the resilience of the urban systems (Fratini et al., 2012).

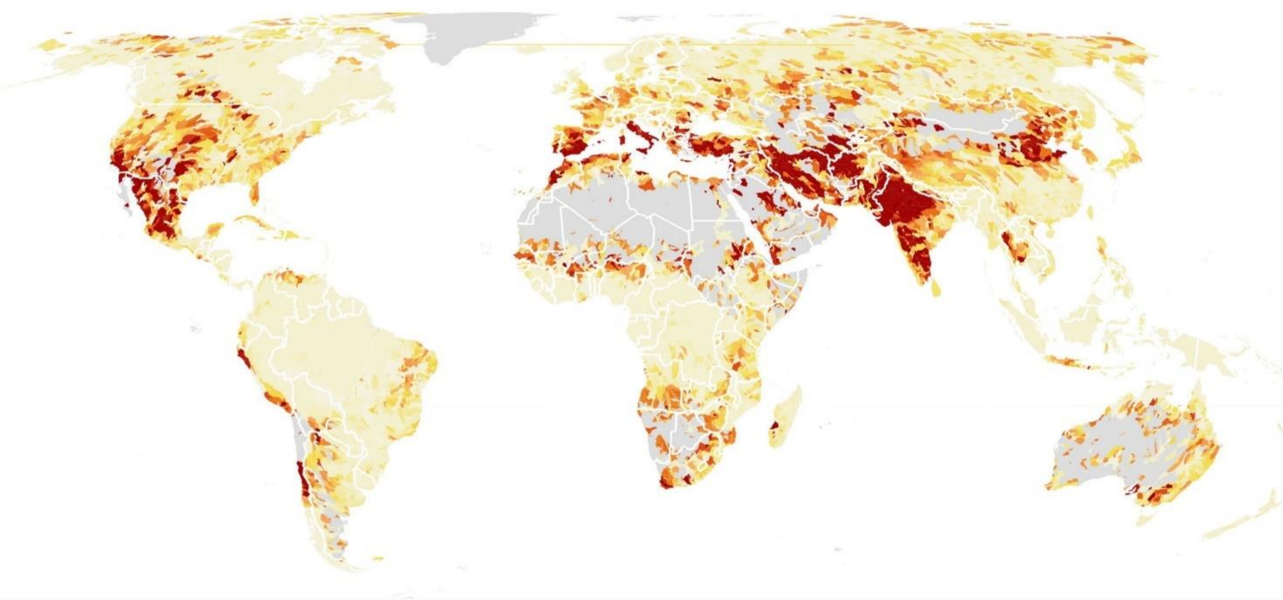
The increasing exposition of urban systems to climate change hazards increases the urgency of improving urban resilience (Pickett et al., 2004), implementing traditional grey infrastructures with green and blue adaptation measures, which are noted to be more flexibles and sustainable and multi-functional than the grey ones. Indeed, more natural solutions are likely to handle nature stresses in a self-adaptive way and bring several co-benefits. Green urban infrastructure is intended as the network of urban green spaces, not covering the urban water network, even though green and blue infrastructure are tightly connected. Voskamp and Van de Ven (2015) concentrated on the integration's importance of blue and green infrastructures since blue infrastructures address not only water supply but also environmental and human health benefits.

2.2 Context

2.2.1 Urban systems and water

It is no coincidence that all the first human settlements, since prehistoric times, arose near water sources. Since urban architectures have become more complex, however, emigration to seek water has become more difficult. Hydraulic interventions, aqueducts, dams, have been present for thousands of years. However, since society has changed, with industrialisation and exponential population growth, water demand has grown exponentially, and the alterations in the water cycle have become much more impactful.

Cities are complex systems where individuals and society interact with the natural environment and the built environment, thereby considering social, economic, environmental, and engineering issues in a systemic manner.
Within a few decades, most of the global population will live in cities (70% by 2050), (UN DESA, 2015).
Worldwide, cities are growing in size and, for the maintenance of normal vital functions, they need more and more energy, consume even more resources, and produce even larger quantities of waste.
This densification of society in cities brings several impacts on the environment, but above all on water. The central problematic is that cities not only demand a massive amount of water, but also that they demand the provision of many other services in the same intense manner.
In the following maps, is represented the areas worldwide that are already looming water crises.



Map 1 Countries looming water crises
Source: https://www.nytimes.com/interactive/2019/08/06/climate/world-water-stress.html

2.2.2 Water

Since the awareness of the limited resources has grown, the concern for water availability has become increasingly severe all over the world. According to UNESCO (2013), approximately 2,53 per cent of total water in the Earth is freshwater, and its primary source is rainfall water that has an annual global average of 110.000 km^3 but, only 40.000 km^3 remains in rivers and aquifers and, only between 12.500 km^3 and 15.000 km^3 are available for human use. It means that only 0.007 per cent of the planet's water is available to feed people.

Moreover, the current global population of 7,6 billion people (World Bank, 2019) is pressuring freshwater resources in urban and rural areas, although the central problematics are urban related. The continuous growth is increasing the demands and according to UN-Habitat (2009) the urban population is expected to reach by 2050 more than 70%.

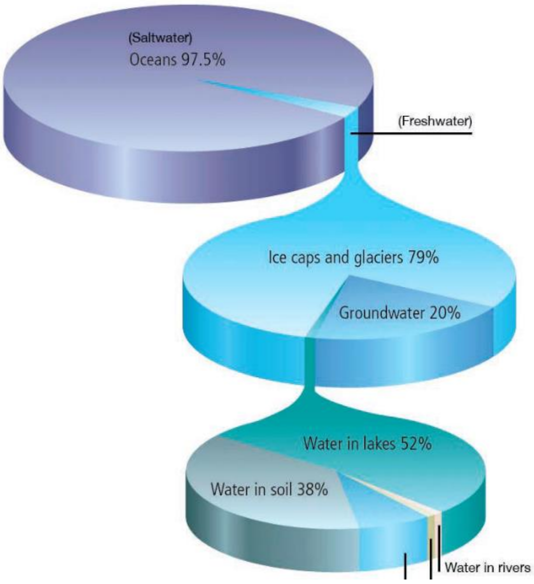


Figure 2 Distribution of Earth's water by type and form (World Bank Graphic)

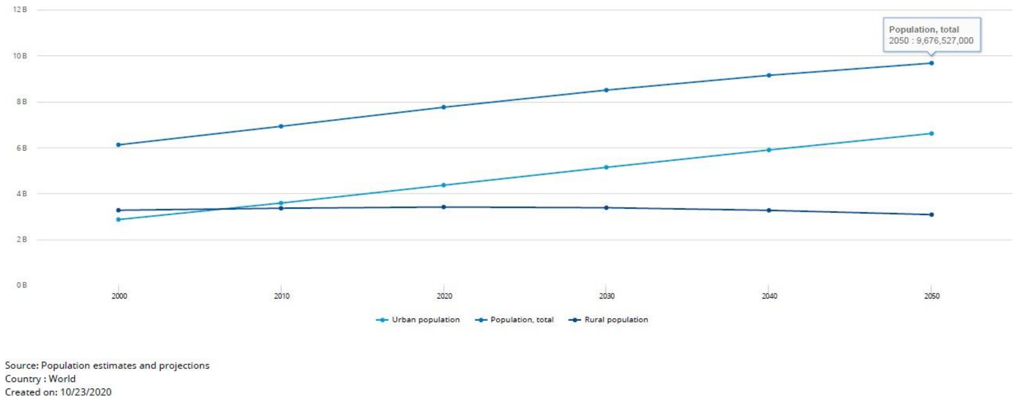


Figure 3 Urban, Rural and Total population 2000-2050
Source: World Bank 2020

Therefore, cities are looking for solutions to ensure the water needs of citizens and systems. It seeks for new water sources up-stream and attempts have been made to manipulate the freshwater hydrological cycle, with consequences to vital ecosystem services, such as biodiversity, food production, and health security.

Different to many natural resources, water is a renewable resource. This renewability occurs through the perfect balance, if untouched, hydrological cycle.

The disciplines that study the hydrological cycle are Hydrology, Applied Hydrology and related ones. In the figure below, there is a map to clarify the fields of the cited disciplines.

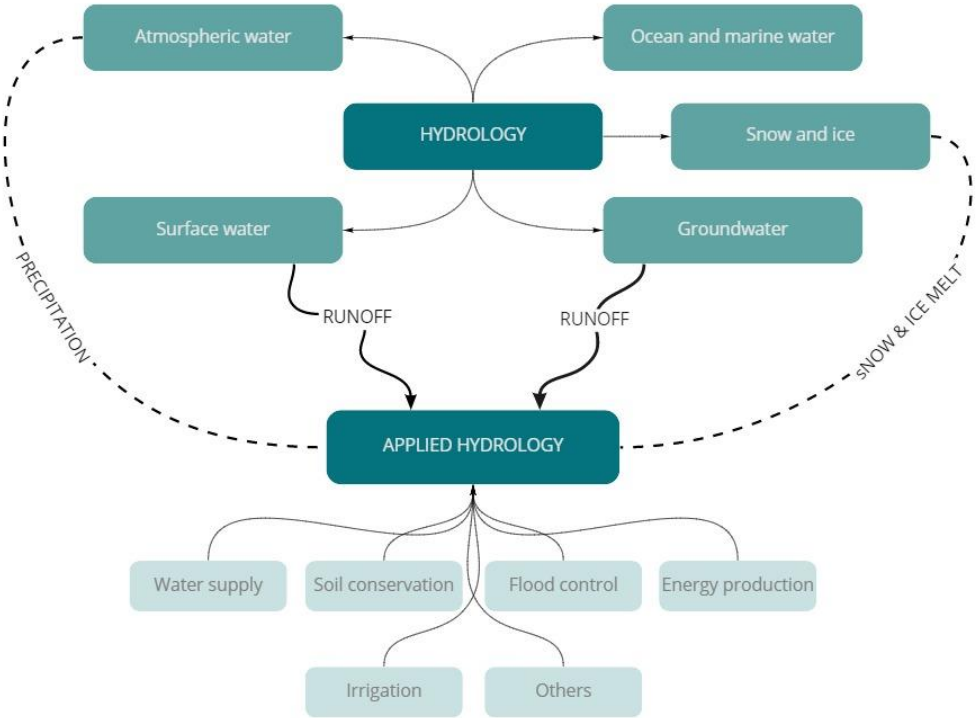


Figure 4 Hydrology and Applied Hydrology
Source: Personal elaboration

Water demand is addressed from the hinterland, from a greater or lesser extensive area. A watershed refers to the land drained by an interconnected system of rivulets, streams, rivers, lakes, and groundwater up to a certain point of outflow (Encyclopedia of Science, 2020).

The related terms catchment and drainage basin refer to the total area of land that drains into a water body. Watersheds receive the contribution of rain and snow too, and they are directly connected with water quality and the intensity of floodings.

Nevertheless, considering the magnitude, the demand for urban water is hardly solved by the natural watershed and aqueducts and pipelines transport water over very long distances. For example, Los Angeles Aqueduct has a total length of 674 km, throughout desert lands.

The excessive water harvesting alters groundwater flow. Groundwater generally moves from recharge areas, where water enters the soil, to discharge areas, where it spills out from the ground into a wetland, river, lake, or ocean. The water quality depends on the groundwater flow, and consequently, all the ecosystems that rely on that.

Aquifer means a saturated area that holds enough water to produce significant amounts of water when a well is drilled. The zone is made of porous or permeable material through which substantial quantities of water flow. Extracting too much water from an aquifer can lead to the risk of not merely drought, rather incurring in cases of soil collapse, which we will investigate later.

The water that runs over the surface is defined runoff. In particular, runoff is referred to the flows made of that amount of rainwater that exceeded the soil's infiltration capacity. Excessive soil permeability can increase the runoff, causing floodings and other problematics for ecosystems and urban systems.

In the following paragraphs, we will analyses how urban system's activities can alter the hydrological cycle.

2.3 Challenges and hazards

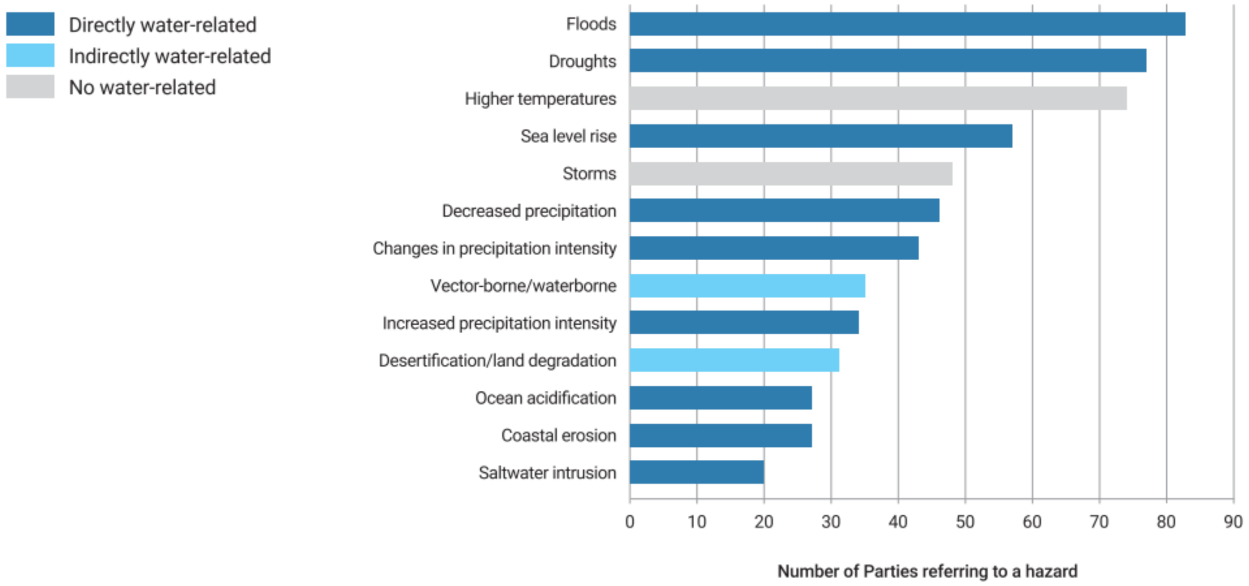


Figure 5 Key climate hazards identified in the adaptation component of the communicated INDCs
Source: (UNESCO, 2020)

2.3.1 Global dynamics and challenges

Besides satisfying our basic needs, water is essential for all our activities: agriculture, industry, energy and so on. All the clothes we wear, the tools we use, the medicines we take, everything needs water to be produced and get to our homes. For these processes, water is used, consumed, polluted, and wasted.

Societies, since the discovery of agriculture, have modified watercourses, collected water, used the resource for their purposes. However, since the industrial revolution happened and started the exponential population growth, their impact on water has become more considerable and problematic. If there is any variation in the water cycle, the consequences are more significant than expected.

Mainly, cities affect water as a resource in terms of its quality and availability, they pollute it, and they modify its spatial distribution by gathering immense quantities in different ways. Urban settlements are minimal areas demanding vast amounts of water of good quality, and where large quantities of polluted water are discharged. It is sporadic, if not impossible, for the natural environment to provide for both requirements of cities: water supply and wastewater treatment. The modification of the natural water cycle by cities has led to developing the urban water cycle concept.

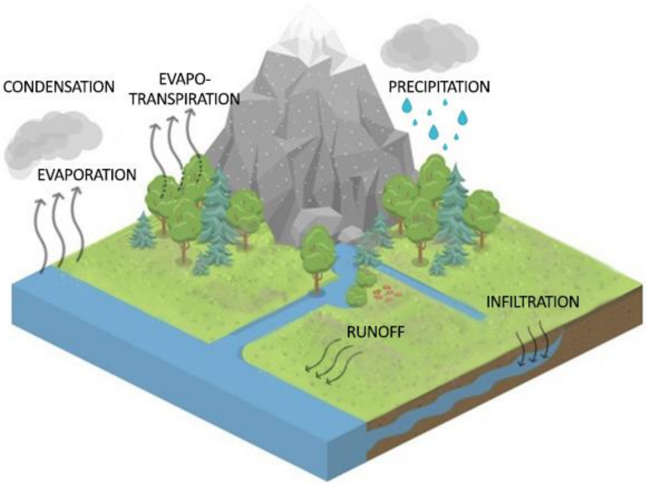


Figure 6 Hydrological cycle
Source: Personal elaboration

The main impacts that human activities can have on the hydrological cycle and on water are represented in the figures below.

Namely: acid rain, alteration in the intensity and frequency of precipitations, less evapotranspiration due to deforestation, more evaporation due to the rise of the temperatures, more runoff due to the impermeabilised soil and general pollution.

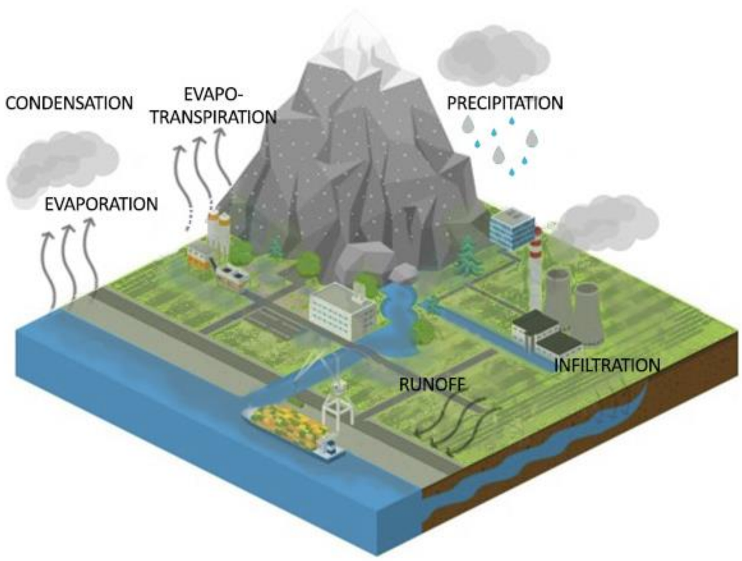


Figure 7 Modification of the Hydrological Cycle by cities (Urban Water Cycle)
Source: Personal elaboratio

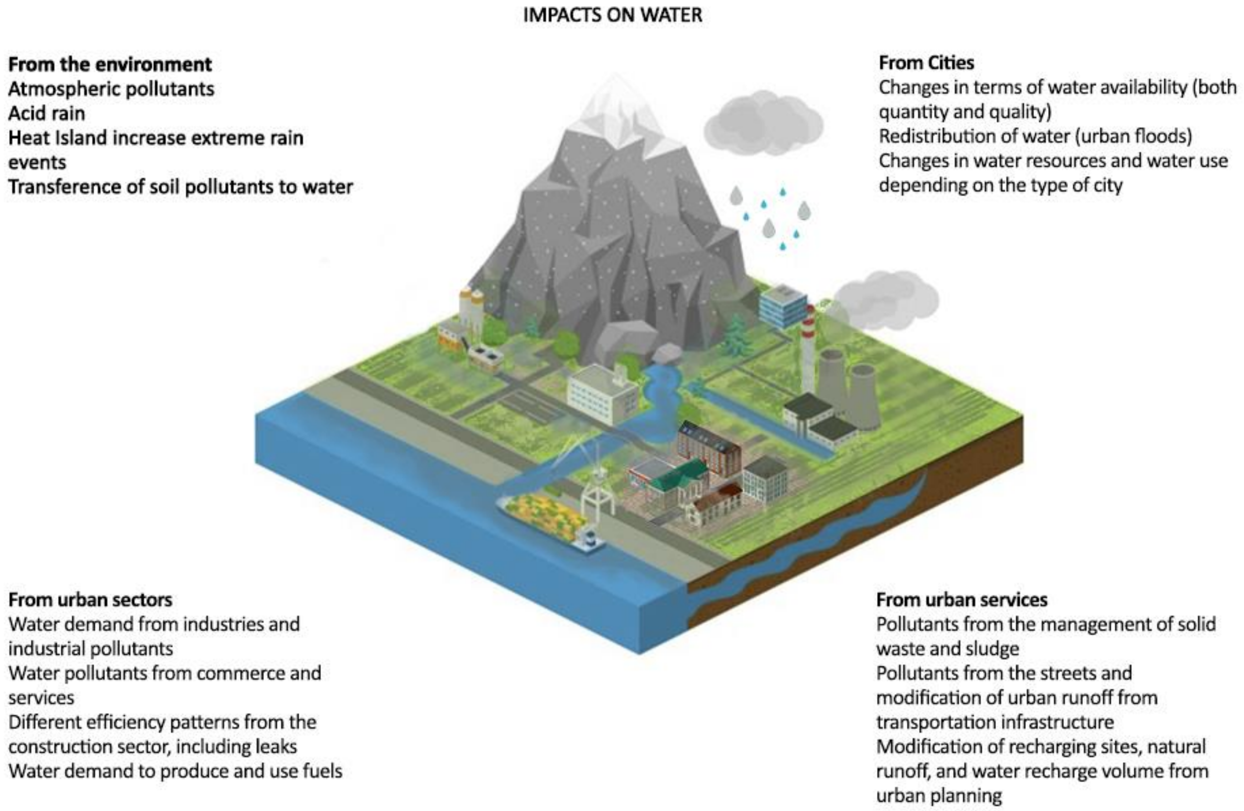


Figure 8 Urban Water Cycle impacts.
Source: Personal elaboration, inspired to: (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019)

"There is too much, too little, or too polluted".

There are some water challenges that the entire world has to face without distinctions of continent, income, or climate-zone. The rise of temperatures affects North to South, melting the ice and turning fertile soils in desertic lands. The sea-level rise is letting disappearing entire archipelagos, salinising coastal fields and putting in danger many cities. Catastrophic events, like hurricanes, typhoons, cyclones and tornados, are improving in their intensity and frequency. Nowadays, heatwaves do not affect only warm areas, but Nordic countries are also experiencing every searing summer temperature, breaking the records every year.

In the graphic below, can be observed the impacts attributed to climate change. The observed impacts are attributed to climate change for physical systems, like glaciers, snow, ice and permafrost; rivers, lakes, floods and drought; coastal erosion and sea-level effects. Impacts on biological systems, as terrestrial ecosystems, wildfire and marine ecosystems. Impacts on human and managed systems, as food production, livelihoods, health and economics.

It is easy to notice that the impacts are all over the world, any area exempted, which makes the challenge global.

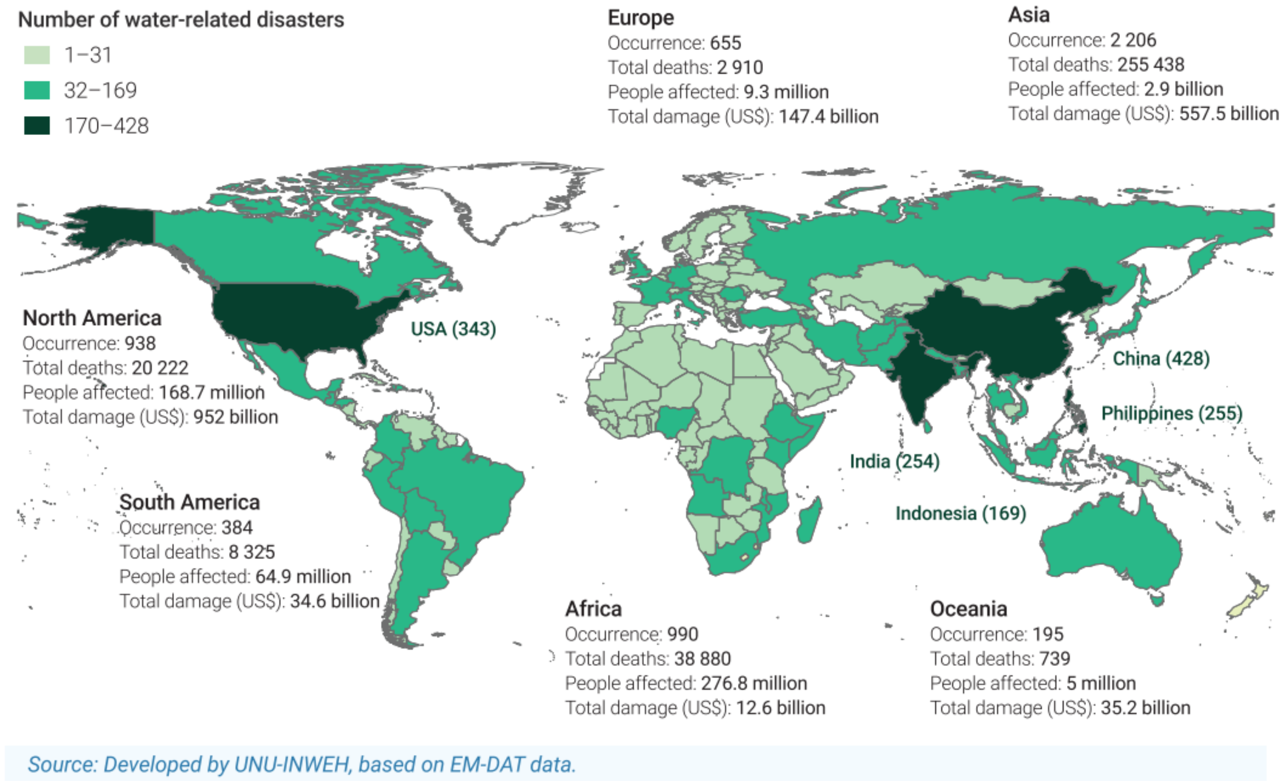


Figure 9 Spatial distribution of water-related disasters (droughts, floods, landslides and storms), 2001–2018
Source: (UNESCO, 2020)

2.3.2 Population Growth

We live in a transition era, the so-called "Anthropocene", and we live the great acceleration period of it. There are several methods of tracking the effects of human activity on the Earth, utilising parameters of population, economics, water demand, food production, transportation technology, pollutants, temperature, and natural resource usage. Since the sensibilisation on the thematic has led to the first data analysis, around the 50', all the parameters show the trend is drastically, or even exponentially, increasing.

The situation is already critical, but we also have to consider that the world population, now 7.6 billion, is forecast to increase to 8.6 billion in 2030, 9.8 billion in 2050 and 11.2 billion in 2100 (United Nations, 2017). The world's population increased around 5,18 and 10 times for agricultural, industrial, and municipal use, respectively. A rise in the world population and its living standards, along with unsustainable practices, has put water resources under ever-increasing pressure (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

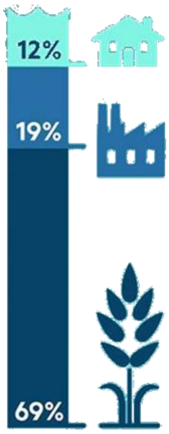
Nevertheless, it is not only a matter of numbers but also and mostly matter of how much water we consume compared to how much we would really need. According to Twente Enschede University study, an average consumer's water footprint is of 1385 m^3, with oscillation between a US's consumer with 2842 m^3 and a China's consumer with 1071 m^3 (Ibid.).

2.3.3 Climate Variability and Change

The threats water-related are significantly exacerbated by the variability and changes of the climate. Recent research shows that 2°C of global warming will lead to a severe decrease in water availability for about 15% of the global population, and it will raise the percentage of people living under absolute water scarcity by another 40% compared to the effect of population growth alone.

Many studies prove that the rise of temperatures can cause an increase in water use and aggressive abstraction, for example, for more irrigation or air conditioners, which will put additional pressure on the already scarce water quantity. Climate change will inevitably lead to a reduction of groundwater recharge to aquifers, storage and discharge. This will bring many other adverse effects related to ecosystems and services' massive dependency on groundwater, with consequences to ecosystems and human systems. Furthermore, it must also be considered the sea level rise, that in the case of the coastal aquifer will cause contamination of freshwater with saltwater, with loss of soil quality and desertification phenomena (Ibid.).

2.3.4 Agriculture



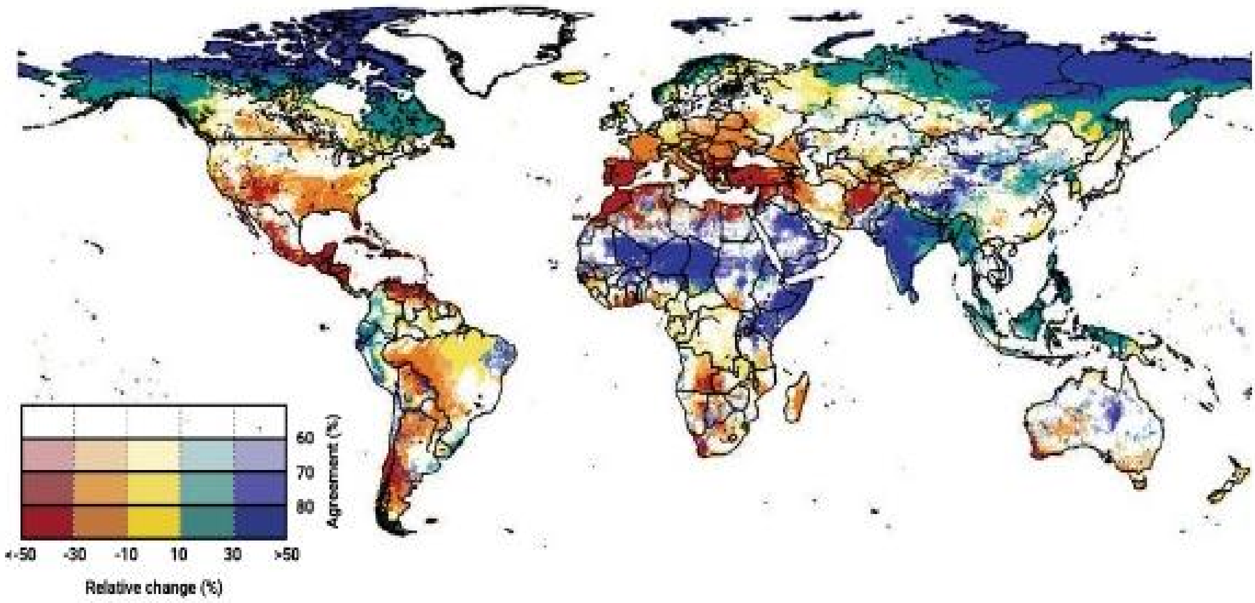
The main responsibility in the use and consumption of water is agriculture. Considering water abstraction, irrigation, and the water used for treatment, agriculture represents about 70% of water's global use. The abstraction of water for irrigation uses in developing countries is estimated to rise to about 14%. Water is not only used for producing crops but to manufacture food as well. In Europe, for instance, food production requires, on average, about *5* m^3 of water per person per day for the manufacturing of food products. In the meantime, almost 250 km3 of water is lost every year because of food wasted, which is around 1.3 billion tonnes of food wasted per year (Ibid.). With food waste we mean the discarding of food that was still good for human consumption but has become spoiled, out of date or just unwanted. Worldwide, the percentage of cereals waste is of 13.4%, while the meat waste's percentage is about 21.7% (Ibid.).

2.4 Local water challenges:

2.4.1 Water Availability:

Urban utilities may be affected by variations in water availability due to increases or decreases in precipitation, increases or decreases in temperature, rising sea levels and increased climate variability. However, the main cause of changes in urban supply is given by causes attributable to the cities themselves. Cities all over the world, with their exponential demand for water, change the availability of the resource in terms of accessibility, distribution and quality, creating great competition for it. The increasing impermeabilisation of soil, typical of urban areas, also reduces the natural recharge of underground aquifers, increasing runoff, the superficial flows of water. By extracting large quantities of water for urban needs, flows into rivers are reduced, which often become insufficient in relation to minimum environmental flow requirements. Extracting large quantities of water can also lead to soil instability, and cases of collapse are frequent (Ibid.).

The first victims of these changes are ecosystems. According to WWF 2016, between 1970 and 2012 there is been a loss of about 80% of vertebrate populations of freshwater habitats. The percentage of freshwater vertebrates is collapsed of 4% per year, at a speed that is more than twice as fast as the one observed in land and marine populations (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).



Map 2 Climate change scenario trends in water availability with a 2°C temperature increase.
Source: (UNESCO, 2020)

2.4.2 Changes on the runoff

As introduced above, urbanisation has led to a considerable increase in waterproofed surfaces. Moreover, deforestation and intensive monocultures have considerably changed the landscapes around cities. This leads to a decrease of the natural infiltration of pluvial water, the consequent decrease in the recharge of the underground aquifers as previously mentioned, and large amounts of water flowing to the surface creating potential damage. Indeed, a common problem that cities have to face are floodings, which are independent of the climatic, economic and geographical conditions but mostly depending on urban planning. Cities are often flooded because of their location, being close to a coastal area, next to a river or being located on a flat area (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

In addition to waterproofing, deforestation and other factors attributable to cities that alter the runoff, it should also be reported that the change in temperatures (urban temperature's increase can be up to 10°C) and climate change are increasing the strength and frequency of extreme rain, as we can sadly notice daily.

These changes do not affect only from a hydrological point of view: consequences may occur in the energy sector, in transports both land and air, compromise fresh water supplies and sewage systems, increasing also the vulnerability to waterborne pathogens. Particularly vulnerable in these situations is the low-income population, who frequently, in addition to not living in safe housing, occupy areas more exposed to hydrogeological risks (Ibid.).

2.4.3 Urban floods

One of the main hazards to which cities are exposed to is urban floods. The causes of floodings can be intense or prolonged rainfall events, rapid snow melt, rapid discharge for collapsing of dams, barriers or locks, and many others. The unusual water quantities overwhelm the capacity of the drainage systems and they can reach considerable velocity and strength, carrying with them material of different nature – mud, rocks but also rubbles, cars and whatever they cross on the way. These events occur very quickly, indeed their speed and temporary scale can be a matter of minutes. Floodings do not occur only in cities but are in urban settings that they have more impacts due to the population density and exposition of infrastructure. Moreover, the factors previously exposed raise the risk level of urban systems, as the urban pluvial flood risk increased by the heat islands and so on. Indeed, all these hazards must my handled in parallel because they often occur in synergy, or in synergy, they create the ground for another one. It can sound diabolic but is the magnificent inter combination of natural cycles and it should be humans interest do not interfere too much with those, or at least doing it with a good plan that considers all the rings of the chain.

2.4.4 Urban land planning impacts

The exponential increase of urban water demand encourages, or requires, land-use changes in the neighbouring areas to ensure cities water supplies, storage, and conveyance corridors. These changes often have severe negative impacts on the environment, but also local societies and economics.

This is happening since millenniums, think about ancient Romans with their aqueducts or Nabataeans with their sophisticated water technologies. With climate change and the demographic growth, however, the problematics connected with urban water demand are exacerbated. The availability of water can prescribe where or where not use the land and provision of water and wastewater treatment and disposal can deeply influence the future of our cities (Omojola et al., 2011).

The examples of land use for water supplies porpoises are several, for instance, California was running out of water and, with massive privatisation of land, a proper water industry was build-up, with all the negative points that privatisation and financialisation of the resource can have.

"Land use of land determines the areas reserved to store water or where its infiltration can occur, and the extent of the imperviousness of the urban soil. Green or forested areas near or within cities act as buffer zones and allow groundwater recharge. Furthermore, according to the land use, the heat island effect may be induced or controlled" (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

2.4.5 Water Scarcity

As the demand for water increases, alternatives are being sought and hydraulic interventions for retention, rerouting or direct use, are being added to climate change's issues. It is estimated that by 2050, 40% of the world's population will live in river basins suffering from serious water stress. Currently, already 450 million people are suffering from water shortages, and by 2050 the additional three billion people on the planet will require about 20% of water more. The water challenges must be considered for the food scarcity too, it will be the primary cause, even before land scarcity, according to UN (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

2.4.6 Water Quality

As a result of the pressure for additional water sources, as previously said related to the demographic growth and the rising of living standards, human activities have increased the number of contaminants and pollutants spread in groundwater and aquifers. The consequences related to that are numerous and different, from a significant decline in water availability and water quality to massive environmental changes.

Rivers and lakes worldwide are polluted, and many main rivers do not flow to the sea for many months per year due to unregulated abstraction (Ibid.)

Coastal aquifers are exposed to a negative water balance, as mentioned above, connected to the excess in utilisation that causes contamination with salt water. Improper or inefficient waste management often ends up in hydrological contamination, releasing pollutants related to noxious compounds, discharging big quantities of fertilisers and wastewater treatment plants products. Chemical fertilisers and pesticides are affecting water quality through infiltration in groundwater aquifers or through runoff (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

These challenges are increasing the cost of water treatment and are dramatically exacerbating socio-political tensions related to the availability of water. Avoiding and managing the competition over water control is every year more challenging, complex, and yet needed (Ibid.).

Moreover, climate change is playing a heavy role in spoliating water quality, even if a comprehensive understanding of the impact is still missing. Nevertheless, experts concur on the necessity of planning and organising responses to climate change to avoid significant water quality issues (Ibid.).

According to the WHO, 844 million people still lacked even a basic drinking water service and 2.3 billion citizen still lacked even a basic sanitation service (WHO/UNICEF, 2017).

All over the world, the quality of water sources is rapidly deteriorating pollutants produced by cities are contaminating surface water bodies and aquifers. Indeed, wastewater, both treated and non-treated, is often discharged in surface water bodies and too often environmental policies and sanctions are not sufficiently strict. Agricultural and industrial compart are first causes of water pollution, but also sewers and storing tanks leaks play their role in it (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

Fortunately, however, technical monitoring and control solutions are becoming increasingly efficient and sustainable.

2.4.7 Water-Related Hazards

Water-related hazards are the most common natural threats we have to face, with floods and droughts that can be considered as the two most destructive hazards to human societies. As already we have been noticing, the climate change is rising their intensity and frequency, affecting the especially precarious population.

According to the World Bank, only during 2010 the water-related disasters killed around 300,000 people, involved with negative consequences 208 million of people and cost nearly $110 billion (World Bank, 2017) (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

Several studies point to a possible increase in the severity of drought worldwide, by the end of the present century, with a rise of more than 20% in areas as South America and Central-Western Europe (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

Between 1960 and 1985, we have already seen a 95% reduction of the Lake Chad attributable to the reduced rainfall.

California, Australia, Alaska, Siberia in the past years, with increasing intensity, have been severely affected by droughts and fires. Southern Quebec, and Montreal in particular, have to face massive flooding. In 2018, Cape Town faced the "Day Zero", a water crisis that severe that the city was rapidly approaching the water demise. In 2019, Houston in Texas was flooded during a hurricane and the estimated economic loss was more than $150 billion (Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, 2019).

The urgency of investing in disaster risk reduction is today higher than ever, for reducing the loss of life, loss of ecosystems and economic loss as well.

Fortunately, awareness is growing worldwide and the attention for strategic risk planning and climate change adaptation is increasing.

In short, those are the main challenges related to water that our cities may have to face:

- Flooding
- Storm events
- Environment loss
- Heatwaves
- Droughts
- Sea Level Rise
- Coastal erosion
- Land Degradation
- Health and vector-borne disease
- Pollution (of water and/or air)
- Wastewater

2.5 Theories

2.5.1 Urban Metabolism

Introduction

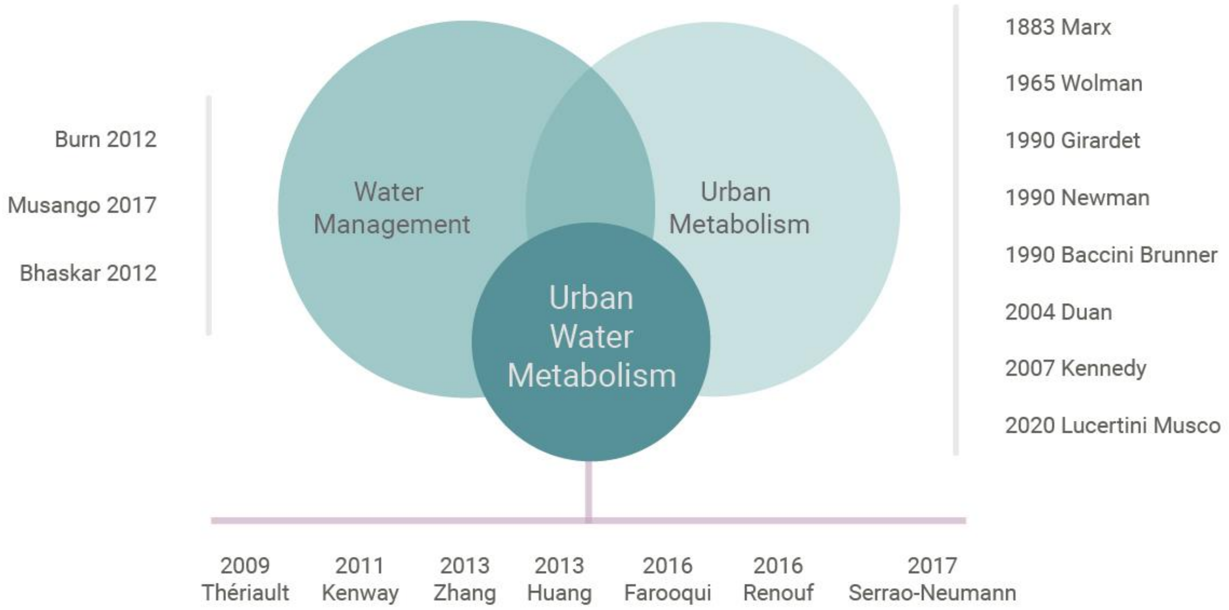
Urban Metabolism is a resulting approach from the application of natural science's methodology on the urban studies, through which urban systems are analysed as ecosystems with their own metabolic systems. By studying the inputs and outputs, the quality of the metabolic system is evaluated, both in general and in particular, identifying the strengths and weaknesses of the entire process.

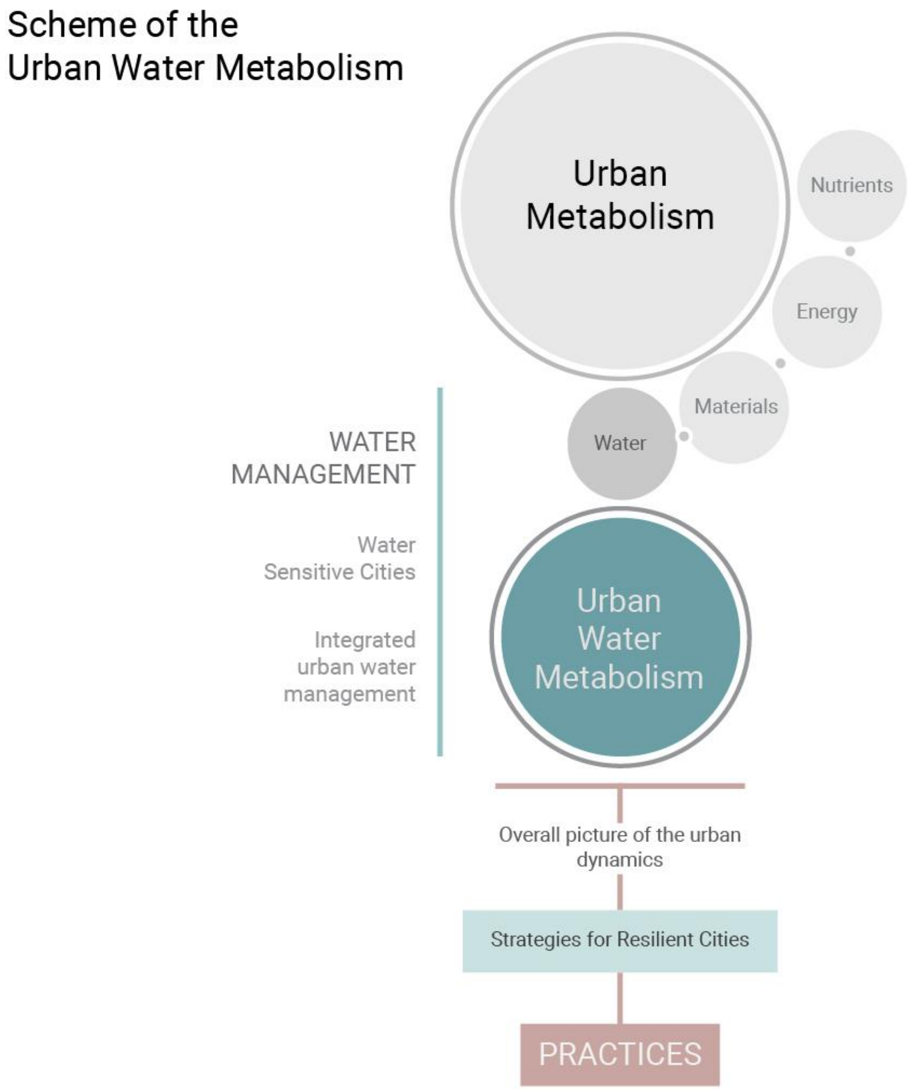
The declinations of urban metabolism are several (economic, social, industrial, and so on), we will mainly focus on the circular urban metabolism applied to water management.

Every year the issues we have to face an increase in number and intensity: population growth and urban growth, inequality and injustice, climate change and catastrophic events, but also pandemics and unexpected events, will increasingly affect our lives and the spaces we live in. To ensure a better and fairer quality of life, and to prevent further inequalities, it is necessary to rethink our urban systems. The issue of water is particularly problematic and it will need to be addressed with increasing urgency and frequency.

Cities are the heart of modern life and the responsibility of many of the issues related to modern life habits can be attributed to them. However, well-planned cities can contribute to reducing the impact that anthropic activities have on nature and the impact that nature has on them. For effective urban planning and design, it is essential to analyse the entire system with its flows and dynamics. Urban Metabolism and Water Urban Metabolism approaches can have an important role in it.

Scheme of the Literature Review
of Urban Water Metabolism





The frame of the research and definitions

The urban metabolism is not a new concept, but in recent years the interest has grown again, and it has been applied to the needs of our times. Referring to (Zhang, 2013), the Urban Metabolism approach has been increasingly adopted as main analysis model for its potential in obtaining information on energy efficiency, recycling of materials, waste management, and the infrastructure characteristics of an urban system. Qualitative information but also quantitative: it can be an effective means to quantify the inputs of energy, water, food, and other materials, as well as waste outputs (Sahely, 2003).

Kennedy et al. 2007 defined the urban metabolism as the "*sum of the technical and socio-economic processes that occur within the cities, resulting in growth, production of energy, and elimination of waste"* (Kennedy et al., 2007).

Dijst and colleagues went further interpreting Urban Metabolism as the process through which cities get resources from the environmental hinterland or through trade, consume them and transform them in economic products, social services and waste (Dijst et al., 2018).

Moreover, they point out the ideal, and not actual, fair distribution of resources and services between citizen, cities, regions. This is something that increases dramatically in case of stress, whether they are catastrophes or pandemics, and for what urban metabolism concept can be also useful.

A further exhaustive definition, that summarizes the previous, is the one that sees the Urban Metabolism as the "*collection of complex socio-technical and socio-ecological processes by which flows of materials, energy, people, and information shape the city, service the needs of its populace, and impact the surrounding hinterland"* (Musango et al., 2017).

Whereas, when we speak of Circular Urban Metabolism, we refer to the application of the Circular Economy Concept to the Urban Metabolism one.

Circular Economy, using the words of Ellen MacArthur Foundation, is *"an industrial system that is restorative or regenerative by intention and design. It replaces the 'end-of-life' concept with restoration, shift towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models" (*Ellen MacArthur Foundation).

A definition more generical and adaptable to the urban scale is the one given by Lucertini and Musco (2020), who said that Circular Economy Concept is "*a process of steps that ensure, from the initial input of resources, that it is possible to construct and reconstruct a material value chain and reduce waste as much as possible"* (Lucertini and Musco, 2020).

The application of this concept to the Urban Metabolism can aid planners and policymakers to rethink our cities and activities and to reach urban realities more liveable, sustainable, and durable.

Lucertini and Musco (2020) convey that the contribution of Circular Urban Metabolism to urban planning can consist in *"identifying spatial and temporal connections among material, energy, and economic and social flows, the approach is able to identify the potential to implement CE principles such as reducing, reusing, and recovering resources"* (Lucertini and Musco, 2020).

If on one hand Urban Metabolism is the process of inputs and outputs of an urban area which guarantees the functioning of the system (Farooqui et al., 2016), on the other hand, Water Urban Metabolism is the process of inputs and outputs tightly connected to water and the other resource flows associated with it, such as energy and nutrients.

For clarity, we specify the difference between Water Urban Metabolism and Water Mass Balance. The first, besides water flows, considers only the trends and magnitudes of flows of energy and nutrients that are involved in the process. The latter, on the other hand, analyses exclusively stocks and flows of water, excluding any energy or nutrient efficiency considerations. In the following figure, Farooqui, Renouf and Kenway report the field division between UM, UWM and WMB.

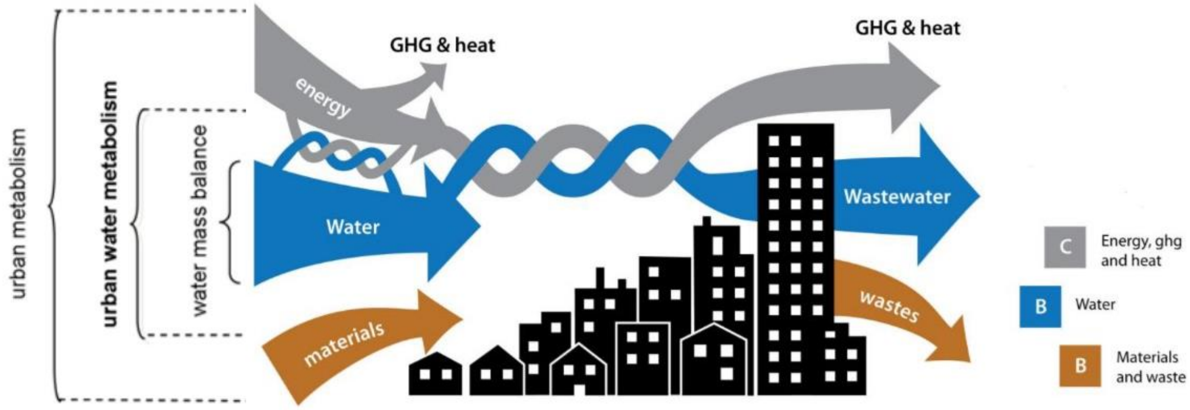


Figure 10 Urban Metabolism, Urban Water Metabolism and Water Mass Balance
Source: (Farooqui et al., 2016)

In the following figure is depicted the analysis of Water Urban Metabolism in its phases. Through the WUM concept, natural cycles and artificial cycles can be both deemed as part of the integrated urban cycle model and urban systems would not be any more exclusively water consumers.

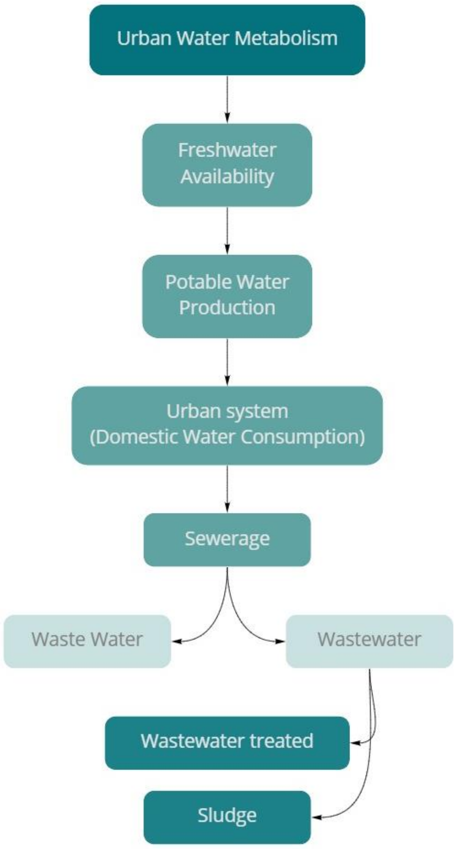


Figure 11 Framework for Urban Water Metabolism Analysis
Source: Re-elaboration of (Juan Godoy Chacha, 2015)

As already said, a system of the size of a city is rarely able to obtain internally the resources it needs to live, and in that case, they rely on the surrounding ecosystem, on the hinterland or on the trade.

"If the system cannot absorb the products and wastes generated by its metabolic activities, those products and wastes must be detoxified. For an urban ecosystem to function as efficiently as a natural ecosystem, the wastes generated by resource consumption must be reused somehow to prevent them from accumulating and harming the internal and external environments that sustain the system" (Zhang, 2013).

In other words, creating circular urban metabolism is about rethinking how resources flow in, out and through cities so that resources are used less and more efficiently.

Previous studies

Karl Marx, in the book "*Capital: Critique of Political Economy*" introduced the concept of Urban Metabolism in 1883 to describe, from a social perspective, the exchange of materials and energies between nature and society. In 1965, a sanitary engineer, Wolman, used the concept of metabolism concerning the deterioration of environmental quality in American cities, comparing the materials and energy flows of an urban system to those of organisms in an ecosystem. The definition he gave of UM was "*all the material and commodities needed to sustain the citizen of a city at home, at work, and at play*" (Wolman, 1965).

Wolman was also one of the first to point the attention on the limits of population growth and resource consumption. This has led also to the awareness of the existing relations between resource consumption and the production of outputs and wastes, that is how urban ecosystems persist (Zhang, 2013).

Urban metabolism had been, until then, conceptualized in linear terms, by analysing what goes in and what comes out.
Then, to represent the functioning of ecosystems and the relationship with organisms in a more realistic way, Girardet in 1990 introduced a cyclical model. This cyclical process of UM was explained with Black-box models, internally analysing the system in every component(Ibid.). The analysis approach utilized took clear inspiration from the biological metabolism studies and was based on the theory of complex urban ecosystems (Ibid.). More recently, Zhang and colleagues proposed a network model of UM, to emphasise the interconnection within the system (Ibid.). In the following figure, the different models are represented.

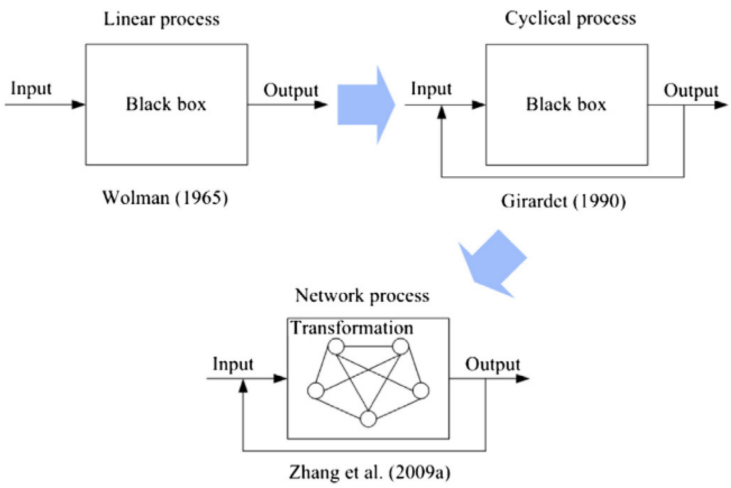


Figure 12 The evolution of models of the processes that define an urban metabolism.
Source: (Zhang, 2013)

In 1990, Newman blended the UM model with the social component, analysing besides inputs and outputs the human factors as well. In 1999, he went further into the concept defining cities not only consumers of inputs, processing resources and producing wastes, but they are also creators of human opportunity and liveability (Newman, 1999). These kinds of fluxes should somehow be taken into account when evaluating

the UM and the social component is now gaining in importance and should be part of the evaluation factors (Zhang, 2013).
In 2004 Duan, analysing the UM processes, concluded that the urban metabolic pathways are too long compared to the natural ones, and this can be one reason of the inefficiency and unsustainability of the actual cycle model. This perspective should be considered while handling urban infrastructures, especially hydraulic ones. Based on modern control theories, the author described the metabolism through the representation of the main factors involved in the material glows and their relations with the urban systems (Ibid.).
Afterwards, he proposed the concept of distinct flows of products and waste, based on the recognition that they follow different paths within the urban system: products are produced by resource paths and the waste is treated by waste treatment and recycling paths (Zhang, 2013).

As reported before, Kennedy in 2007 introduced the idea of using UM as a model for analysing the combination of anthropic activities and the related urban infrastructure (Kennedy et al., 2007). The author and colleagues argue that, to conduct an in-depth analysis aimed at assessing the efficiency of an urban system, the following main flows should be the main terms of the evaluation: water, materials, energy, and nutrients. Speaking about water, they defined it in terms of sheer mass as the largest component of urban metabolism, and its impact on the sustainability of cities as an impact of further dimensions, more than the vital need of inhabitants to have a safe and reliable water supply (Ibid.).

These models were superseded but have nevertheless provided the methodology of quantitative and qualitative analysis of UM. Recently, the UM studies divided into two main streams. The first one is the energy method, developed by H.T. Odum, emphasizing the qualitative differences of mass or energy flows and using the standard unit of solar energy of measurement to calculate energy, nutrient and waste movement in a system (Kennedy et al., 2011). The second one is the material flow analysis, developed by Baccini and Brunner in the 1990s that quantify the inputs and outputs that flow through a system, entering as resources and exiting as pollution, waste or exports, useful to evaluate water, materials and nutrients metabolism (Ibid.).

Starting with evaluating these flows, the system's dynamics will appear clearer and easier to handle. If all these flows and dynamics will be interconnected among them, trying to create as much circularity as possible, the system is most likely to be more sustainable and resilient.

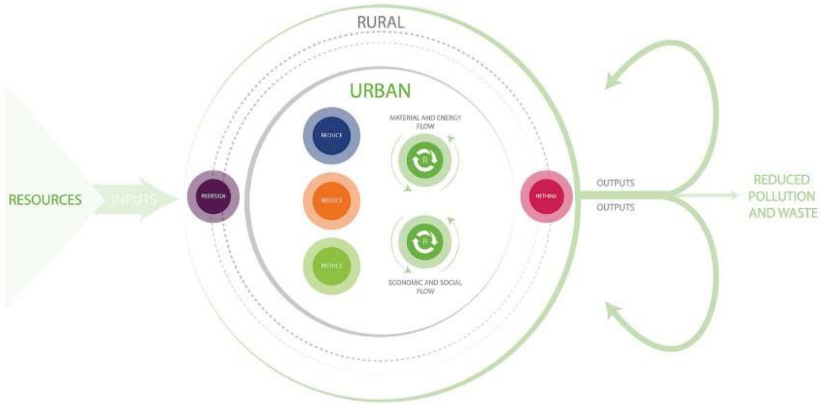


Figure 13 Circular Urban Metabolism framework
Source: (Lucertini and Musco, 2020)

As illustrated by the figure, Circular Urban Metabolism takes some of the Circular Economy principles, such as reduce, reuse, recover and others, and it applies them not only to the production/consumption process but to all the processes proper of cities. Furthermore, the authors differentiated the urban context from the rural context to emphasize the need to include both realities in the redesign and rethinking processes, in order to increase their connections and nexi (Lucertini and Musco, 2020).

All these studies on UM applied to different fields contributed to the Water Urban Metabolism both theoretically and practically, giving tools and methodology to evaluate and account urban water flows. Indeed, it is evident that water is related to almost all the component and fluxes that cross an urban system. Nevertheless, the adaptation of UM to evaluate water performances must be attributed to Kenway in 2011 and Renouf and Kenway in 2016 (Renouf et al., 2016). The use of this analysis to evaluate the urban water fluxes brought a comprehensive statement of all water flows, both natural and anthropogenic, which enter, cross, and exit from an urban system and the supporting environment. Thanks to this account, an urban water mass balance can be realized and from the indicators of water metabolism performance of efficiency and quality are derived (Ibid.). These indicators, introduced by Renouf and colleagues in 2017 and reviewed by Serrao-Neumann and colleagues, will be explained later in more details (Serrao-Neumann et al., 2019).

The Water Urban Metabolism has been used to assess the water balances and water performances of urban systems and metropolitan areas, mostly comparing different water servicing options. (Bhaskar and Welty, 2012);(Kenway et al., 2011);(Bhaskar and Welty, 2012); (Thériault and Laroche, 2009).

Farooqui and colleagues in 2016 used Water Urban Metabolism as a tool for a comparative analysis to try different water servicing scenarios and to give a new perspective to complement broader sustainability assessments of urban water (Farooqui et al., 2016).

According to Huang in 2013, the UWM can be understood through an analysis of the fluxes and of the system structures, including social-economic factors and driving mechanisms. Thanks to these evaluations, it can be identified the congestions knot in the metabolic system. Once identified them, should be easier and more efficient to develop strategies for a faster transition to sustainable and resilient cities (Huang et al., 2013).

Huang and colleagues spoke about the water metabolism processes and Water Urban Metabolism efficiency (WME) (Huang et al., 2013). They also speak about the importance of virtual water metabolism analysis to show more efficiently the effects on the socio-economic system (Ibid.). The virtual water reflects the amount of real water already used to generate a product or service and it is used to calculate direct and indirect real water demand for a given product or service, or a given system (Ibid.). In this respect, future investigations are encouraged.

The author has given an important contribution also on the relation within UWM and planning. According to him, through the evaluation of the UWM is possible to gain a holistic frame of the condition in which the water gets out of a city and this information can be useful for urban planning practice (Ibid.). Indeed, with strategies that foster the protection of water resources and water fluxes, the identification of the different water functions, and the resource efficiency and supply internalisation, the transition toward cities sensitive to water is most likely to be faster (Ibid.).

Renouf and colleagues have also pointed out that the UWM concept can be particularly useful to help integrate the management of water supply, stormwater and wastewater systems, to reduce their environmental impacts whereas apporting social and economic benefits (Burn et al., 2012). Renouf and Kenway in 2016 said that water metabolism in a urban systems has to be considered as how effectively urban areas utilise water from the point of view of the entire urban system (Renouf et al., 2016).

Arriving to the European context, in 2011 the Technische Universität of Berlin realized a report for the European Environment Agency, “Developing a pragmatic approach to assess urban metabolism in Europe”, to give a common methodology for the quantification of urban metabolism, based on publicly available data.

In 2020 has been launched a platform called “Metabolism of Cities” to collect worldwide data from every city and foster urban metabolism analysis. These data are of different natures and uploaded by who wants to contribute, divided into the layers: Context, Biophysical Characteristics, Infrastructure, Stocks and Flows. Information about water can be found in "Biophysical Characteristics" and in "Stocks and Flows". This platform might be a great starting point to normalize, collect and share the data needed to promote Water Urban Metabolism analysis.

Resuming methods related to Water Urban Metabolism:

- **Input-Output Analysis (IOA)** method to assess the material flows between sectors in an economy by tracking product and sector-specific resource flows (Musango et al., 2017).
- **Urban water mass balance** method that quantifies all flow and fluxes of water that get into, through and out of a urban system, both anthropogenic and natural (Kenway et al. 2011a).
- **Ecological network analysis** (ENA) is a system-oriented method for examining the flow of the material through the ecosystem (Hannon., 1973).
- **Material Flow Analysis** (MFA) Baccini and Brunner in the 1990s, can provide a basis for material flow management and dematerialisation strategies on a regional or city-scale, and can contribute to the definition of public environmental policies (Musango et al., 2017).

  Eurostat MFA The Eurostat method that Hammer and colleagues tailored for the urban scale (Hammer et al. 2003a; Hammer and Giljum 2006).
- **Accounting materials** Currie, P.K. and J.K. Musango. 2016. "*African Urbanization: Assimilating Urban Metabolism into Sustainability Discourse and Practice"*: African Urbanization. Journal of Industrial Ecology. http://doi. wiley.com/10.1111/jiec.12517. Accessed January 9, 2017.
- **Accounting Energy and Carbon** Chen, G., T. Wiedmann, M. Hadjikakou, and H. Rowley. 2016. City Carbon Footprint Networks. Energies 9(8): 602. http://www.mdpi.com/1996-1073/9/8/602. Accessed January 27, 2017
- **Hybrid** (Huang, L., L. Yan, and J. Wu. 2016.)
- **Footprint Analysis** *"converts a population's resource consumption into a single indicator of how much land area is needed to sustain that population indefinitely*" (Goldstein, B., M. Birkved, J. Fernández, and M. Hauschild., 2016); (Musango et al., 2017).
- **Simulation** The simulation methods are mainly three (system dynamics, agent-based modelling, and discrete event). System dynamics, the most used one, combines qualitative and quantitative analysis and is based on relationship structures, allowing models to be used effectively even in lack of data situations (Musango et al., 2017).

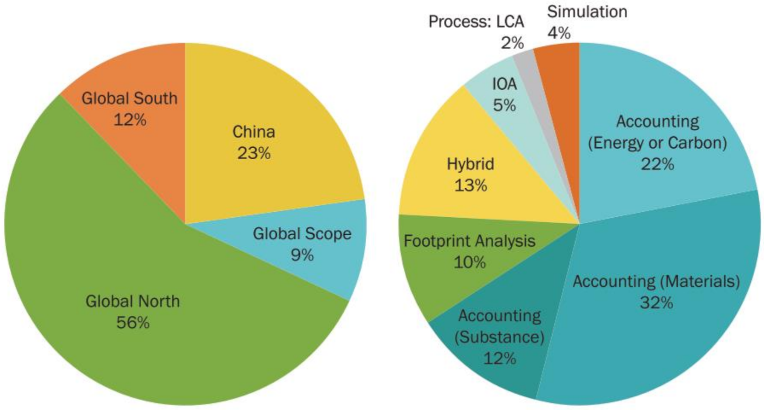


Figure 14 The location of case studies and method utilised in 165 urban metabolism
Source: (Musango et al., 2017)

Indicators related to water in Urban Metabolism

For UWM the indicators used so fare are several. We will briefly try to sort the main ones, relying upon future research for insights.

Kenway and colleagues, in 2011, claimed that UWM analysis has used an urban water mass balance method to quantify all natural and anthropogenic water flows through a defined urban area, from which the following indicators of performance can be generated (Kenway et al., 2011).

- **Underutilisation of rainwater**
- **Storm and wastewater as water supplies for cities**
- **Assess how urbanisation influences natural hydrological flows**
- **Compare the water performance of different urban areas**
- **Consider how different water servicing option influence the water metabolism performance of urban areas at local or city-region scales**

Indicators by Technische Universität of Berlin:

- **Territorial water extraction**
  Share the water extracted on urban territory
- **Groundwater levels**
  Change in groundwater level on urban territory over the last 5 years
- **Water scarcity**
  An adequate indicator of water scarcity
- **Water use efficiency**
  The annual amount of water used on urban territory per capita
- **Wastewater treatment**
  Share of wastewater released back into environment untreated
- **Water quality extraction**
  Water quality of water extracted for urban use
- **Water quality release**
  Water quality of water released back into the environment
- **Water footprint**
  The annual amount of direct and indirect water use from final consumption activities in a city by major categories (food, housing, transport, other) and region of water extraction (Climatecon. et al., 2011).

Renouf and colleagues in 2017 have reviewed and categorised water-related resource management objectives for city-regions, to derive quantitative indicators as the main metabolic features of urban water management. The key UWM objectives they have identified are:

- **Resource efficiency**
- **Supply internalisation**
- **Urban hydrological performance**
- **Sustainable extraction**
- **Recognition of the diverse functions of water**

The first three indicators' data can be gained through urban water mass balance methods. For the others, "sustainable extraction" and "recognition of the diverse functions of water" will be required applied methodologies for those. Energy and nutrient efficiencies, according to the authors, will be possible to be generated through the combination of energy and nutrient data and urban water balance (Renouf et al., 2017).

These indicators were re-elaborated by Serrao-Neumann in the following (Serrao-Neumann et al., 2019):

- **Resource efficiency**
    - **Water efficiency**
    - **Water-related energy efficiency**
    - **Water-related nutrient efficiency**
- **Supply internalisation**
- **Protection of water resources and hydrological flows**
- **Recognition of the diverse functions of water**

Urban water efficiency per unit of functionality

Water-related energy efficiency per unit of functionality

Nutrient recovery from urban water

Water supply internalisation

Water use within safe operating space

Water pollutant load within safe operating space

Hydrological performance

Supporting diverse functions

Applications of Urban Water Metabolism

The applications of the Urban Water Metabolism analysis are, for urban planners, designers an policy makers:

- **Sustainability analysis and evaluating resource efficiency and hydrological performance**
  One of the main uses of Urban Water Metabolism is to evaluate the efficiency level of water use, with the purpose to optimize it in order to reduce both the inputs and the outputs that urban systems need. Thanks to the global monitoring of the system, UWM can give important advices on how to improve the integration between flows and fluxes, that especially in the perspective of adaptation to climate change can be resolutive.
- **Mathematical modelling**
  Starting from the actual quantification of fluxes, urban metabolism and Water Urban Metabolism started to develop mathematical models to quantify and predict the future has begun to develop mathematical models to quantify and predict future amount of resources and outputs. Equivalents of water and virtual water are applications of this mathematical modelling, useful for policy analysis or forecasts.
- **Urban design and target urban development**
  Water Urban Metabolism can be used by researchers and policymakers to create greener and more sustainable system from the bases. By tracing flows of water and the related fluxes of energy, materials and waste through urban systems as a whole, alterations and optimizations can be made

to close the loops in order to create a more efficient and circular metabolism where resources are recycled and less waste is produced. These interventions are becoming more frequent and applied to different scales, as regional, urban, district up to the scale of singular building. UWM can be useful in fostering small and large infrastructures maintenance and innovation as well.

- **Social and institutional innovation**
  The present approach can have application, and should have application, in the social and institutional sector, with a bottom-up approach, including and integrating different disciplines and social processes.
- **Monitoring water resource use and quality**

We reiterate that the urban metabolism is not restricted used to functional analysis but is used also to examine the relational aspects of urban relationships between resources, infrastructures, and citizens.

Gap of knowledge

The Urban Metabolism is deeply investigated with a long tradition of researches on it, meanwhile, the Water Urban Metabolism still seems to have much that needs to be explored. Primarily, it seems necessary to agree on a common and internationally recognized methodology to analyse Water Urban Metabolism.

Even if, it has to be said, that Water Urban Metabolism's potential is mainly related to the evaluation of the system itself and on how it can be improved, and less in comparison to other realities, because every urban system has is own characteristics and peculiarity. Nevertheless, working on the commensurability of most of the data (-most of- because eventual peculiar indicators shall be taken into account) can ensure quality and comprehensiveness to the analysis.

Regarding data, methods and tools, the research filed has been broadly investigated but what is missing is standardization and normalizations of the methodologies to obtain more inter-comparable data. In particular, to sort and select the indicators can be a good starting point to have commensurable data between cities and regions (Renouf et al., 2017). Moreover, easy guidelines for drive and foster this kind of evaluations would be highly useful. Future analyses should investigate on that.

Another point that future research should consider is to previously and systematically define the urban system boundaries (Serrao-Neumann et al., 2019).

The institutional and legislative frameworks have often been identified as one of the main barriers in transitioning towards a resilient and water sensitive city. This can be connected to a downturn in knowledge and insights regarding the role and the potential that institutions have in fostering Water Urban Metabolism analysis.

Water management and Water metabolism, especially when related to energy, industry and agricultural compartments, are pretty close to the financial sector. However, this research has not deepened these sectors and future research is encouraged.

There is little literature about how urban metabolism evaluations can be related to land-use planning and water management policy (Serrao-Neumann et al., 2019), the field is however very important and must be investigated as much as possible, especially in the practical applications.

It contributes to filling this gap by empirically investigating how the information provided by UWM evaluations can meet practitioners' knowledge needs for planning water sensitive city-regions. Specifically, how can UWM evaluations support urban and water planning for water sensitive city-regions? This is important because it helps tailor the information generated by UWM evaluations to maximise their usability by practitioners, and hence is a step towards enabling science-informed strategic planning.

Furthermore, it could be useful to consider, as Musango suggested, the spatial and temporal level in the urban metabolism analysis. There are differences in the two dimensions even within the same flows, and this must be considered for creating a more exhaustive picture of the system.

For urban planning and design intervention, can be useful to promote, once standardised, the modelling of the system dynamics in every urban system, trying to integrate as much as possible different disciplines and the different physical and social processes, including the stakeholders (Musango et al., 2017).

Conclusions

Water Urban Metabolism is an interesting and useful tool that might be the key to planning more liveable and sustainable future cities. However, this approach is still little known and little used. This can be related to a lack of easy guidelines, poor understanding of the potential and the applications, and a lack of shared methods, as mentioned above.

Many authors convey that creating circular urban metabolism means rethinking the flows networks and trying to connect previously separated systems so that resources' use can be optimized, and the input amount can be reduced.

Water Urban Metabolism is an interesting approach because it allows analysing even very complex systems, such as examples megacities, to have a general picture of everything that function and doesn't function inside. Trying to improve systemic efficiency with data at hand is undoubtedly a more comfortable and more efficient way.

Moreover, by interconnecting different flows, decentralising inefficient energy poles, speeding up or slowing down flows when necessary, it can be expected to lower the water demand considerably. The more efficient a city is, the less water it will need, and the better the quality of the water waste will be.

This is according to the principle that cities are the main source of consumption and pollution, but with good planning, they can also represent the water solution, reintroducing it back into the water cycle in the same, or even better, quality of before.

During the present research, the idea we came up is that Water Urban Metabolism represent an excellent tool of analysis to lay the foundations for the design and strategies that other theories, as Water Sensitive Cities and Integrated Water Management, can bring to realization.

References and bibliography

A New Era in Global Health (2018) Transforming Our World: The 2030 Agenda for Sustainable Development. DOI: 10.1891/9780826190123.ap02.

Bhaskar AS and Welty C (2012) Water balances along an urban-to-rural gradient of metropolitan baltimore, 2001-2009. *Environmental and Engineering Geoscience* 18(1): 37–50. DOI: 10.2113/gseegeosci.18.1.37.

Blanca Jiménez-Cisneros; Alexandros K. Makarigakis (2019) UNESCO's Contribution to Face Global Water Challenges.

Blanca Jiménez-Cisneros; Alexandros K. Makarigakis (n.d.) Managing the urban water cycle Blanca.

Brunetta G, Caldarice O, Tollin N, et al. (2019) *Urban Resilience for Risk and Adaptation Governance*.

Burn S, Maheepala S and Sharma A (2012) Utilising integrated urban water management to assess the viability of decentralised water solutions. *Water Science and Technology* 66(1): 113–121. DOI: 10.2166/wst.2012.071.

Climatecon., Minx J, Creutzig F, et al. (2011) Approach To Assess Urban Metabolism in. 240(1): 1–83.

Dijst M, Worrell E, Böcker L, et al. (2018) Exploring urban metabolism—Towards an interdisciplinary perspective. *Resources, Conservation and Recycling* 132(October 2017): 190–203. DOI: 10.1016/j.resconrec.2017.09.014.

Encyclopedia of Science (2020) Encyclopedia of Science.

Faragò M, Rasmussen ES, Fryd O, et al. (2018) Coastal protection technologies in a Danish context.: 1–74.

Farooqui TA, Renouf MA and Kenway SJ (2016) A metabolism perspective on alternative urban water servicing options using water mass balance. *Water Research* 106. Elsevier Ltd: 415–428. DOI: 10.1016/j.watres.2016.10.014.

Fratini CF, Geldof GD, Kluck J, et al. (2012) Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality. *Urban Water Journal*. DOI: 10.1080/1573062X.2012.668913.

Hammond MJ, Chen AS, Djordjević S, et al. (2015) Urban flood impact assessment: A state-of-the-art review. *Urban Water Journal* 12(1): 14–29. DOI: 10.1080/1573062X.2013.857421.

Huang CL, Vause J, Ma HW, et al. (2013) Urban water metabolism efficiency assessment: Integrated analysis of available and virtual water. *Science of the Total Environment* 452–453(February 2019). Elsevier B.V.: 19–27. DOI: 10.1016/j.scitotenv.2013.02.044.

Jarraud M and Steiner A (2012) *Climate Change 2014, IPCC*. DOI: 10.1017/CBO9781139177245.003.

Juan Godoy Chacha (2015) Harvesting rainwater in households a strategy in short term to improve the current water metabolism in Cuenca, Ecuador.

Kennedy C, Cuddihy J and Engel-yan J (2007) The Changing Metabolism of Cities. 11(2).

Kennedy C, Pincetl S and Bunje P (2011) The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution* 159(8–9). Elsevier Ltd: 1965–1973. DOI: 10.1016/j.envpol.2010.10.022.

Kenway S, Gregory A and McMahon J (2011) Urban water mass balance analysis. *Journal of Industrial Ecology* 15(5): 693–706. DOI: 10.1111/j.1530-9290.2011.00357.x.

Lucertini G and Musco F (2020) Circular Urban Metabolism Framework. *One Earth* 2(2). The Authors: 138–142. DOI: 10.1016/j.oneear.2020.02.004.

Meerow S, Newell JP and Stults M (2016) Defining urban resilience: A review. *Landscape and Urban Planning* 147. Elsevier B.V.: 38–49. DOI: 10.1016/j.landurbplan.2015.11.011.

Musango JK, Currie P and Robinson B (2017) Urban Metabolism for Resource-Efficient Cities. *Paris: UN Environment*: 1–40. Available at: www.sustainabilityinstitute.net.

Newman PWG (1999) Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning*. DOI: 10.1016/S0169-2046(99)00009-2.

Omojola A, Dettinger MD and Diego S (2011) Climate change, water, and wastewater in cities. *Choice Reviews Online* 49(07): 49-3876-49–3876. DOI: 10.5860/choice.49-3876.

Renouf M, Kenway SJ, Serrao-Neumann S, et al. (2016) Urban Metabolism for Planning Water Sensitive Cities: Concept for an Urban Water Metabolism Evaluation Framework. *Cooperative Research Centre for Water*

Sensitive Cities: 1–43. Available at: http://watersensitivecities.org.au/.

Renouf MA, Serrao-Neumann S, Kenway SJ, et al. (2017) Urban water metabolism indicators derived from a water mass balance – Bridging the gap between visions and performance assessment of urban water resource management. *Water Research* 122. Elsevier Ltd: 669–677. DOI: 10.1016/j.watres.2017.05.060.

Serrao-Neumann S, Renouf MA, Morgan E, et al. (2019) Urban water metabolism information for planning water sensitive city-regions. *Land Use Policy* 88(February). Elsevier: 104144. DOI: 10.1016/j.landusepol.2019.104144.

Thériault J and Laroche AM (2009) Evaluation of the urban hydrologic metabolism of the greater moncton region, New Brunswick. *Canadian Water Resources Journal* 34(3): 255–268. DOI: 10.4296/cwrj3403255.

Tollin N (2020) Urban Resilience & Water:Research, Policy and Practice.

UN DESA (2015) World Population Expected to Reach 9.7 Billion by 2050.

UNESCO (2020) *Water and Climate Change*.

UNESCO IHP (2014). Available at: https://en.unesco.org/themes/water-security/hydrology/IHP-VIII-water-security.

Voskamp IM and Van de Ven FHM (2015) Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Building and Environment* 83. Elsevier Ltd: 159–167. DOI: 10.1016/j.buildenv.2014.07.018.

WHO/UNICEF (2017) Progress on Drinking Water, Sanitation and Hygiene - Joint Monitoring Programme 2017 Update and SDG Baselines. *Who*: 66. Available at: http://apps.who.int/bookorders.%0Ahttp://apps.who.int/iris/bitstream/10665/258617/1/9789241512893-eng.pdf%0Ahttp://www.wipo.int/amc/en/%0Ahttp://www.wipo.int/amc/en/.

World Bank (2017) Reducing Inequalities in Water Supply, Sanitation, and Hygiene in the Era of the Sustainable Development Goals. Synthesis Report of the WASH Poverty Diagnostic Initiative. *World Bank Group*.

WWDR (2020) *The United Nations World Water Development Report 2020: Water and Climate Change*.

Zhang Y (2013) Urban metabolism: A review of research methodologies. *Environmental Pollution* 178: 463–473. DOI: https://doi.org/10.1016/j.envpol.2013.03.052.

2.5.2 Water Sensitive Cities

Acknowledgement

This research was carried out together with the SDU.resilience research group at BloxHub, Copenhagen. In particular, the next section was realised in collaboration with the student from the University of Padua, Martino Zadra.

Background context

Water Sensitive City paradigm emerged in the first decade of the 21st century to solve the problem of urban water management in contemporary cities (R. R. Brown et al., 2009b; Lloyd et al., 2012).

As above mentioned, water management within cities has increasingly become a challenge.

For this reason, the Water Sensitive City proposes a new socio-technical approach (Rijke et al., 2013) which revises the conventional dynamics between the community, the government, and the planning to ensure a more liveable, sustainable, and resilient cities (Dobre, 2013). The concept is based on integrating the water cycle (Dobre, 2013) in urban planning and design, to protect water quality, reduce flood and drought risk, and create public space as harvesting, cleaning, and recycling water systems. The water-sensitive approach recognises water as a fundamental element of urban society (Ashley et al., 2013) (Dolman et al., 2013).

Theoretical concept

Water Sensitive City is a theory introduced by Australian Commonwealth's National Water Initiative (R. R. Brown et al., 2009a) as: "*Innovation and Capacity Building to Create Water Sensitive Australian Cities*" (COAG 2004):

(COAG 2004, Clause 92, p20)

The increasing awareness about climate change and water-related disasters led to the Australian government to change water policies. Thus, a new water management approach was introduced to integrate social and institutional capital with diverse and sustainable technology, and so protect and enhance water (Wong & Brown, 2009b).

One of the main issues and challenges of this transition is searching for a socio-technical resiliency, which can reduce the exposure to climate change hazards. Indeed, the external disturbances as new opportunities for development and innovation is a topic shared within many urban planning theories, including WSC. A socio-technical approach to connect governance with the infrastructure's network is essential to develop the ability to change under external events' (Folke, 2006).

The Water Sensitive City vision is not a rigid theorem but is rather a series of indicators, specific to the context of analysis, that could lead a city towards more sustainable management of water (Lundqvist et al. 2001 in Brown et al., 2009, 848).

Clause 92

"The Parties agree to undertake the following actions regarding innovation:

i) develop national health and environmental guidelines for priority elements of water sensitive urban designs (initially recycled water and stormwater) by 2005;

ii) develop national guidelines for evaluating options for water sensitive urban developments, both in new urban sub-divisions and high-rise buildings by 2006;

iii) evaluate existing 'icon water sensitive urban developments' to identify gaps in knowledge and lessons for future strategically located developments by 2005;

iv) review the institutional and regulatory models for achieving integrated urban water cycle planning and management, followed by preparation of best practice guidelines by 2006; and

v) review of incentives to stimulate innovation by 2006."

(COAG 2004, Clause 92, p20)

In this vision, it is common to talk about the 'hydro-social contract' (Lundqvist et al. 2001 in Brown et al., 2009, 848) as an agreement between stakeholders (especially community of citizen), governments, and the compartment of business on the governance of water. The hydro-social contract aims to find a proper way to "t*ransform cities through reconnecting best thinking and practice in urban water management, urban design, and social and institutional system*" (Wong & Brown, 2009a, 675).

Urban Water Management Transition Framework

Brown et al. (2009) developed a transition theory that analyses the cities evolutions in its ecological, demographic and climatic dynamics through the concept of the hydro-social contract. The theory, defined as Water Urban Transition Framework, has been developed as a comparative tool to help local governments in transforming cities to more water sensitivity and sustainable environment (Buurman & Padawangi, 2018).

According to Brown, to reach the condition of water sensitive city, it is necessary a pass through six different stages characterized by a specific hydro-social contract modelled on a technological, ideological, and institutional background. The transition process is a sequence of phases starting from a rigid and conventional systems towards more flexible and diversified urban states: Water supply city, Sewered city, Drained city, Waterways city, Water cycle city and Water sensitive city (R. R. Brown et al., 2009b). Each stage is characterised by two specific indicators: the "Cumulative Socio-Political Drivers", that defines the rise and evolution in demand and expectation about water management; and the "Service Delivery Functions", which represents the translation of drivers in concrete services (R. R. Brown et al., 2009a).

Analysing the urban system evolution through these indicators, it is possible to gain an assessment of the hydro-social contract. The contract is structured to provide diverse and flexible technologies, infrastructure, and urban forms, designed to reinforce sustainability and social capital within a strict collaboration between society and the technology sector (Wong & Brown, 2009b). Each stage is linked to the following one, and the skeleton of the later city stage puts the basis of the subsequent (R. R. Brown et al., 2009b).

The transition model has been represented as a linear path, but this does not preclude the possibility of leapfrogging from not consecutive stages (Barron et al., 2017). Indeed, the purpose of the water management transition framework is to represent a set of water infrastructure related to specific institutional and community attitudes that could foster the city journey towards a water sensitivity (De Haan et al., 2015).

As developed in Brown framework, the six stages through which cities transit are defined as (R. Brown et al., 2016.; R. R. Brown et al., 2009b):

- Water Supply City

The primary stage of modern water management, with a by a centralised system that provides water supply and distribution, through the use of infrastructures like pipes and dams. The community believes that water is an unlimited resource.

- Sewered City

A sewered city, despite guarantying water supply, also ensures the public health protection through infrastructures aimed at collecting and removing wastewater to reduce the proliferation of diseases and infections. Hence, a sewerage system discharges the wastewater into a receiving waterway. As in the earlier stage, the release of wastewater into natural waterways is not considered as an environmental problem.

- Drained City

A drained city aims to protect the urban environment from flooding, caused by the rapid urbanisation process and soil consumption. The institutions involve new urban water service providers and stormwater management policies by implementing drainage and channelisation dumping ground systems to divert water to receiving waterways.

- Waterways City

The waterways stage is crucial, and there is a change in the perspective. The awareness of environmental impacts on water led to a new approach. In this stage, community and institutions attention is addressed to new decentralized and green infrastructure, that can guarantee a less impactful infrastructure, providing filtration of waterways and new green recreative urban solution for social health and amenity.

- Water Cycle City

The acknowledgement of the limits of natural water resources characterizes the water cycle city. Hence, stakeholders and decision-makers also consider integrating urban water management focused on new practices of water conservation and unconventional water supply solutions. The water cycle city needs a co-management approach between business, communities, and the government to find new water conservative and protection policies.

- Water Sensitive City

The Water Sensitive City state has the peculiarity of integrating water cycle in urban management for a better liveability and more resilience to the climate challenge effects. The close collaboration between society and technology is its basement: community is actively engaged and sensitised to water in city; innovation and technology in planning have the responsibility to create adaptive and multifunctional infrastructures to protect the quality of waterways, mitigate floodings risk and create new opportunities through the design of green public spaces.

Principle of Practice

Based on the six transition stages, Brown and colleagues identified three pillars as fundamental for the application of the hydro-social contract to reality and for operationalising the system resilient structure (Wong & Brown, 2009b):

I. Cities as Water Supply Catchment

The rising pressure on urban water supplies has increased the awareness about the alternative solution to collect and use water a part of conventional infrastructure. It becomes necessary to access to a diversity of water sources via centralized and decentralized infrastructure through adaptive and multi-functional infrastructure (Lloyd et al., 2012).

The diversity of sources is associated with harvesting, treatment, storage, and deliver water in the urban environment to minimizing the import and export of water from outside the city boundaries.

Cities have access to water inside the dynamics of the urban water cycle composed of potable water, stormwater, and wastewater systems. Conventional approaches in urban water managing use principally potable water and wastewater, while stormwater is not seen as a potential water source yet (Dobre, 2013). To transform cities into water supply catchment, it is necessary to replace or implement conventional infrastructures with decentralised infrastructures capable of reducing the impact on freshwater, managing the water resource locally. Using decentralized infrastructure provides diversification in local water utilities with the positive consequence of reducing freshwater demand and usage; upgrading aged and obsolete technologies; delivering more adaptive systems to an adverse event (Leigh & Lee, 2019).

II. Cities Providing Ecosystem Services

The rise of environmental problems and pressure on urban water systems provides the new idea of ecosystem services for built and natural environments in cities, trying to reach harmony between water planning and urban planning (Lloyd et al., 2012).

Cities need to become more sustainable and resilient to climate change, global warming, and the impact of urbanization on the natural ecosystem.

In general, ecosystem services related to urban planning consist of the design of public spaces as a source of amenity for the wide-city concept (metropolitan area and citizen). The complexity of this point is in the definition of practical solutions capable of conferring functional but environmentally friendly spaces.

To achieve the goal, it has stated the idea of implementing blue and green infrastructure related to the concept of WSUD, especially in stormwater management, as quality and quantity. WSUD largely contributes to the idea of rehabilitating waterways through the union of treatment technologies and urban design solution such as wetlands, bioretention system.

III. Cities Comprising Water Sensitive Communities

The concept of Water Sensitive City involves a whole series of principles related to the technical and the social sphere of urban water management. For new water management technologies to be effective, they must be socially related and accepted by local institutions to ensure their successful implementation.

Furthermore, to reach a Water sensitive community, the social socio-political contribution to sustainability and water sensitive behaviour needs a strict collaboration between science, policy, institutions, and community (Lloyd et al., 2012).

The importance of creating a benchmarking network between public and private institutions at a different urban scale, encourage the inclusion of water-related issues in the political administration priorities. In conclusion, the implementation of decentralised infrastructures allows the adoption of water management solutions on a different scale. This multi-scale capability is essential to ensure that the community is brought closer to water, as it provides the opportunity to involve citizens in planning processes or awareness-raising campaigns about water and the environment in general (Leigh & Lee, 2019).

From WSC **concept** to Water Sensitive Urban Design **solution**

The theory of Water Sensitive City (WSC) is commonly associated, in the literature, to the concept of Water Sensitive Urban Design.

The WSC concept appeared for the first time in 1992 in a publication by Mouritz (Fletcher et al., 2015) in which the design of urban water management aimed at the balance between water supplies and water hazards; preserving the water quality and the protection and conservation of natural spaces by providing water-related opportunities.

In the 2000s the concept took popularity, and scientific opinion began to associate the principles of WSUD to those of Integrated Water Management of the urban water cycle (i.e. clear water, stormwater, and wastewater) (Hoyer et al., 2011). Furthermore, the WSUD is often confused with the WSC theory, even though one is the consequence of the application of techniques and practices of the other (Fletcher et al., 2015).

Indeed, even the meaning of the term emphasizes the necessity to bring water sensitivity into cities landscape, through urban design, combining traditional planning approach with environmental and engineering science's one (Ashley et al., 2013).

In this way, water becomes an intrinsic element of urban planning, that shall consider solutions not only related to the maintenance of water resources and the environment, but also to provide protection from climate change's hazards and guarantee a series of multiscale environmental benefits (Dolman et al., 2013). According to the Royal Haskoning agency, for helping future cities in the transition towards water sensitive cities, they should please the following series of indicators and parameters, application of WSUD principles (Dolman et al., 2013):

- liveability of the urban environment
- sustainable use of water resources
- climate control solutions
- energy from water
- protecting water quality
- water-resilient spatial solutions

In conclusion, the Water Sensitive Urban Design approach developed several practical-technological solutions, tightly connected to urban and architectural planning. These solutions mainly concern systems (Hoyer et al., 2011): rainwater harvesting; bioretention; biotopes; retention system; infiltration zones; swales; detention ponds; drainage surfaces.

2.6 Comparative analysis

The two theories, apart from the supreme intention of making our cities more sustainable and liveable, have two different approaches.

Urban metabolism aims to first create a general frame of the urban situation, with data and dynamics, and then, once the weak points or potential ones have been identified, to optimise them.

On the other hand, the second theory focuses more on general strategies that a city shall work on to achieve the goal of water sensitivity.

UWM is mostly considering fluxes and networks and how to implement them with a circular perspective. WSC, with its indicators, gives precise directives regarding what a city should work on. It takes in consideration networks as well, but mostly the evolution of the contract and relation with water, also from a historical-sociological perspective. UM does not consider the social sector very much, except for the flows and consumption perspectives, and only in few studies. Whereas in the WSC one of the three fundamental pillars is precisely the creation of water sensitive communities.

In general, WSC seems to have a more standardised and systematised status, whereas UWM still lacks a systematisation of indicators, approach and objectives. However, this gives the UWM the flexibility and versatility of investigation that the WSC lacks.

In conclusion, it is believed that the theories are equally useful for making our cities resilient and water-friendly, but in different times and ways. In fact, the UWM is ideal for pre-action investigation, to create the big picture and understand where to intervene to make improvements. It is also essential for monitoring activities.

WSC is useful for outlining the strategies and objectives that a city should achieve, and through WSUD to arrive at practical actions.

As will be deepen later, the synergetic approach between theories and researchers is fundamental for saving valuable time and gaining effectiveness.

2.7 Solutions

- Strategy (Urban planning, Urban resilience, Water management)
- Cooperation
    - Vertical (International, National, Regional, Local)
    - Transversal (Decision-makers, research groups, technicians, stakeholders and citizen)
    - Orizzontal (who has the know-how or is looking for it)
- Synergy between Theory and Practice

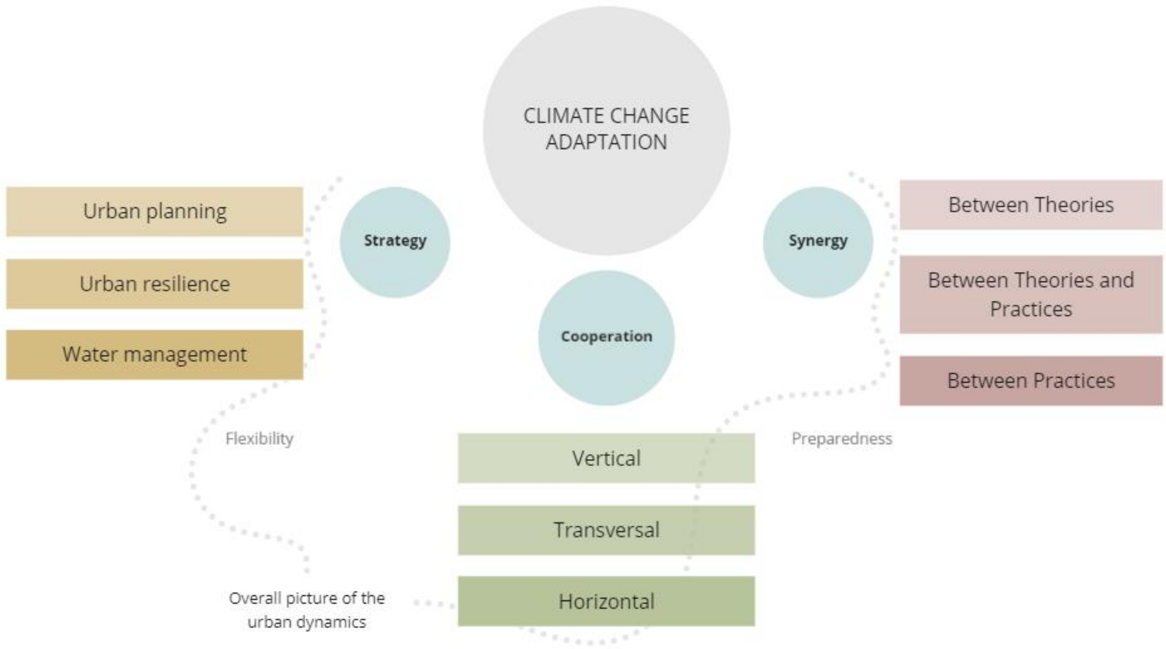


Figure 15 Requirements to face the adaptation to climate change. Source: Personal elaboration

2.7.1 Water for cities and cities for water. Urban resilience and urban planning

Social, environmental and economic problems related to the water issues will be increasingly present in the international debate.

As already mentioned, demographic increase, urbanisation, the spread of crumbling buildings, construction in improper areas, and the lack of an overall vision have led to a loss in our cities' liveability and elasticity. At this time of crisis, with climatic epidemics and social inequalities, we have understood that it is no longer enough to face emergencies and reconstruction. As never before and as much as possible, it is necessary to prevent future crises and limit the damage. Which can be the role of urban planning in that?

Cities are both the responsible and victims of climate change effects, and yet also the potential saviours. With efficient urban planning, cities can turn in the best optimization of resources and risk reduction.

At this purpose, urban planning shall regain, though, the contact with reality, using the many theories left on paper to move to a broader vision able to read, and hence govern, the ongoing change. There should be, therefore, more communication between research groups, decision-makers and technicians.

From a strategic perspective, urban planning was responsible for managing cities' expansion dynamics in continuous development. Today, it is rather asked to work on the existing buildings to avoid further land consumption and secure the already constructed. Instead of static plans that ice entire processes, it is necessary to move to the drafting of dynamic, more interactive, and shared plans. A new urban planning season, devoted to experimentation of flexible uses and disciplines, shall implement, as soon as possible, the urban regeneration, so necessary for the present city to be prepared for emergencies.

To build the resilient capacity of cities is necessary to read the territory in all its trends, with an increasingly multi-layered knowledge, composed by the study of the subsoil, soil, topsoil and relational network (Trecciano, 2014).

Our cities must learn to respond to present necessities, but above all to future ones. For this purpose, the plans should start including the concept of reversibility and fast adaptation.

For instance, a well planned urban system can support water management in optimize transportation, demand, consumption and waste. Plans should diversify the water sources, supplied by an integrated network of centralized and decentralized infrastructures, increasing water recycling and optimizing wastewater treatments.

Cities deserve water and are the leading cause of consumption and pollution, but cities can also represent water the solution. With well and efficient urban planning, cities can think to release water better than they received. Many theories could be applied for this aim, and there are many sustainable practices, nature-based solutions, and policies going in this direction.

Urban planning is a soft and non-structural measure that provides excellent opportunities for disaster risk reduction and climate change adaptation. For example, urban systems can increase resilience to flooding risk developing urban drainage networks, perhaps integrated into infrastructure systems designed to protect from flooding. Thus, when a city acts as a sponge, limiting congestions and using rainwater as a resource, it also reduces the risk of floodings (Liu et al., 2016). Two good examples of urban planning applicated to practical projects are "*The Delta Programme"* adopted by the Dutch Government to protect the Netherlands from flooding (van Herk et al., 2013; Gersonius et al., 2016) and *"The Tsurumi River Multipurpose Retarding Basin*" in Japan (Ikeuchi, 2012), which uses spaces customarily used for parks and stadiums as floodwater retarding areas (UNESCO, 2020). Further investigations about these projects will follow.

Urban resilience is the perfect synthesis of the requirements and approaches mentioned above that urban realities should adopt.

Resilience is a process of continuous evolution, not only result of action-reaction to unexpected inputs. It should be the spinal cord of the urban system's character, fostering the spatial development through policies, planning, self-organisation and creativity (Brunetta et al., 2019).

We can define a city resilient if it can, together with all its socio-technical and ecological networks, resist and assimilate the changes and rapidly restore the required functions. An urban system can reach it, recovering from the effects of a hazard and quickly transforming its constituents that limit the present or future adaptive capacity (Meerow et al., 2016).

Urban planning shall embrace the resilience paradigm not only to overcome shocks, but also to foster preparedness and take the disturbation as an opportunity of changes. Spatial planning must identify the different types of risks and the connections between them, with their locations and natures, and only then it can be effective in the adaptation process and risk reduction (Brunetta et al., 2019).

2.7.2 Water management

Water management is the control and administration of water resources, and related infrastructures, to reduce damage to lives and properties and to optimize the efficient and beneficial use of water. Good water management, through dams, river banks or urban interventions, reduces the risk of flood damage or droughts.

Cities consume the largest amount of resources and generate huge waste outputs that impact their local and global surroundings. However, they also offer opportunities to enhance efficiency and to reduce the environmental impacts. Urban areas and their networks are mainly managed at a subnational level, municipal or city level. Urban Water Metabolism approach suggests moving from a linear perspective, with inputs and outputs, towards a networked and circoular view, where waste turns into new inputs and minimises the hinterland's dependence.

According to Musango, indeed, *"This implies that urban metabolism assessment is a relevant concept for spatial planning and urban development in order to support a resource efficiency transition"* (Musango et al., 2017).

Although there is some useful information about managing the urban water cycle, it is commonly characterized by a general fragmentation and absence of standardization of collection, analysis, and representation *(Blanca Jiménez-Cisneros; Alexandros K. Makarigakis, n.d.).*

However, research into water management is a major and indispensable step in understanding strengths and weaknesses in managing the resource, optimising it and thus reducing exposure.

2.7.3 Cooperation

- Vertical cooperation (International, National, Regional, Local)

Since the challenges that climate change is carrying are global, global must be the answer. Cooperate at the international, national and sub-national level is therefore essential to adopt practical solutions. What happened with the Paris agreement is emblematic: it would be advantageous only if all the countries, or at least all the highly polluting ones, would sign it. It is nevertheless true that anyone has to do his part, and the difference is also made through tiny steps.

In 2030 Agenda, water has the unrecognised but essential role of linking factor for achieving the various Sustainable Development Goals (SDGs). Indeed, failure to adapt to climate change puts the achievement of SDG 6 (the "water goal") at risk and with it also the achievement of most of the others. SDG 13 "*Take urgent action to combat climate change and its impacts*", from its side, includes specific targets and indicators, while there is not a particular connection between SDG 13 to the Paris Agreement targets, that remains a separated and parallel iter. Even if there is no direct reference to water in the Paris Agreement, it is a fundamental element of almost all mitigation and adaptation strategies foreseen in the agreement. However, water is the number one priority for adaptation actions in most national adaptation contributions (INDCs) and linked to all the priority fields. In the National Adaptation Plan (NAP), signed by 20 countries of the Global South in the occasion of the Cancun Adaptation Framework, there are several mentions to water. Similarly, Nationally Determined Contributions (NDCs), result of the Paris Agreement (COP 21, Paris, 2015) and of National Urban Policy (NUP), result of Habitat III (Quito, 2016), address the water issues as one of the main challenges that climate change brings to national and urban realities. In this regard, future research is encouraged.

In parallel, water is barely referred to in the Sendai Framework, even though water is an integral part of the priorities for action and central to its seven goals. The challenges of development, poverty fight and sustainability are deeply brained with climate change mitigation and adaptation, especially through the water. Given the role of water in climate change mitigation and adaptation, water could bridge the gap between the SDGs and policy frameworks, such as the Paris Agreement (WWDR, 2020).

- Transversal cooperation (Decision-makers, research groups, technicians, stakeholders and citizen)

The cooperation between the active actors is equally of primary importance towards the transition process to resilient and adaptable urban systems. It is nowadays shared that the participatory process, the top-down as the bottom-up dynamics, learning communities, are all benefits for the development framework. However, it is still too wide to use the process mentioned above only as a shallow feature, namely greenwashing or social washing. Nevertheless, especially now, the cooperation between research groups and citizen, research groups and technicians, and all of them with decision-makers is essential to address everybody's needs.

- Horizontal cooperation (Between who has already found a solution or is looking for it)

Horizontal cooperation, on the other hand, is the tool to save precious time. Indeed, collaborating with fellow citizens, international colleagues, or those who share the same problem, can lead to faster and more effective solutions. For instance, if there is a problem before to invest time and resource on understanding how to handle it, it is always better to check if anyone else has already solved it. It may never have been solved yet, of course, but throughout the investigation process, one can find interesting hints and ideas to solve it.

For this purpose, it is above all important to encourage and facilitate these kinds of networks. The database that this thesis proposes is meant precisely to foster and promote the three cooperation levels.

2.7.4 Synergetic approach

- Between theories

Many theories address the same problem, perhaps from different perspectives, but with the same objective. Aware of the delicacy of the following statement, I believe that all too often, probably because of the competitive nature of the research universe, there is a tendency to want to create one's own personal theory, thus deviating from the real final objective. Since we don’t have any longer the time of thinking at our interest, theories must communicate with each other, understanding what has already been done and what shall be implemented.

- Between theories and practices (preparedness)

Considerable effort is being put into making theories practical and operational, and the results are visible. However, in the case of emergencies there is still a tendency, and rightly so, to respond with sudden engineering or even political practices to remedy the situation as soon as possible.

The strength of the synergy between theory and practice, though, lies precisely in avoiding to reach that point. If theories were applied and operationalised into practices, we would increase preparedness, thus preventing the problem's onset.

- Between practices (multifunctionality)

The problem faced by urban systems is never unique. Indeed, given the complexity of ecosystem balances, alterations are always equally complex.

For this reason, practices should seek to respond to the most significant number of challenges, making multifunctionality the first paradigm.

3 PRACTICAL RESEARCH

Urban water solutions

Case studies

Database examples

World Heritage List for the future

The UNESCO lists are aimed at the preservation of past cultural heritage, whose safety in past years had priority. In the face of sudden climate change, it is becoming increasingly necessary to change perspective in the future.In this regard, it was decided to propose a database of best practices worldwide, the sharing of which can facilitate the flow of ideas and above all save precious time.

And especially in these difficult times, in which the attention has returned to the strictly national dimension, more than ever it is necessary to relaunch international cooperation and the sharing of beautiful and useful ideas, preferring praise rather than blame.

Sewers, pumping stations and canals form the backbone of the urban water system, and are essential for a climate-resilient city. Therefore, these are being well maintained. But that is not enough: even a robust system cannot cope with heavy downpours. The urban development needs to be adapted in order to deal with these climate effects. This is climate adaptation. We cannot do that alone as a municipality, so we are linking up and collaborating with everyone is active in the city. And climate adaptation also offers opportunities. If we do it right it offers added value for the living environment, society, ecology and economy. The RAS is a useful roadmap and forms an integral part of Rotterdam Weatherwise.

3.1 Urban water solutions

From what has been studied above, and applying the suggestions of the different theories, a change in the planning of our urban systems is necessary. The responses that could be adopted from cities are mainly of two types: for controlling the quality of water and for controlling the quantity.

- **Quality control**

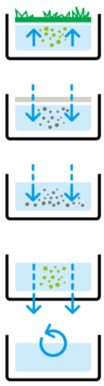
The aim of the intervention is to enhance the quality of the resource. That can be reached through different technologies and also with natural solutions. There are of course differences in timing and efficiency of the approaches but, on balance, natural solutions are considered preferable for the urban necessities.

For instance, several plants (as rise, common reed, cattail and several others) can remove from water heavy metals, pollutants or bacteria, in addition of course of absorbing CO_2 from air . A permeable soil allows water to infiltrate and recharge the reservoirs aquifers. This kind of water treatiments has optimal performances in several different conditions and combinations, with as many side effects, like soil erosion reduction and increased amenity.

- Biological uptake:

This kind of solutions aim at feeding plants by absorbing nutrients from water and soil (some examples will be discussed further below).

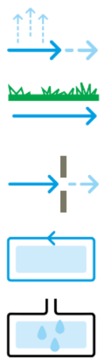
- Filtration:
  Through the insertion of a filter the sediment is separated from the resource.
- Sedimentation:
  The undesired particles deposited and get separated from the water flow
- Infiltration:
  Water get filtered through the penetration in the soil
- Recycle:
  Putting clean water back into the demand system helps to reduce the demand.



○ Quantity control

When it rains in natural areas, part of stormwater seep into the soil recharging the aquifer, part of it evaporates and partly flows on the soil, namely run off. In urban areas, the amount of run off is bigger and a good part of it can get conveyed to retention areas. It is possible to design infrastructures with the ability of plugging the over-measure volumes of water, breaking down the water speed. This kind of intervention, integrated with the previous investigated, can both control the quantity and the quality of the water, reducing the extreme event's risk. Examples of quality control solutions are:

- Conveyance:
  Controlling and fastening the run off can be effective to avoid water congestion.
- Detention:
  The detention interventions aim at controlling, preventing and minimising peaks in the rain flows.
- Storage:
  Collect and store rainwater is useful to reduce the pressure downstream and also to store water for the dry periods.
- Infiltration:
  Working on the infiltration means to increase the ground ability to absorb rainwater.
- Evaporation and evapotranspiration:
  The interventions to enhance evaporation and evapotranspiration (increasing the number of trees and plants) are useful to reduce the pressure of the rainwater, and it has as a side effect to reduce heatwaves.



As mentioned before, special attention is deserved by Natural Based Solutions. The definition that UNESCO gives of the Nature Based Solutions is "*use or mimic natural processes to enhance water availability (e.g. soil moisture retention, groundwater recharge), improve water quality (e.g. natural and constructed wetlands, riparian buffer strips), and reduce risks associated with water-related disasters, and climate change (e.g. floodplain restoration, green roofs.)*" (UNESCO).

These solutions are showing over the years the most satisfactory results in terms of effectiveness, durability and self-sufficiency.

However, it is important to emphasise that all practices, however successful they may be, should be accompanied by policies on different disciplines (awareness-raising, general climate change mitigation, energy transition, transport system transition, etc.), different time-scale (they must be part of a forward-looking strategic plan) and space (even if acting with punctual actions, it is still essential not to lose the overall network). Indeed, although it is true that even single intervention makes a difference, a network of actions is certainly more effective.

3 PRACTICAL RESEARCH

Case studies

Rotterdam
IABR Project

01 CS

Location

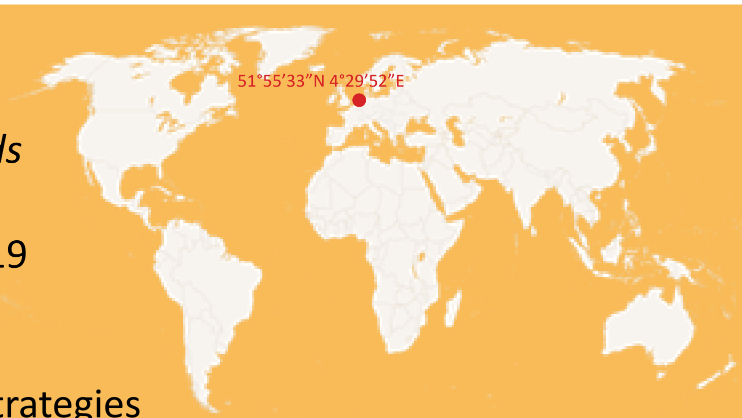
Rotterdam,
The Netherlands

Status

Finalized in 2019

Type

Analyses and strategies



Population size
2.7 million inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

Climate region
Marine West Coast
source. Kopper-Geiger

Description

The city of Rotterdam understood that to face these climate impacts, plus the urbanization problem, and ensuring at the same time liveability, equality, and sustainability, it was indispensable to have a global frame of the city.

For the International Architecture Biennale Rotterdam, continuing the path of research set out in 2003, and together with Rotterdam's municipality, it was established in 2014 the IABR PROJECT ATELIER ROTTERDAM, to study the urban metabolism.
The cities' dynamics are analysed and studied, and

Indicators

- **Multi scale metabolic integration**
- **Multi sectorial metabolic integration**
- **Resource efficiency**
- **System circularity**
- **Climate change resilient**
- **Multifunctionality of water**
- **Benefits**

Context

Rotterdam, with its 651,446 inhabitants and a density of 2.9/km2, is the second-largest city of the Netherlands and Europe's largest seaport, which makes it an ecological and economical central node. In fact, the city is located in the Rhine-Meuse-Scheldt delta, by the North Sea. The climate is temperate oceanic, with no dry season and warm summer.

Rotterdam had to handle its high vulnerability to climate impacts, such as rising water levels, intense rainfalls and heatwaves (Molenaar et al. 2013).
Regarding water management, it has to be pointed out that over the past few decades, the Rhine river, that before was a glacier river, has increasingly changed into a rain-fed river, following more significant discharge peaks lows. This leads to a higher probability that Rotterdam will be affected by floodings. Moreover, the combined effect of sea-level rise, increasing discharge dynamics and the increased likelihood of dry periods make Rotterdam vulnerable to salination. The consequences are affecting flora and fauna, which largely depend on fresh water and threatens agriculture and the city's drinking-water production.
With years of plans, policies, and interventions, (included Rotterdam's Circularity Programme 2019-2023), it is now considered one of the pioneer cities in addressing climate change-related issues, and its policy programmes and practical solutions to foster sustainability and resilience are taken as examples all over the world. However, the way is still long.

Outcomes

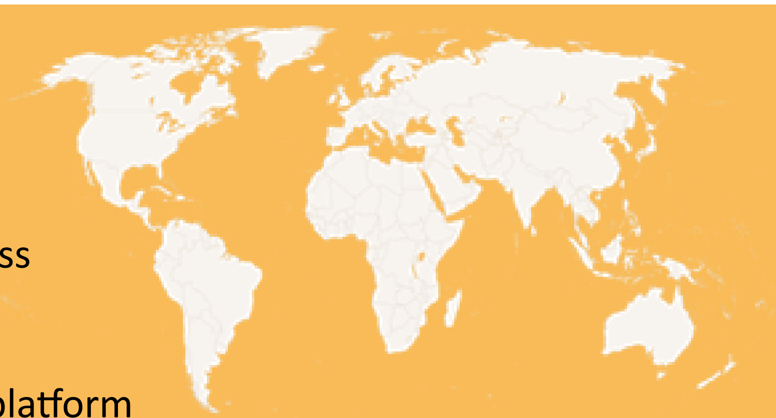
Nine vital substance flows were identified: Goods, People, Waste, Biota (e.g. fluxes of plants and animals), Energy, Food, Fresh Water, Sand & Clay, Air. The course of the various substance flows was examined, and a way was seek to increase – using these nine flows – Rotterdam environmental performance, quality of life and economic vitality.
The results of the atelier's flows analysis led to four strategies that can help create a more efficient urban metabolism with more positive effects on the quality of life. Those strategies are: Collecting resources, and so obtaining raw materials from waste and food; Creating biotopes, that exerts the improving of urban nature by local use of freshwater, sand and clay; Channelling energy waste, so the use of by-products of energy extraction; Catalysing re-industrialization, through the boosting the quality of flows of goods, people and air.

Metabolism of cities Data Hub

Database

02
CS

Location
Online



Status
Work in progress

Type
Database and platform

Population size
-
source. Worldbank

Area size
-
source. OECD

Economic type
-
source. Worldbank

Climate region
-
source. Kopper-Geiger

Description

The Metabolism of Cities Data Hub serves as a central repository for a wide variety of information about urban metabolism in cities around the world. Whether you are looking for resources on a city's infrastructure, stocks and flows, biophysical characteristics, or more, the Data Hub's well-defined structure allows users to easily search through available information. As an ongoing project, this tool is continuously improved through crowdsourcing uploads of new data and information sources.

Indicators

Multi scale metabolic integration

Multi sectorial metabolic integration

Resource efficiency

System circularity

Climate change resilient

Multifunctionality of water

Benefits

Context

Outcomes

In 2014 was set up by Paul Hoekman the no-profit organization Metabolism of Cities to share information and tools regarding the material flow analysis, and it was called MFA Tools. It has always been an open-source project, open to the contribution of people coming for the academic community.

The platform aims to help cities in achieving the United Nations Sustainable Development Goals (SDGs) by 2030.

The project aims to provide an online data dashboard for cities and researchers alike. The protype was launched in December 2018, with the official launch scheduled for March 2019.
The database is structured in three phases: data collection, data processing and data analysis.
In the data collection phase, is mainly focused on gathering datasets, geospatial information, give reports, academic work and other contextual and supporting material to provide a strong baseline before starting to work with the data.
The second phase, the data processing, consists in converting the uploaded data into a consistent format so that it can be loaded into a single database. All the data must pass through a review and being tagged and get a label before to be loaded into the system.
In the third and last phases, the data analysis, the uploaded information are put together into a system-wide look, and the information are reported in system diagrams. The aim is to better understand the dynamics of the cities in order to connect the different layers and to drive new insights.

In the project there is also an Education perspective, with the Metabolism of Cities Education Hub, Urban Metabolism & Minorities and Metabolism of Cities Living Lab. Many conferences, seminar series, exhibition and masterclass are organized every year, with a strong community sensitized to the topic.
Metabolism of Citied Hub has information about the urban metabolism of more than 80 cities, and the database helps every day in finding the data needed for better understanding urban realities.

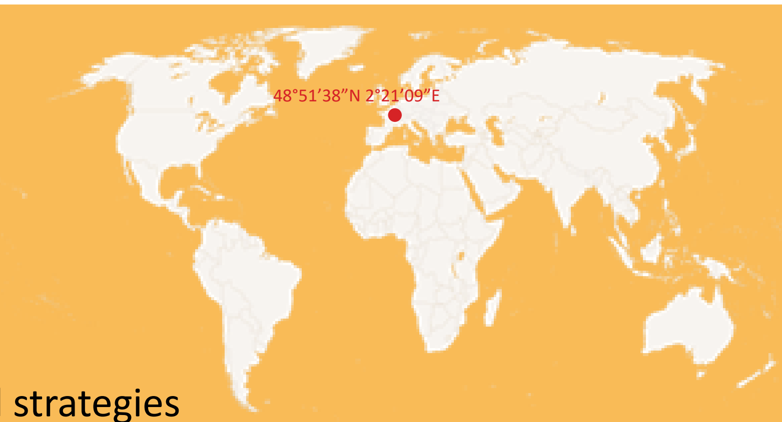
Paris

Urban Metabolism analysis

03
CS

Location

Paris, France



Status

Finalized

Type

Analyses and strategies

Population size

12.1 million inhabitants

source. Worldbank

Area size

Large Metropolitan

source. OECD

Economic type

High-income

source. Worldbank

Climate region

Marine West Coast

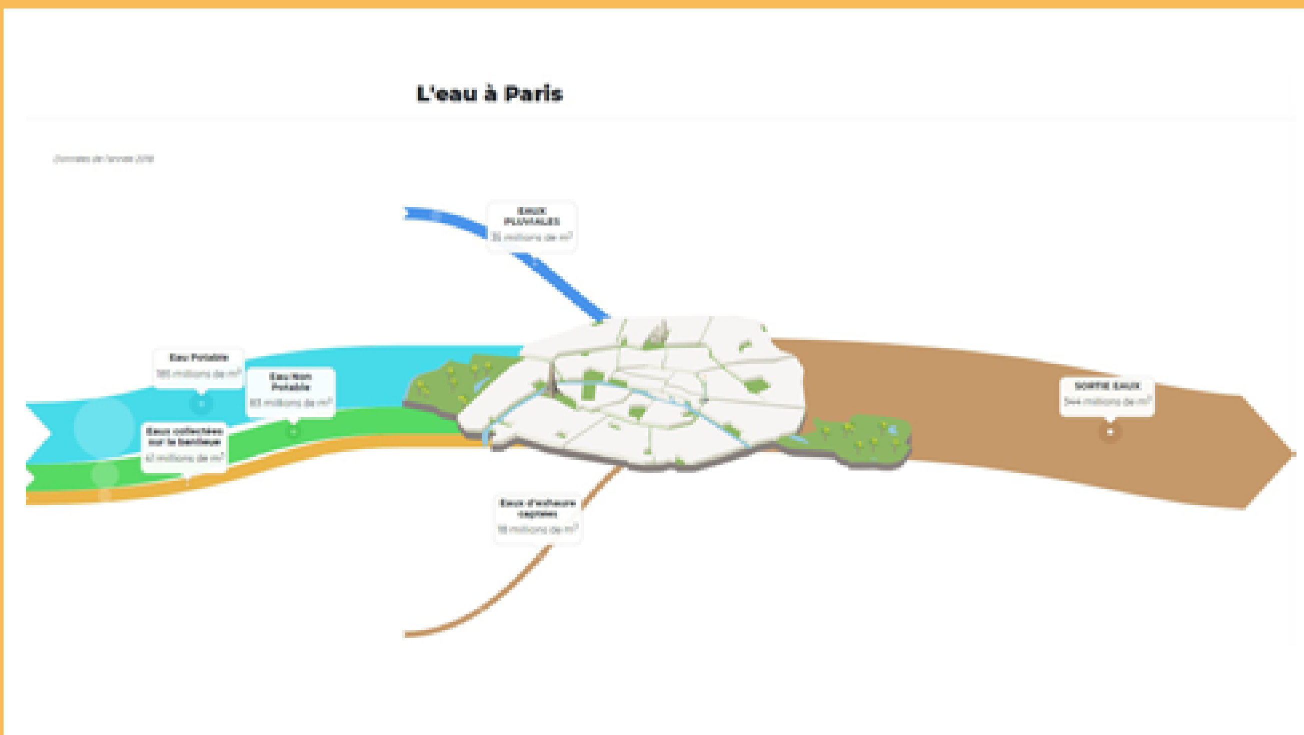
source. Kopper-Geiger

Description

For water metabolism analysis, it was done an inputs-outputs analysis in three intervals (2010, 2015, 2018), considering imported water, water collected in the suburbs, rainwater, water output and discharges to the natural environment. Subject to variations from one year to the next, the volume of rainfall in Paris has been estimated at 35 million cubic metres in 2018.

Indicators

- **Multi scale metabolic integration**
- **Multi sectorial metabolic integration**
- **Resource efficiency**
- **System circularity**
- **Climate change resilient**
- **Multifunctionality of water**
- **Benefits**



Context

Paris is the largest urban area in France and one of the largest in Europe. The population of the Greater Paris Region is about 12.1 million, with a demographic density of 20,000 inhabitants for km2. In 2017, the Paris Council adopted the Plan économie circulaire de Paris 2017-2020 and the municipal strategy was presented at the Horizon 2020 to foster a coordinated and deep change in the current economic model. This has led to a general sensitization regarding the internal fluxes, followed by analysis and strategies in different fields.
In the context of the previously mentioned platform "Metabolism of Cities", the city of Paris is the only city appearing with a 100% score of uploaded information to the platform. Indeed, the city can certainly be defined as well and widely monitored.

In 2019, according to the Global Footprint Network, the global ecological footprint was 1.75 planets. With the consumption standards of France's residents, it would have been necessary 2.7 planets: the Footprint in the country is currently almost 3 times higher than what nature can sustainably support. Starting from the circular economy model, the new aim is to maximize the use of resources that have already been extracted and inserted, in order to have less inputs as possible. This should lead to a lower level of pollution of the environment and in particular aquifers.
The promote a circular model, a better knowledge of the incoming, outgoing, or stored flows is needed, it increases the knowledge of how the territory functions and allows us to better manage its resources.

Outcomes

The scope of the study is to select the methodology for analysis, identify the available data and show the results in order to prepare the ground for strategies and plans.

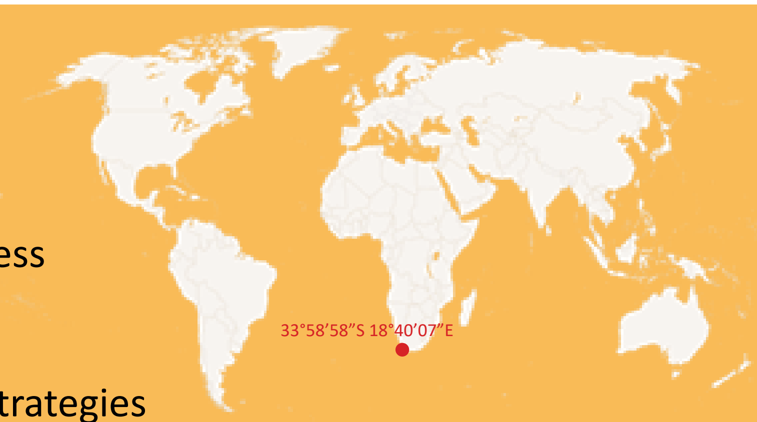
Thanks to this analysis was possible to evaluate that the resource is currently under-utilised: the vast majority of it is collected directly in the sewer network, which in case of extremely heavy rainfall may require the occasional use of "storm overflows" to prevent the network from overflowing. Strategies and directives followed to optimize the network fluxes, trying to incorporate the "cradle to cradle" approach for specific material flows as water, energy, heating. For example, one of the outputs has been the provision of heating to public buildings using heat recovery from wastewater, the rationalisation of water use and the remote monitoring of public water fountains which also helps to prevent leaks and optimised consumption.

Cape Town
Urban Metabolism analysis

04
CS

Location
Cape Town,
South Africa
Status
Work in progress

Type
Analises and strategies



Population size
433,688 Inhabitants
source. Worldbank

Area size
Large metropolitane
source. OECD

Economic type
Middle-income
source. Worldbank

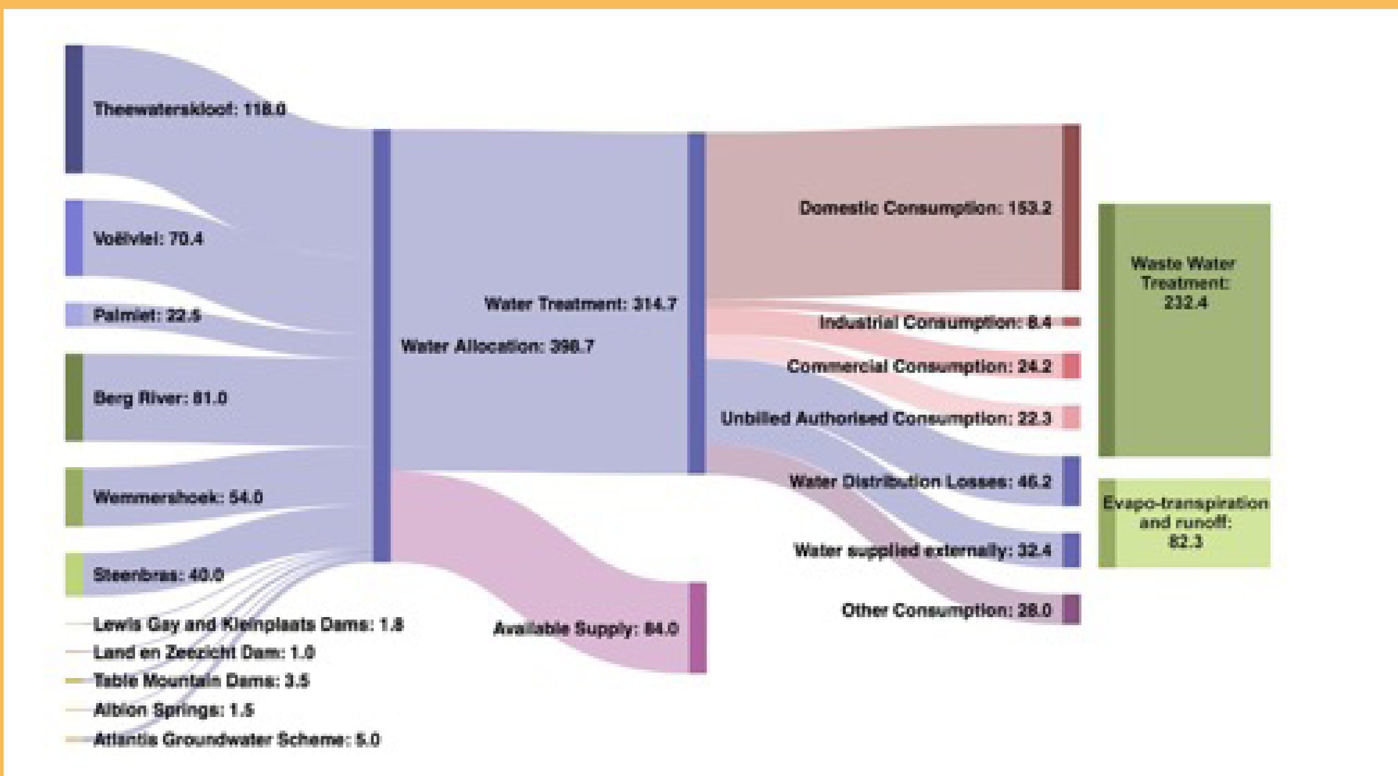
Climate region
Mediterrean
source. Kopper-Geiger

Description

The Open Data Portal of Cape Town has a starting point dataset, but it is far to be comprehensive if the purpose is to give an overview of the city's water flows. Indeed, unbundling the water metabolism of Cape Town gives greater insights about the urban water supply and about the consumption of water in the city. The project aims to accomplish the dataset, putting in connection water demand and supply, and analysing the whole network of water fluxes within the city, at both household and city-wide levels, a greater insight can be achieved, better supporting the process of decision making.

Indicators

Multi scale metabolic integration
Multi sectorial metabolic integration
Resource efficiency
System circularity
Climate change resilient
Multifunctionality of water
Benefits



Context

Cape Town, city and seaport, is the legislative capital of South Africa. With a population of 433,688 and density of 1,530/m2, it is the third biggest city of the country. The city is Mediterranean in type and the climate can be defined as temperate with dry hot summer.
Cape Town is experiencing an extreme water shortage, which has woken up the attention worldwide on the importance of water and its management. There was the necessity to analyse the entire system to understand the relation between the city and the surrounding areas, and so understand the reasons why the city found itself in that crisis and how to intervene. For this purpose, the water metabolism analysis helps to identifying the resource flows and the ways to optimize their networks, and can contribute to make the city's metabolism more effective, reducing the demand of fresh water and reducing the wastes.

Outcomes

The effect of this water crisis and the metabolic analyses was a change in vision: Cape Town is now on the way towards became a water sensitive city, where the decisions regarding water are made in more resolute and comprehensive manners.
In this vision, several shifts are expected to be seen in the way blue infrastructures are developed and the water is distributed. In particular, there is the need of changing the excess in consumption and to educate on the conservation of limited resources, it should be preferred the multiple water sources and reuse of wastewater, decentralised infrastructure systems should be preferred, diving the responsibility not only on the State but on several actors, and preferring an eco-design that absorbs and reuse water.
To realize this vision, starting from the metabolic analyses and with a water sensitive policy making process, it was realised the "Cape Town's Water Strategy" 2019, with the following strategies:

- Safe access to water and sanitation
- Wise use
- Sufficient, reliable water from diverse sources
- Shared benefits from regional water resources
- A water sensitive city

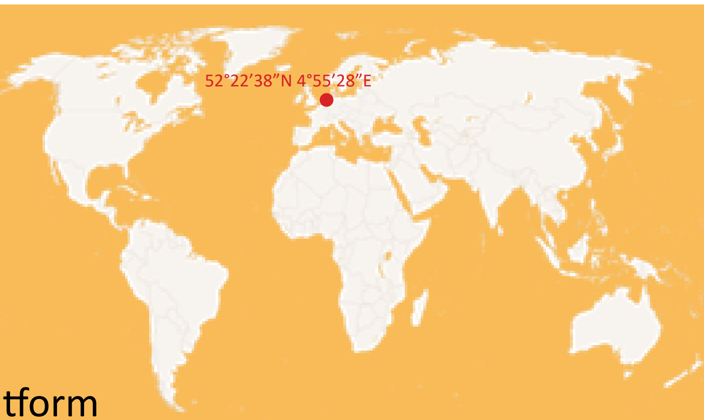
Amsterdam
Urban Metabolism analysis

05
CS

Location
Amsterdam,
The Netherlands

Status
Work in progress

Type
Database and platform



Population size
844.947 inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
HIgh income
source. Worldbank

Climate region
Marine West Coast
source. Kopper-Geiger

Description

The strategy plan of "Amsterdam Circular 2020-2025" (City of Amsterdam, 2020) has led to a general awareness on the urban metabolic fluxes and all incoming and outgoing flows were analysed, trying to transform them as circular as possible and reducing then water demand. The adopted solution was based on water reuse techniques with educational programmes and procurement tools.

Indicators

Multi scale metabolic integration
Multi sectorial metabolic integration
Resource efficiency
System circularity
Climate change resilient
Multifunctionality of water
Benefits

Context

The Netherlands is a country with a high population density, especially Amsterdam with 4,439 persons per km2 and 844.947 inhabitants in total (CBS, 2017). The Netherlands is a low-lying country surrounded by water and for this reason it is extra vulnerable to sea-level rise, as well as peak river discharges. Another issue that is notices is more intense and more frequent rainfall, which especially burdens the urban areas. A further issue concerning climate change that has been noticed is the more intense and frequent rainfall, which mainly affects urban areas.

The strategy plan of “Amsterdam Circular 2020-2025” (City of Amsterdam, 2020) has stressed the necessity to put the nutrient flows in system between them. Water reuse allows nutrient recovering (phosphates from sewage) and reduces the use of synthetic fertilisers in the city and its surroundings. The city intends to raise awareness on the benefits of water reuse targeting citizens. A single-person household consumes 52.000 litres of water per year (on average 133.4 per day) (Waternet, 2019).

Outcomes

The project, besides analysing all incoming and outgoing flows, aims to make water flows circular, especially in buildings, to reduce drinking water consumption and thus reduce water demand. Circular procurement is signalled as a key tool to promote these changes. For this regard, the main stakeholders involved in the project are the utility companies, to facilitate innovation for nutrient recovery from wastewater, and public housing associations for the implementation of closed water systems in buildings. The strategy foresees the use of organic waste and wastewater sludge as fertilisers, with the purpose of close the local nutrient cycles, lessen transportation impacts and increase the water absorption capacity of the city by expanding green spaces.

For the metabolic analyses conducted, the City of Amsterdam decided to focus on closing local nutrient cycles. The adopted solution was based on water reuse techniques with educational programmes and procurement tools.

Cape Town, South Africa

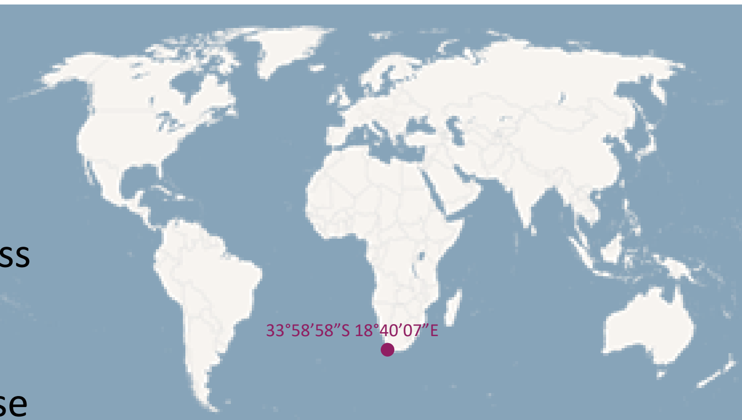
Strategies and actions

06
CS

Location
Cape Town,
South Africa

Status
Work in progress

Type
Reduction of use



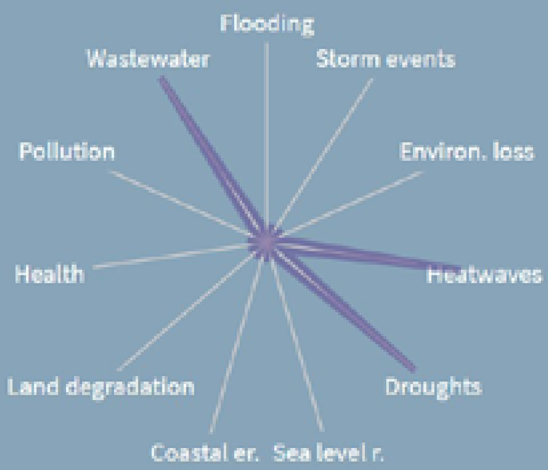
Population size
433,688 Inhabitants
source. Worldbank

Area size
Metropolitane
source. OECD

Economic type
Middle-income
source. Worldbank

Climate region
Temperate
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic

Context

Cape Town, city and seaport, is the legislative capital of South Africa. With a population of 433,688 and a density of 1,530/m2 inhabitants, it is the country's third-biggest city. The city is Mediterranean in type, and the climate can be defined as temperate with dry and hot summer. Cape Town is experiencing an extreme water shortage, which has woken up the attention worldwide on the importance of water and its management.

Despite the situation of increasing water stress, Cape Town managed to provide to its inhabitants clean and safe water. The city started a broad program, followed by strategies and actions, to increase water conservation and optimise water demand management. The final aim was to reduce water consumption and promote efficient and circular water use. The extensive program targets improvements in technical and behavioural aspects, including public awareness building, introducing a water tariff to encourage water savings, fostering recycling, and several different types of technological interventions to reduce water losses. Moreover, Cape Town's city started an initiative of free plumbing services for low-income citizens and training community plumbers. Recycled water is now used to irrigate public green areas, and 6% of all potable water is re-introduced into the circuit.

Outcomes

More than 4,000 householders have been visited to identify and repair leaks, and 258 km of water pipes were changed to reduce pipe bursts and water dispersions. The program results have been for the moment an increase of water demand at an average of 1.78%, much lower of the 4% before the interventions and also taking into account the considerable demographic growth.

Thika, Kenya

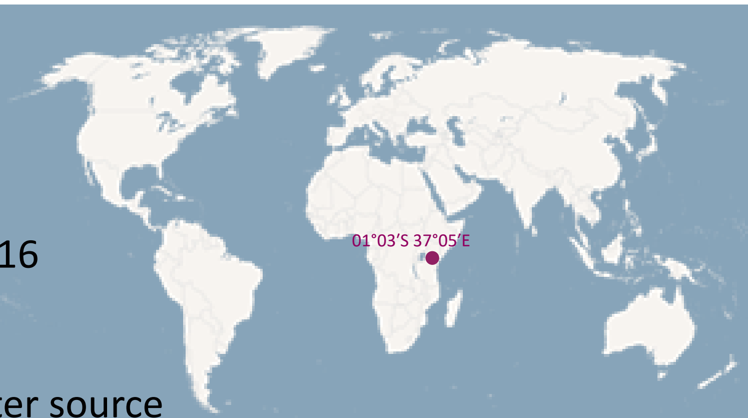
Project Majik Water

07
CS

Location
Thika,
Kenya

Status
Active since 2016

Type
Alternative water source



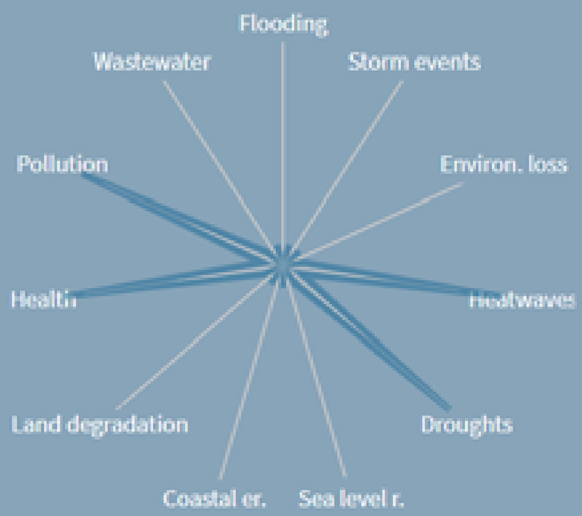
Population size
279,429 inhabitants
source. Worldbank

Area size
Medium Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

Climate region
Subtropical zone
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

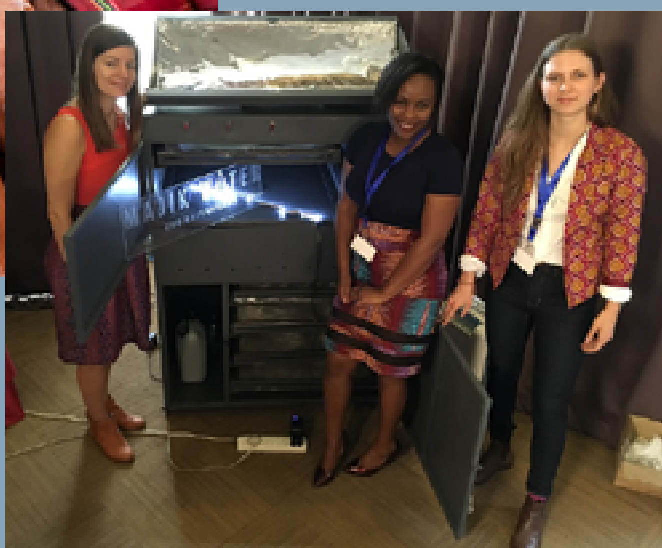
Knowledge creation

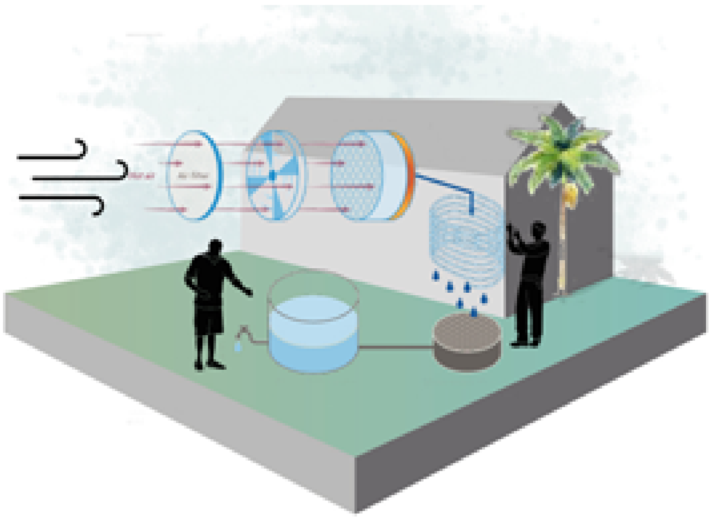
Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic





Context

Thika, in Kenya, is an industrial town with a population of 279,429, that is rapidly growing. Thika has a subtropical highland climate, with a long rains season that supplies the rivers Chania and Thika.

In 2016 Kenya had to face a considerable drought, and rivers' water was not enough to consider the possibility of filtering. Moreover, rivers have a high level of chemical contaminants that would require expensive filters. It was necessary to look for an alternative that could diversify the water sources, ending, or at least reducing, the dependence on only one water source. The solution was easier than expected: the atmosphere. "There is six times more water in the atmosphere than there is in all the well around the world," said Beth Koije, a local entrepreneur that found a possible solution to the problem, looking at the methods of plants and animals to get water.

The project Majik Water that in 2017 won the Africa start-up awards led to the construction of a machine that extracts clean water from the atmosphere, called Majik. The technology is effortless: the air is pulled in by a fan and then passed through a condenser coil. Thanks to the condensation, water is accumulated and collected in tanks, ready to be drunk. As long as you have air, you have drinking water.

Outcomes

Majik produces 50 litres per day of clean, safe drinking water, generated from the atmosphere, and the prototype is located at the Ark Children's Home, allowing them to study instead of covering miles to fetch water.

Naivasha
Sanivation

08
CS

Location
Naivasha,
Kenya

Status
Active since 2015

Type
Wastewater and energy

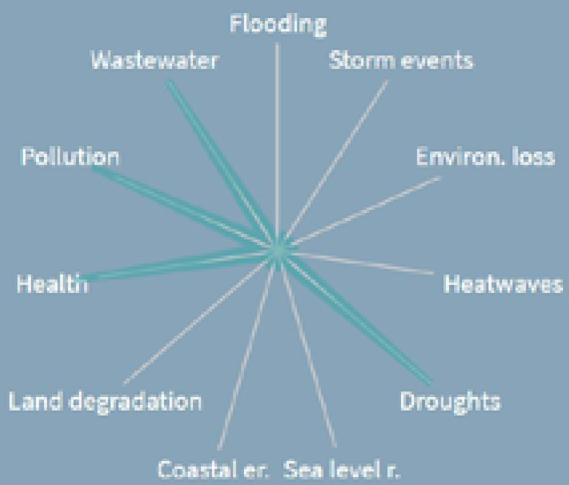
Population size
198,444 inhabitants
source. Worldbank

Area size
Small Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

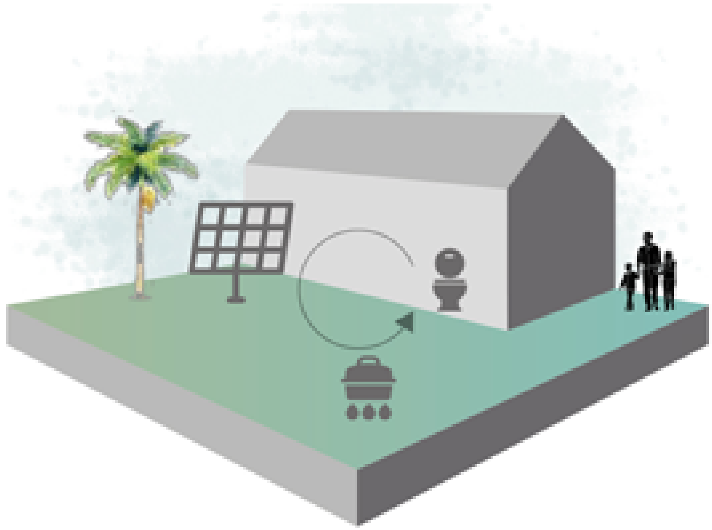
Climate region
Subtropical zone
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

Naivasha is a town in Nakuru County, in Kenya. The inhabitants are 198,444, and the primary industry is agriculture, that clearly has a high impact on aquifers. The climate is subtropical highland.

The Naivasha wastewater treatment plant facility was unable to treat all the waste properly is received and regularly released inadequately treated waste into Lake Naivasha. Meanwhile, the sanitary situation, with the spread of diseases, was becoming increasingly critical.

The project, called Sanivation, started in 2015 and is already active in three cities.
With the intent of reducing the use of water and at the same time ensuring the right to sanitation, this local initiative starts providing toilets and waste treatment to the population. The idea is to intake and treat faecal sludge, transforming it into biomass fuels to replace firewood in industrial boilers. The waste is treated with a solar-powered technology, ensuring that all the pathogens are killed in a very sustainable way. Moreover, the revenue from the product's sales, the fuel, covers the operational costs, ensuring the sustainability also from the economic point of view.

Outcomes

Already 20,000 people have now access to sanitation services, and the number is expected to rise up to 100,000, producing 1,200 tons of fuel per month.
The benefits are not only for population: thanks to the biomass fuels produced, the number of trees cut down is reduced, and less carbon dioxide is emitted because the burning time is inferior compared to the traditional charcoal.

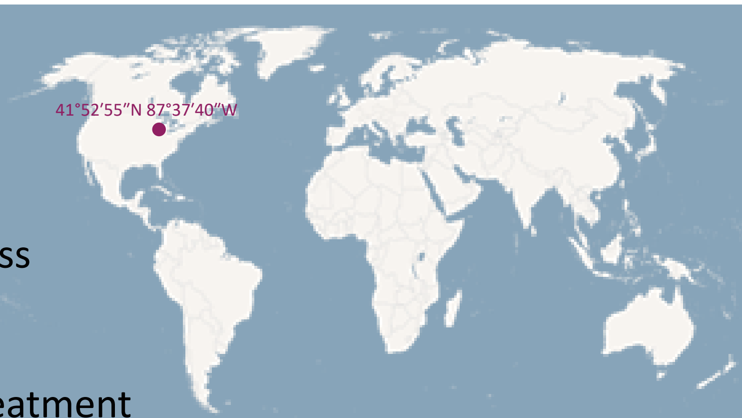
Phosphorus Recovery System
Wastewater treatment and phosphorus

09
CS

Location
Chicago,
USA

Status
Work in progress

Type
Wastewater treatment



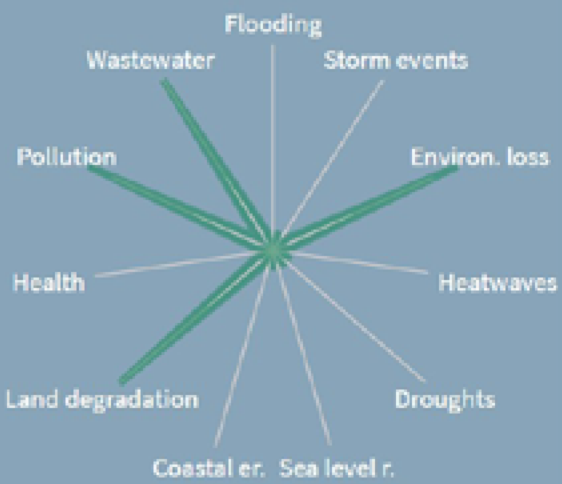
Population size
2,6 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
High income
source. Worldbank

Climate region
Humid continental
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

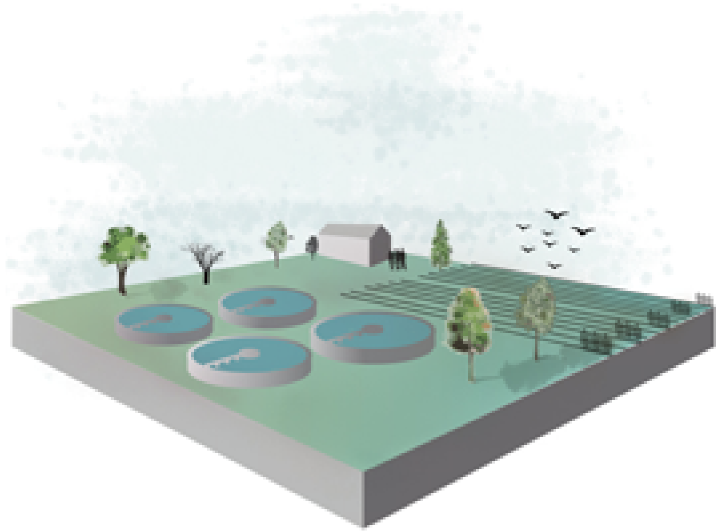
Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic



Context

Chicago, the third most populous city in the USA, has an estimated population of 2,6 million. A humid continental climate characterizes the city, and it is often prone to heat as cold waves.

The city has the world's largest sewage treatment plant, and about 750 million gallons (almost 3 billion litres) of water are discharged every day. This means that a massive amount of wastewater is discharged in rivers all the way to the Gulf of Mexico, with all the pollution connected to that. One of the pollutants that they had to remove in the treatment plant is phosphorous, because in excessive quantities in the waterway encourages algae to grow, risk inking clogging the waterway. Excess phosphorus can also be a critic threat to aquatic life in lakes, rivers and ocean. However, phosphorous is an essential element for life and a finite resource: scientists fear that there could be a global shortage of phosphorous as early as 2035.

Phosphorus Recovery System at Stickney Water Reclamation Plant starts from the idea of recovering and not wasting the important resource of phosphorous and trying to harvest it. In more details, phosphorous is bound up in the organic material, which they separate from the water.

Outcomes

Thanks to this project, they manage to recover about 85% of the phosphorus was recovered and more than the 15% of the nitrogen was recycled from the wastewater. The plant has a capacity of up to 10,00 tons of high-value, continuous-release fertilizer.

All-gas
Wastewater treatment and biomass

10
CS

Location
Chiclana,
Spain

Status
Active since 2017

Type
Wastewater treatment

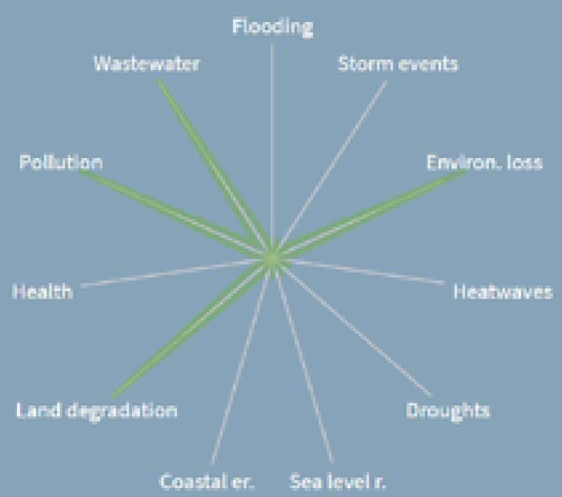
Population size
83,831 inhabitants
source. Worldbank

Area size
Small Metropolitane
source. OECD

Economic type
High income
source. Worldbank

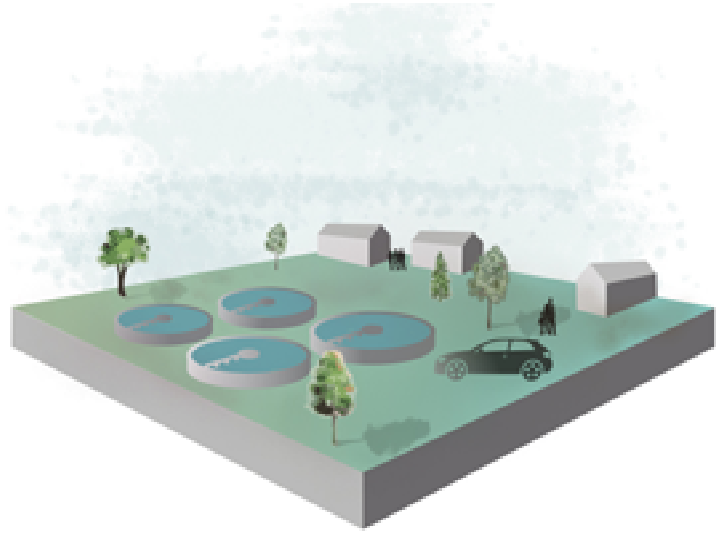
Climate region
Temperate
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

Algae are historically considered, and used, as for the water industry. Starting from a call launched by the European Union Commission, Aqualia understood the potential of using algae for biomass, using wastewater in order to avoid artificial fertilizer and do not waste that resource. From this idea, the project to convert algae into low-cost clean energy using wastewater grew successfully and saw its first crop of algae biomass in Chiclana, Southern Spain.

The principle is to harvest the nitrogen and phosphorus from wastewater through microalgae biomass, feeding the algae with wastewater. With flotation, they separate the algae from the water and pump them into the digestor where it gets converted into biogas or methane, once they add the gas purification steps.

Outcomes

The algae clean the wastewater and have enough algae to harvest and use for biofuel. They could put these algae ponds all over Andalusia, and this would be enough to fuel 20 car each running 20,000 km per year. The biomass obtained has shown a high energy potential, with a methane production capacity of around 200-300 litres of gas per kilogram of biomass processed by anaerobic digestion. The microalgae, at the same time, purify the wastewater, preserving the environment quality.

Vancouver Coast

Climate Change Adaptation Strategy

11
CS

Location

Vancouver,
Canada

Status

From 2012

Type

Adaptation strategies and coastal protection

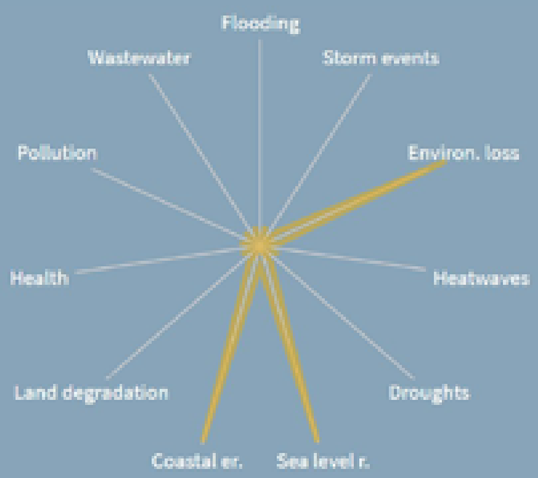
Population size
631,486 inhabitants
source. Worldbank

Area size
Small Metropolitane
source. OECD

Economic type
High income
source. Worldbank

Climate region
Oceanic
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

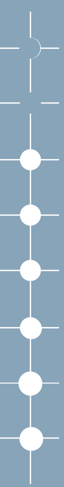
Knowledge creation

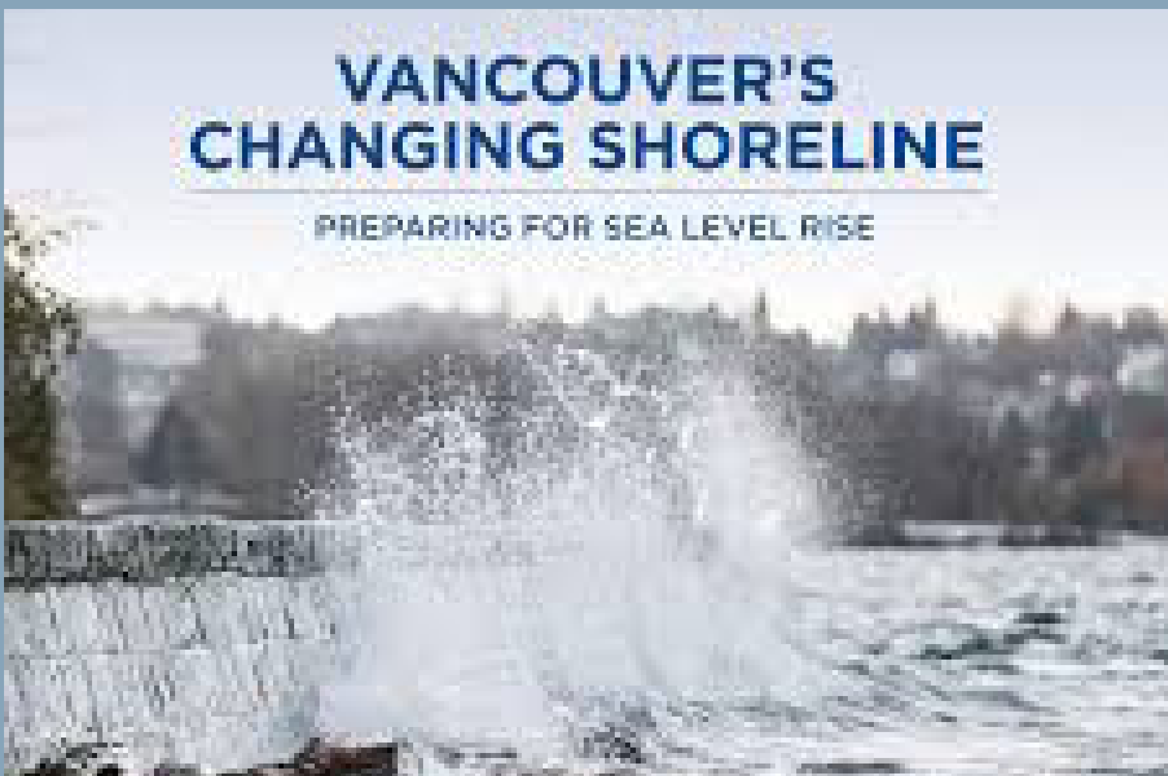
Replicability, efficacy, sustainability

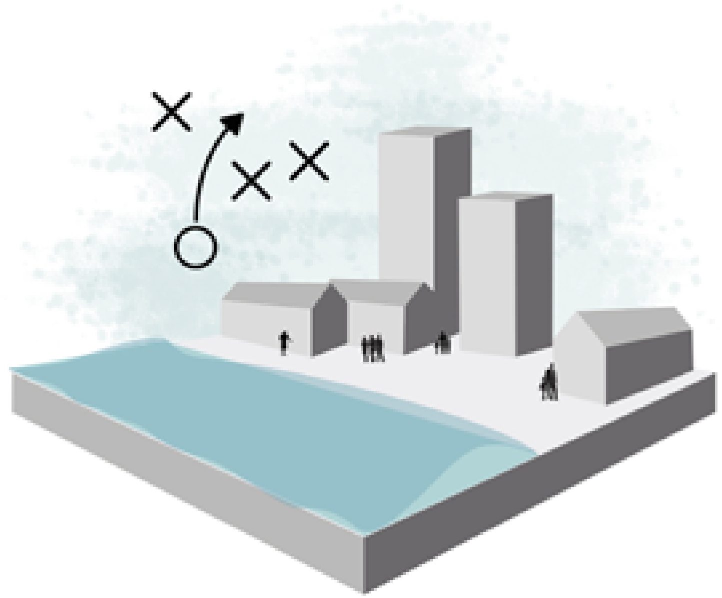
Participation and governance

Special criticism

Benefits Ecosystemic Social Economic







Context

Vancouver, the third-largest metropolitan area of the country, is located on the western side of Canada, in British Columbia, with 631,486 inhabitants and a density of 2,584/km2. The climate is oceanic west coast, characterized by one of Canada's warmest winter.

Vancouver has been ranked among the most vulnerable cities to sea-level rise and the consequences of climate change, as coastal erosion and rise, are visible in many areas. Coastal floodings are expected to cause massive economic implications for the city, and they realized that it was necessary to protect human, physical and financial capital. This has led to a general increase in awareness about the city's vulnerability to climate change hazards.

In 2012, the Vancouver City Council adopted an extensive Climate Change Adaptation Strategy. The construction regulations require any new development to take account of sea-level rise by considering the appropriate elevation. Furthermore, a Coastal Flood Risk Assessment (CFRA) was developed, with specific adaptation solutions for every area for sea-level rise and flooding risk.

Outcomes

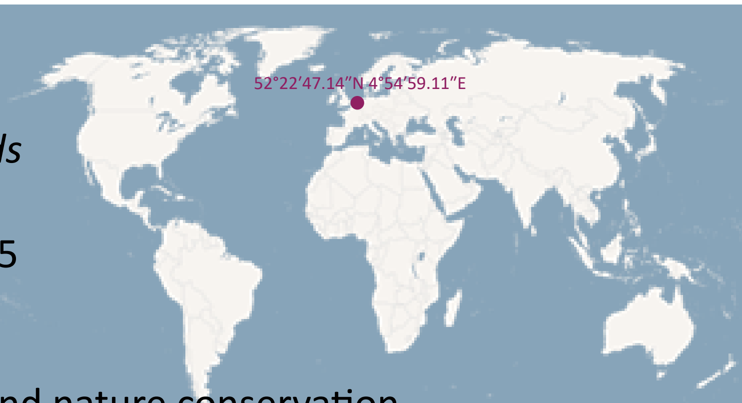
All this has generated a widespread awareness, including transportation compartment, government agencies and stakeholders. Moreover, Vancouver gave an example, and many other cities are mobilizing their energy to develop climate change adaptation strategies.

Amasterdam Dunes
Water supply and nature conservation

12
CS

Location
Amsterdam,
The Netherlands
Status
Pilote p. in 1995

Type
Water supply and nature conservation



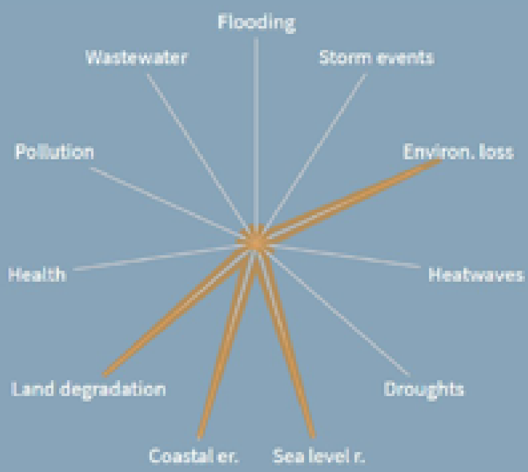
Population size
source. Worldbank

Area size
source. OECD

Economic type
High income
source. Worldbank

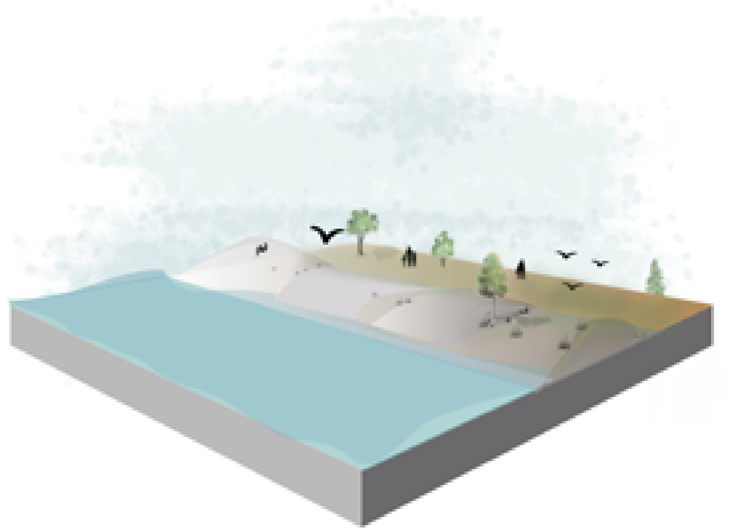
Climate region
Oceanic
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

The site is a 3,400 ha area, propriety of Amsterdam’s municipality, and part of the Natura 2000 network of sites. The area is located in North Holland, in the northwestern part of the country, on the North Sea, with a temperate maritime climate.

Since 1850 the area was affected by a deterioration in size and quality, due to the desiccation from water extraction and the acidification and eutrophication from air pollution. Fortunately, in the last years, the general environment quality has improved thanks to a change in water management.

Amsterdam Dune project, coordinated by Waternet, started in 2012 and is part of a series of large-scale projects aimed at restoring the natural dune systems and wetland habitat. The aims of the project are nature conservation, drinking water supply and recreation of the population. This led to grass and shrub encroachment and accumulation of nitrogen-rich organic matter in the topsoil. In recent decades, these negative environmental impacts have decreased but to stimulate the recovery of nature, it is necessary to remove the nitrogen-rich top layer of soil and carry out other nature management measures, such as tackling the recent expansion of invasive black cherry (Prunus serotina). Project implementation will focus on the removal of vegetation and soil organic matter to begin the process of recovery.

Outcomes

Despite the short time, the project is already showing benefits in nature conservation and is protecting the coasts from erosion. Benefits are also visible concerning the “humid dune slacks”, which have been rapidly recolonised by several fauna and flora species. Amsterdam’s water supply is no more depending on deep pumping of groundwater, and in fact, it has been replaced by the freshwater obtained by filtering the Rhine water through the dunes.

Chengdu
Rivers clean up and Living Water Garden

13
CS

Location
Chengdu,
China

Status
Since 2000

Type
Water quality and flooding protection

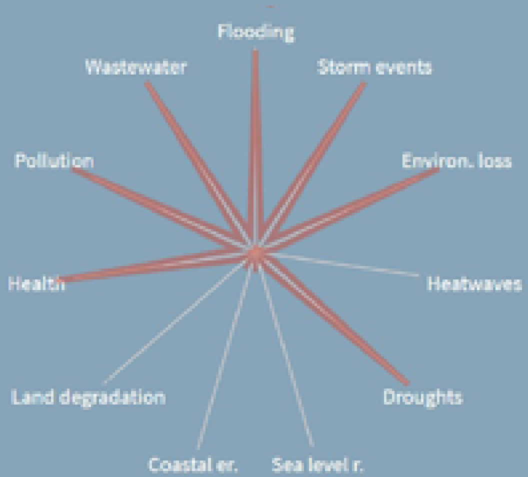
Population size
11,2 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
Middle income
source. Worldbank

Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Context

Chengdu, localized in Sichuan's Chinese province, is one of the three most prominent cities in Western China. The urban population is about 11,2 million and the economy is one of the poorest of the country. The climate zone is humid subtropical with the influence of monsoon.

The increasing demand of water, the high level of pollution of the rivers, and the population's sanitation needs prompted a widespread mobilisation, both public and private, to improve the water quality of the two rivers Fu and Nan. Furthermore, in 2008, a heavy earthquake gave the administration an impulse to invest in better infrastructures and disaster preparedness.

Outcomes

The city of Chengdu, with the involvement of inhabitants and local firms, decided to invest in catchment protection initiatives in order to improve the water quality, both surface and ground reservoirs. They dredged 16 km of river and cleaned 750,000 cubic metres of sludge. Two new sewage treatment plants were built in the area, and they did a plan to redirect the traffic along the river to reduce pollution and congestion.
Interventions for widening the rivers have been realised to prevent floodings. Furthermore, the already existing Living Water Garden, one of the most ancient river diversion system, is now a living, environmental education centre with a fully functioning water treatment plant.

The area of Chengdu was also the object of several re-naturalization projects that have led to the spread of plants and parks on riverbanks, creating several green corridors and contributing to a rapid nature conservation action. General awareness, economic boom and green policies are only a few of the several benefits this project brought to Chengdu.

VicInAqua
Victoria Lake

14
CS

Location
Victoria Lake,
Kenya, Tanzania, Uganda

Status
Pilot p. in 1995

Type
Water quality and aquaculture program

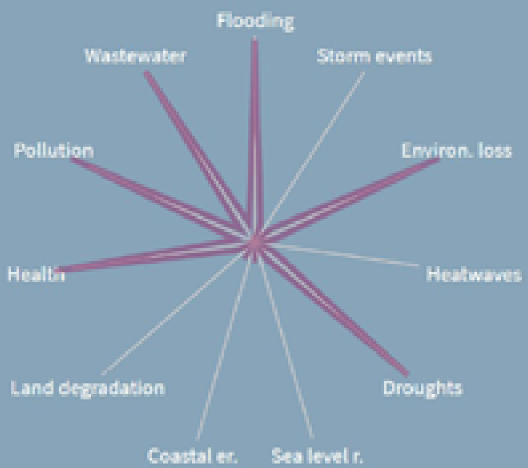
Population size
source. Worldbank

Area size
source. OECD

Economic type
Low income
source. Worldbank

Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic

Context

Lake Victoria, shared by Kenya, Tanzania and Uganda, is the largest lake of Africa and the world's second-largest freshwater lake.

Many cities and towns rely on the lake for freshwater, and the lake is also the largest inland fishery. The demographic growth, the overfishing, in addition to climate changes, are seriously endangering the equilibriums of the lake's ecosystem.

VicInAqua, funded by the EU in collaboration with eleven partners from seven Africa and European countries, launched Lake Victoria's project. This consists of an integrated approach to aquaculture and water management to guarantee the nature conservation, fishing productivity, and the increase of freshwater supply. The project also aims to regulate the use of fertilisation, that had caused an increase in nitrogen and phosphorus levels.
Regarding the aquaculture, the Recirculating aquaculture system (RAS) can reuse up to 95% of process water combined with membrane bioreactor (MBR) treating domestic wastewater and turning it into quality water for aquaculture and irrigation. A Recirculating Aquaculture system occupies a little portion of land; it can be localised and used close to settlements. The core concept of the project is to create an integrated system of sanitation and aquaculture.
The system that would be structured in the self-cleaning water process through natural filters and the water will be used for agricultural irrigation and the surplus sludge for production of biogas.

Outcomes

This project has already brought several benefits from the environment point of view and from a socio-economic perspective. Indeed, it has boosted job creation, a better gender balance and several green policies and strategies.

Eco-Boulevard and the Water Arena

Bologna, Italy

15

CS

Location

Paris,

France

Status

Realised in 2018

Type

Mapping for preparedness

Population size

390,000 inhabitants

source. Worldbank

Area size

Medium Metropolitan

source. OECD

Economic type

High-income

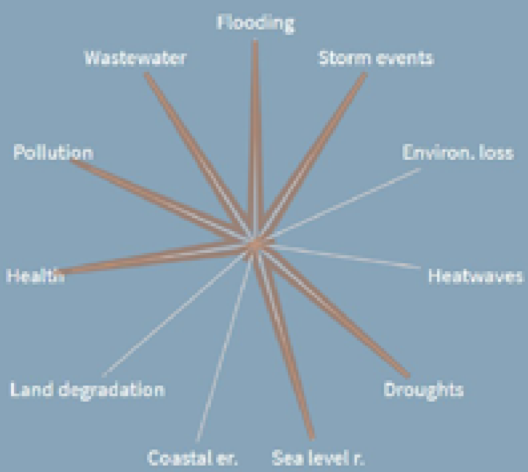
source. Worldbank

Climate region

Temperate

source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

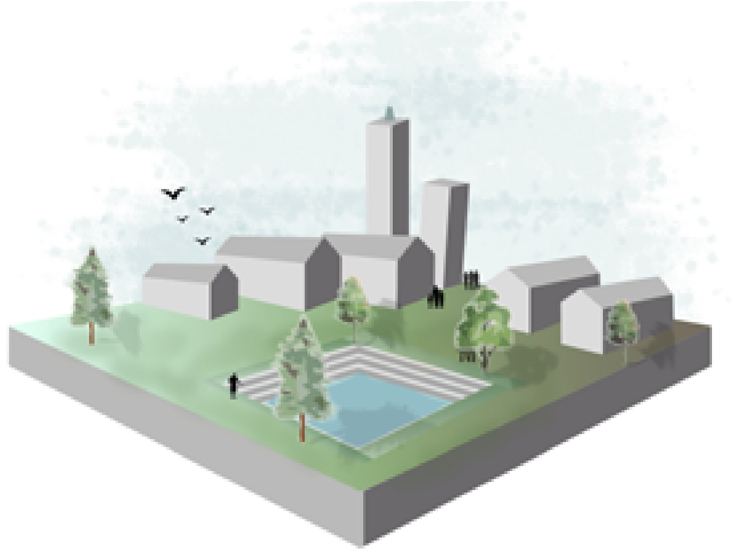
Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic



Context

Supported by IRIDRA and funded by the European Investment Bank, Bologna and Atkins developed the study “Climate Change Adaptation and Resilient Cities”. In this framework, The Water Arena was one of the project proposals made by IRIDRA for the adaptation to Climate Change of the Municipality.

The project proposal has been developed in more detail at the level of architectural insertion in order to enter the “Guidelines on the adoption of sustainable urban drainage techniques for a more climate resilient city”, one of the actions of the Bologna Climate Change Adaptation Plan, developed within the Life BlueAp project, www.blueap.eu). The project proposal foresees an Eco-Boulevard and a Water Arena, conceived along the central ridge of the new Lazzaretto district and including the insertion of sustainable urban drainage solutions (Sustainable Drainage Systems - SuDS) along a 200 m stretch of road, conceived as a pedestrian area, and a 2500 m2 square. Fourteen bioretention systems, each of about 15 m2, dry vegetated channels with drainage (Swales), and a dry urban detention basin of 1400 m2 were placed. Rainwater falling on the right-hand side is sent to the bioretention areas, while rainwater falling on the left-hand side is conveyed by the vegetated channels to the detention basin in the square.

Outcomes

The purpose of the bioretention areas is to store and treat runoff. The detention basin, which is part of the urban context of the Arena dell’Acqua, receives rainwater falling on the left-hand side of the Eco Boulevard, conveyed by the vegetated channels, and rainwater falling on the square itself. The rainwater is discharged into a gully with a calibrated inlet, while a second gully is equipped with an overflow. In this way, the rainwater is laminated, reducing the peak flow rate discharged into the sewer system and allowing controlled flooding in different parts of the square according to different rain intensities, while maintaining a safe water level (maximum 50 cm).

Mangroves and Markets Project
The Mekong Delta

16
CS

Location
Ca Mau province, Vietnam, Thailand

Status
Started in 2013

Type
CC adaptation strategies and aquaculture

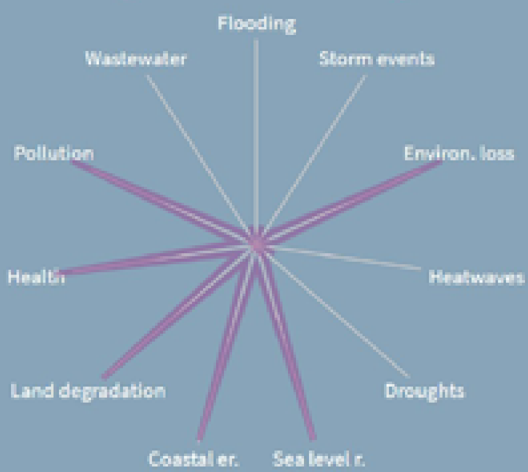
Population size
315,279 inhabitants
source. Worldbank

Area size
Medium Metropoli-
source. OECD

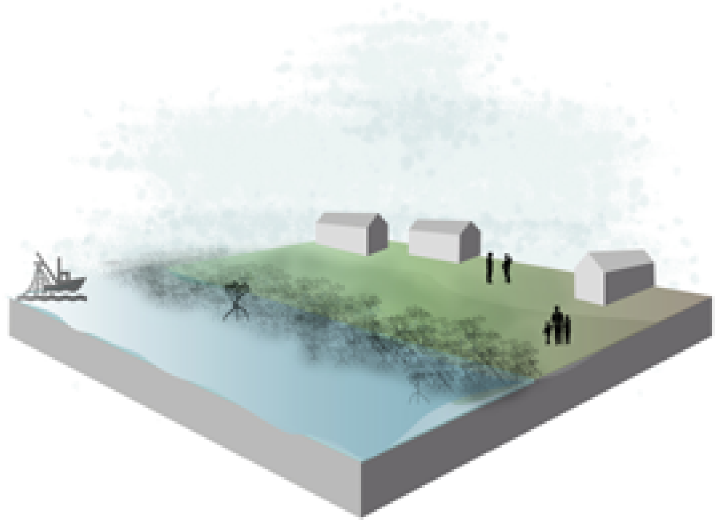
Economic type
Low income
source. Worldbank

Climate region
Tropical
source. Kopper-Geiger

Description



Indicators



Context

The Mekong Delta, located in the western part of Vietnam, is the region where the river reaches the ocean. The climate is tropical, with an annual average of 23°. The Mekong Delta is known as an “ecosystemic treasure”, due to its high biodiversity. The area is naturally susceptible to floods, and with climate change and sea-level rise, the situation has been exacerbated.

In the past 30 years, the region suffered from a massive loss of its mangroves (it has been estimated more of the half of them), connected to the shrimp industry and its ponds. This led to several ecosystemic consequences, as mangroves protect against tidal waves and swells, and are vital for fish growth.

The Mangroves and Markets (MAM) project took birth precisely in Ca Mau province, with a collaboration between Vietnam and Thailand, and wanted to couple the climate change adaptation and the sustainable aquaculture.
Indeed, the organic farming of black tiger shrimps, thanks to integrated national and international policies, was linked with the coastal protection and the restoration of coastal mangrove forests.

Outcomes

This project, started in 2013 and currently ongoing, has already improved the subsidence of 2,000 families, restored and conserved 12,600 hectares of mangroves, thus giving a massive contribution to climate change adaptation and mitigation.

Fondo Agua
Por la Vida y la Sostenibilidad

17
CS

Location
Cauca Valley, Colombia

Status
Started in 2009

Type
Several projects for preserving water

Population size
4,4 million inhabitants
source. Worldbank

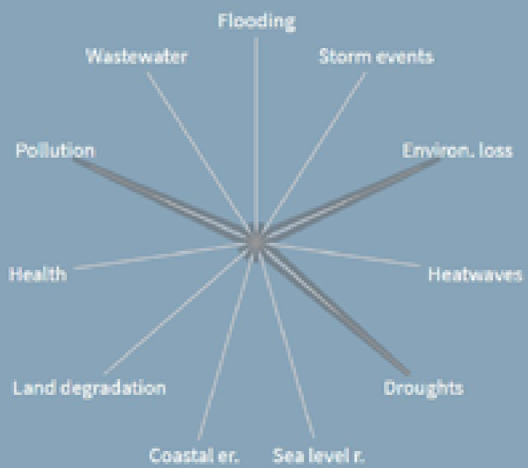
Area size

source. OECD

Economic type
Low income
source. Worldbank

Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

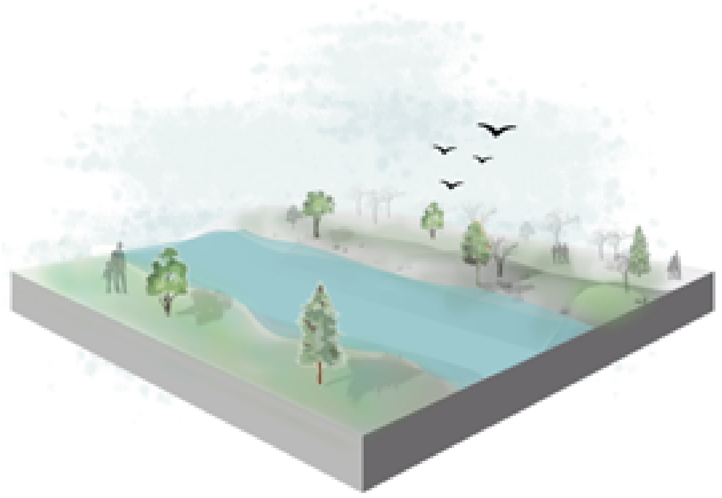
Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic



Context

Cauca Valley is a region located in the western part of Colombia. The Pacific Ocean and the Cordillera Central bound the area, creating different types of climate, generally tropical but also savannas, deserts and mountain climate. In the region, there are 4,4 million inhabitants with a density of 200/km2.

The area has been subject to several and severe droughts in the dry season, and it is affected by a general impoverishment of the quality of the water resource.

To interrupt this trend and to preserve the resource quality, in 2009, this fund was established. From that moment, several projects were launched, improving the likelihood for rural inhabitants and protecting the biodiversity. The project themes vary from reforestation, riparian conservation, improvement of agricultural and breeding practices. The local communities understand that with more sustainable techniques, they would have economic benefits as well and in the region, general awareness about climate change effects can be seen.

Outcomes

Since its creation, Fondo Agua por la Vida y la Sostenibilidad has invested more than 32 billion pesos in 29 municipalities where water is supplied to more than 3.5 million inhabitants in 3 departments.

Through the foundation, the design, management and implementation of integrated watershed protection projects will continue, in order to contribute to improving the quality of life of the communities, taking into account watershed management and current environmental regulations

Turn Green and RESIN Project
Bratislava

Location
Bratislava, Slovakia

Status
Plan 2017-2020

Type
Climate change adaptation strategies

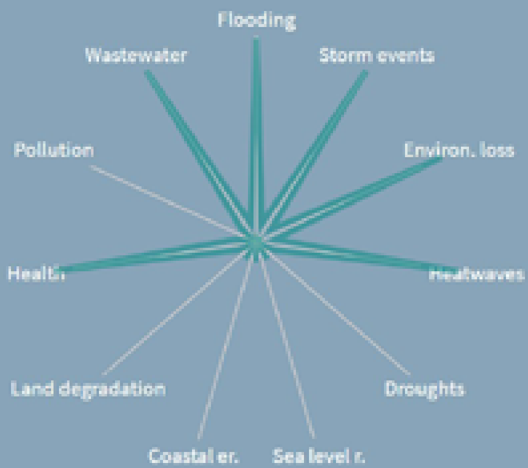
Population size
430,000 inhabitants
source. Worldbank

Area size
Medium Metropoli-
source. OECD

Economic type
High income
source. Worldbank

Climate region
Continental
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic

Context

Bratislava, the capital of Slovak Republic, has a population of about 430,000. The city is watered by the River Danube and the River Morava. The climate is continental, with an average temperature of 10.5°.

In the past years, Bratislava suffered from heatwaves, droughts and also of floodings and heavy storms.

To face the increasing climate change effects, Bratislava started an effective political commitment through several adaptation actions. In 2012 Bratislava signed the Covenant of Mayors and in 2014 the Mayors Adapt, starting a pledged period of sustainable city development, urban planning and urban water agenda.

In particular, the plan for adaptation to climate change 2017-2020 foster the following strategies: protecting the vulnerable population and reducing the risk exposure, minimising the carbon footprint and developing green infrastructures and soft adaptation solutions to harvest and recycle rainwater.

Outcomes

The municipality also promoted the private participation in the flooding protection through subsidy and fiscal incentives up to 50% of the total.

This led to a spread of rainwater catchment tanks, rain gardens, green roofs and many other solutions, both in private and public spaces.

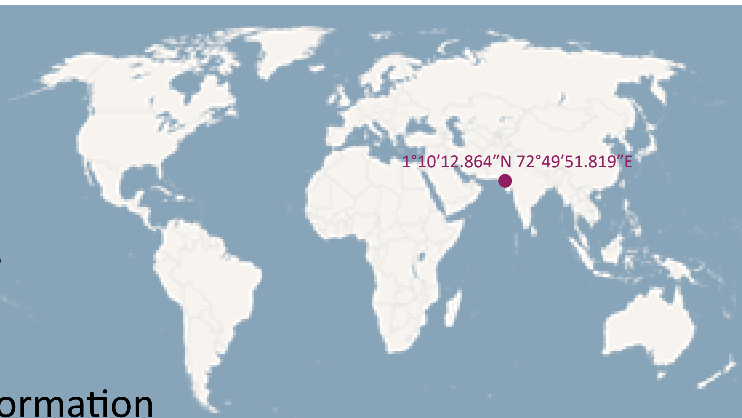
Surat
India

19
CS

Location
Surat, Gujarat, India

Status
Started in 2018

Type
Resilient transformation



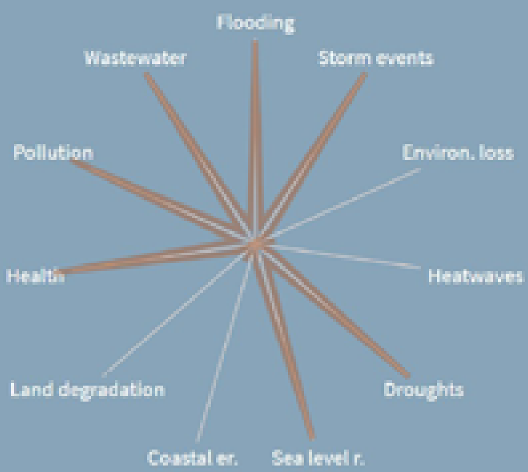
Population size
6,1 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic

Context

Surat is a city situated in Gujarat's Indian state, with 6,176,000 inhabitants, and it is located at Tapi river's estuary in the Arabian Sea.

The location has historically exposed Surat to floodings, and besides, seasonal droughts and flooding from rainfall exacerbate these problems. Indeed, the city loses an average of $30 million per year due to flooding, and 6.4 million people are highly risk exposed. These numbers are predicted to rise due to the increasing impact of climate change and the demographic increase.

Thanks to a partnership with the city of Rotterdam and the European Union, Surat started in 2018 his strategic resilience process, developing technical and infrastructure-oriented water management strategies. In particular, they decided to increase the quality of drinking water, mitigating water pollution, protecting against flooding, and harvesting rainwater. The resilient process was led by two projects to install rainwater harvesting systems and create water plazas.

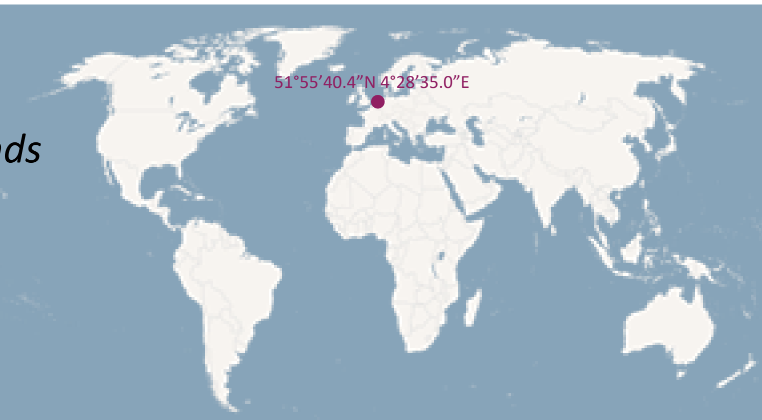
Outcomes

Surat can now rely on 1,350 rainwater harvesting systems. This helps to replenish groundwater and ensuring an alternative source of water supply. Moreover, the water plazas in designed to collect 200 million litres of flood and rainwater per year, with a capacity of 2.95 million litres.

Water Square Benthemplein
Rotterdam

Location
Rotterdam,
The Netherlands
Status

Type
Rainsquare



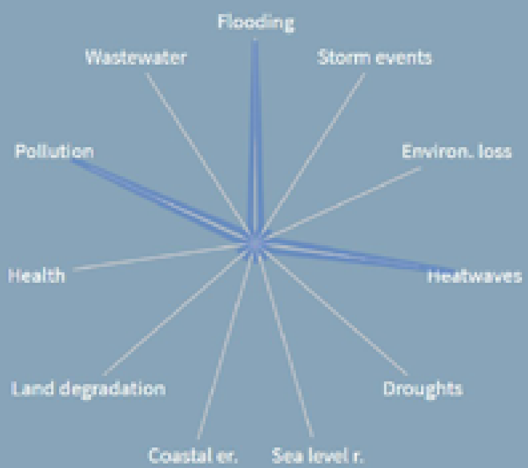
Population size
651,446 inhabitants
source. Worldbank

Area size
Metropolitane
source. OECD

Economic type
High income
source. Worldbank

Climate region
Temperate oceanic
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic

Context

With its 651,446 inhabitants and a density of 2.9/km2, Rotterdam is the second-largest city of the Netherlands and Europe's largest seaport, which makes it an ecological and economical central node. The city is located in the Rhine-Meuse-Scheldt delta, by the North Sea. The climate is temperate oceanic, with no dry season and warm summer.

Rotterdam had to handle its high vulnerability to climate impacts, such as rising water levels, intense rainfalls and heatwaves (Molenaar et al. 2013).
Regarding water management, it has to be pointed out that over the past few decades, the Rhine river, that before was a glacier river, has increasingly changed into a rain-fed river, following more significant discharge peaks lows. This leads to a higher probability that Rotterdam will be affected by floodings. Moreover, the combined effect of sea-level rise, increasing discharge dynamics and the increased likelihood of dry periods make Rotterdam vulnerable to salination. The consequences are affecting flora and fauna, which largely depend on fresh water and threatens agriculture and the city's drinking-water production.

Outcomes

The square has the multi-function of protecting the population from extreme events and creating a usable space for the citizen. Three basins collect the water with an estimated amount of 1,700 m3 water delayed.
After the rainfall, the water from the two shallow basins seeps through an underground infiltration system and from there it gradually penetrates the groundwater. In this way, the aquifer level is maintained and can also face periods of drought. This helps to keep the urban vegetation in good condition, which helps to reduce the risk of heatwaves.

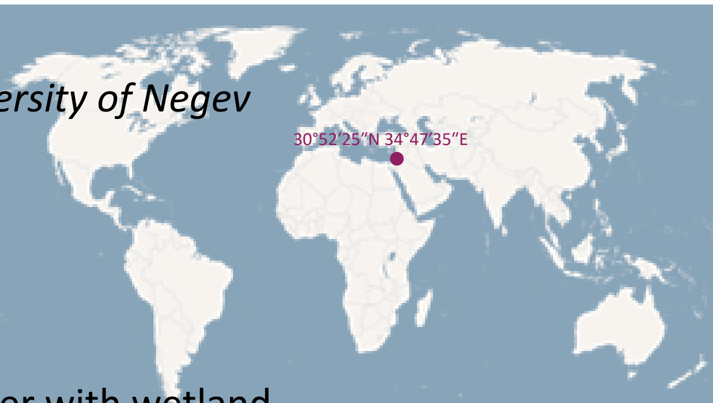
Recycling domestic water
Israel

21
CS

Location
Ben-Gurion University of Negev
Israel

Status
Work in progress

Type
Filtering greywater with wetland



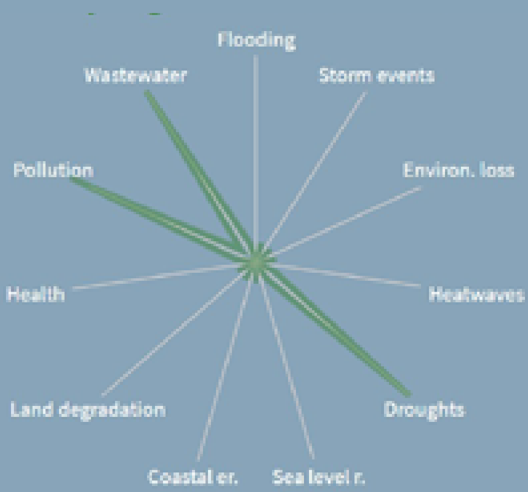
Population size
11,2 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

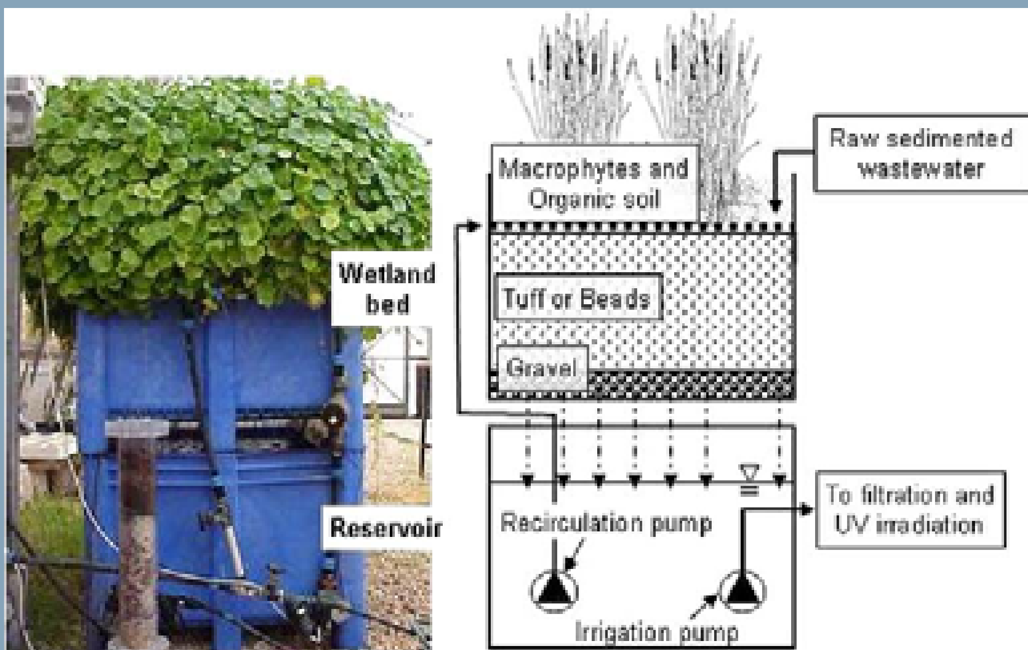
Climate region
Tropical
source. Kopper-Geiger

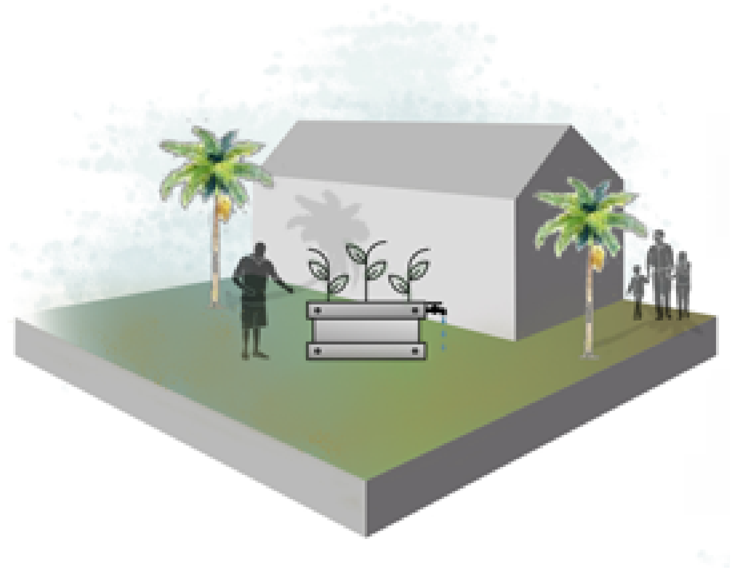
Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic





Context

In Israel, in Ben-Gurion University of the Negev, in the middle of the Negev Desert, research and technologies to optimes the use of every single drop of water are pioneering. The climate is arid, with an average of only 24 mm of rainfall per year.

The quantity of freshwater is decreasing worldwide, and in the desert, inhabitants have a long tradition in optimizing the use. Israel has invested considerable funds in developing technologies of water management.

Moreover, privatisation and general water scarcity have made the resource use complicated and expensive for inhabitants. Many privates are already reusing greywater for irrigation or other purposes.

Outcomes

Therefore, researchers are looking for a treatment method to filter greywater a small scale, to decentralize the treatment process. They developed the recirculating vertical flow constructed wetland (RVFCW). The system is made of a bed of planted organic soil with filtering media, and a layer of limestone pebbles. Water flows between these layers many times, passing through passive aeration until the purification is achieved.

Unfortunately, legislation is not yet in their favour, and parliament has not yet authorised the use of such filters at the domestic level. However, research is progressing, and system performance is expected to don’t leave any doubts within politicians.

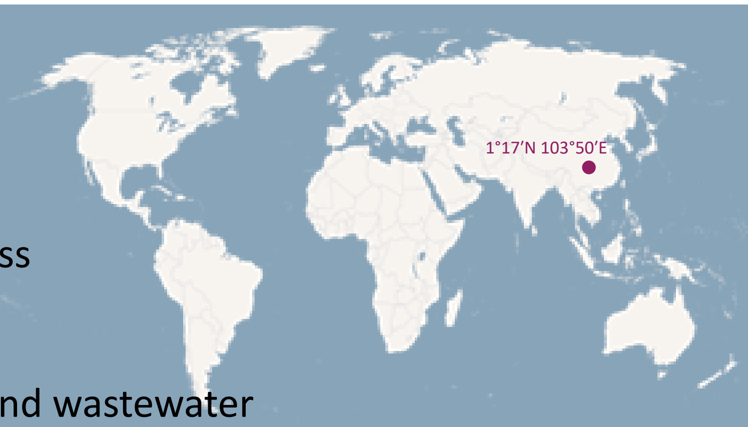
Singapore NEWater
Singapore

22
CS

Location
Singapore

Status
Work in progress

Type
Water supply and wastewater



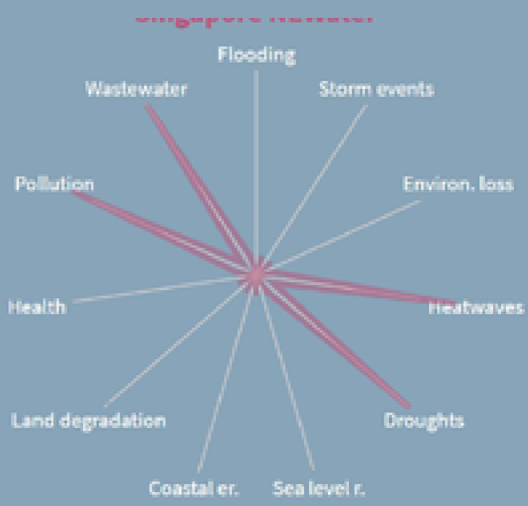
Population size
5,6 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

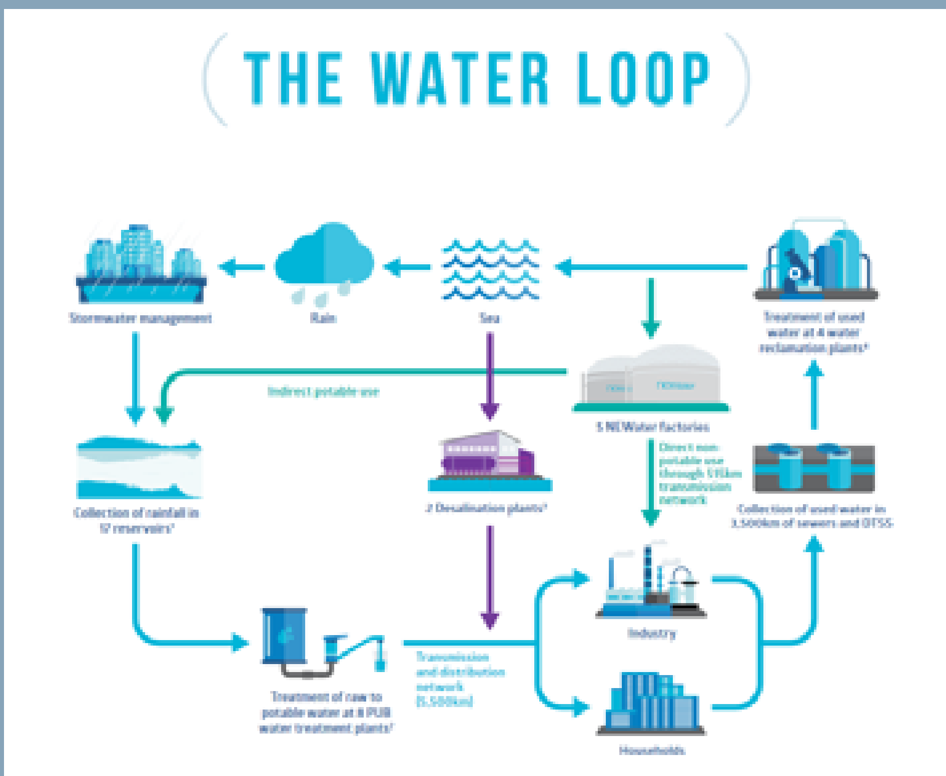
Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

Singapore, located in Southeast Asia, with 5,603,600 inhabitants, has a tropical rainforest climate.

The city-state island is increasingly affected by sea-level rise, heatwaves and droughts. These effects have consequences on the low-lying coastline and of course, on the quantity and quality of freshwater available.
Even if Singapore is a pioneer in the sustainable management of resources, particularly water, the city-state is heavily depended from Malaysia's water.

Therefore, the aim is to reduce the consumes, incentive the water reuse technologies, and then reach the water independency. In this direction, The NEWater, one of Singapore's national taps, and takes care of the recycles process.
Through advanced membrane technologies and ultra-violet disinfection, the NEWater company cleans water and allows fabrication plants to use its water instead of a new fresh one.

Outcomes

Indeed, the water quality has exceeded more than 20,000 analyses, resulting in excellent quality according to internationally set standards and better quality than PUB water.
NEWater supplies about 40% of Singapore water and its ultraclean water are mostly used for industrial and air-cooling purposes.

Fighting mosquitos
National Environment Agency

23
CS

Location
Singapore

Status
Work in progress

Type
Filtering greywater with wetland

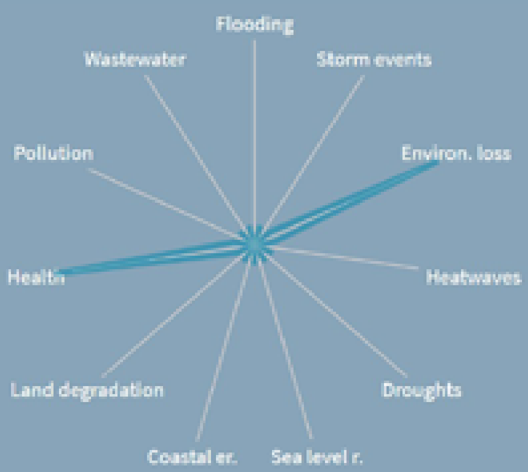
Population size
5,6 million inhabitants
source. Worldbank

Area size
Large Metropolitane
source. OECD

Economic type
Low income
source. Worldbank

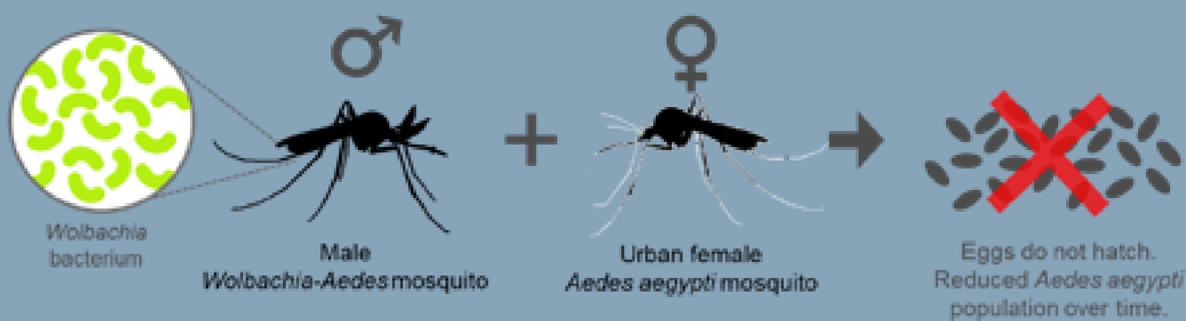
Climate region
Tropical
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

A widespread problem of water management interventions is that the retention of water can allow mosquitoes' proliferation.

Mosquitoes carry many diseases and can have particularly tragic consequences in some countries. In particular, the Aesdes aegypti mosquitoes are vectors of dengue, Zika, chikungunya and yellow fever.

A possible solution has been found from NEA researchers, that are exploring the possibility to spread the male Wolbachia-carrying Aesdes aegypti mosquitoes to reduce the proliferation of the first. Wolbachia are common bacteria, present in several insect species. When a male Wolbachia-carrying Aesdes aegypti mosquitoes mates a female Aedes aegypti mosquitoes, they generate unfertile eggs.

The process is a long-term technique but has the benefit of not using insecticides, being sustainable, with more efficient long-term results and moreover is self-sustaining.

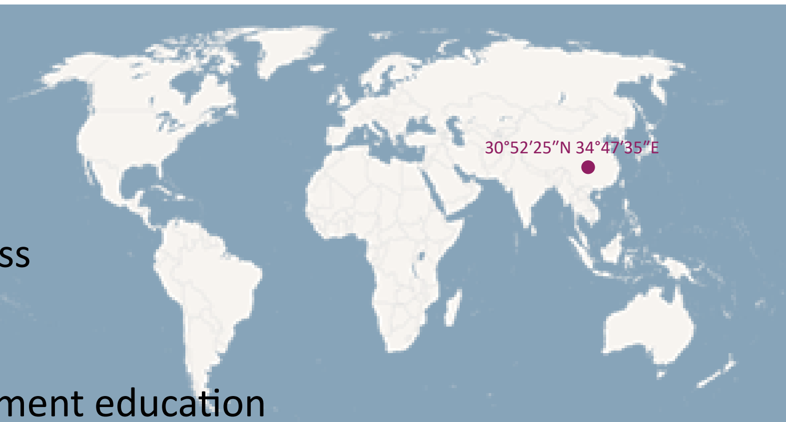
Outcomes

This method is reducing the pollution related to insecticides, which have a huge negative impact on ecosystems.

Surface Water Management in refugee camps

24
CS

Location



Status
Work in progress

Type
Water management education

Population size

source. Worldbank

Area size

source. OECD

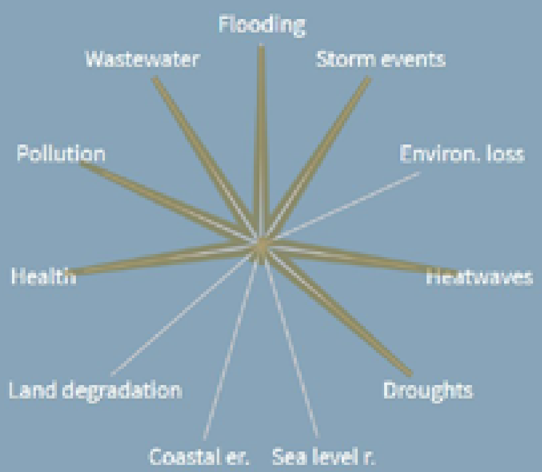
Economic type

source. Worldbank

Climate region

source. Kopper-Geiger

Description



Indicators

Multiscalarity

Integration with the context

Multifunctionality

Knowledge creation

Replicability, efficacy, sustainability

Participation and governance

Special criticism

Benefits Ecosystemic Social Economic

Context

Refugee camps, which are precarious situations themselves, are also subject to the harshness of extreme events related to climate change. Improper surface water management often causes flooding and waterlogging. In addition, these conditions drive the proliferation of vector-borne diseases, including malaria, dengue fever, hepatitis cholera, typhoid, and others.

Elrha, with Ove Arup and Partners Ltd, launched a project to improve the strategic planning of these camps and to manage the surface water better. The project, started in 2017, aims at delivering the guidance document. This document includes several developing directions, indications for good practices' application and instruction for sustainable drainage. Practitioners and decision-makers are therefore involved in raising awareness on these issues and thus create a guidance toolkit.

Outcomes

Indeed, the guidance document wants to focus on water quality and quantity to address the health and wellness of people and the environment; it wants to reduce the risk maximising in the meantime, the opportunities.

The project also aims at providing refugees with skills and knowledge about climate change prevention and adaptation techniques, which are increasingly needed.

Green schools
Paris

25
CS

Location
Paris,
France

Status
Work in progress

Type
Schools oasis vs heatwaves

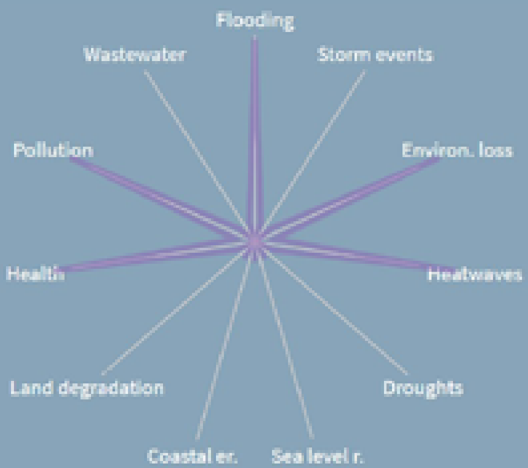
Population size
12.1 million inhabitants
source. Worldbank

Area size
Large Metropolitan
source. OECD

Economic type
High-income
source. Worldbank

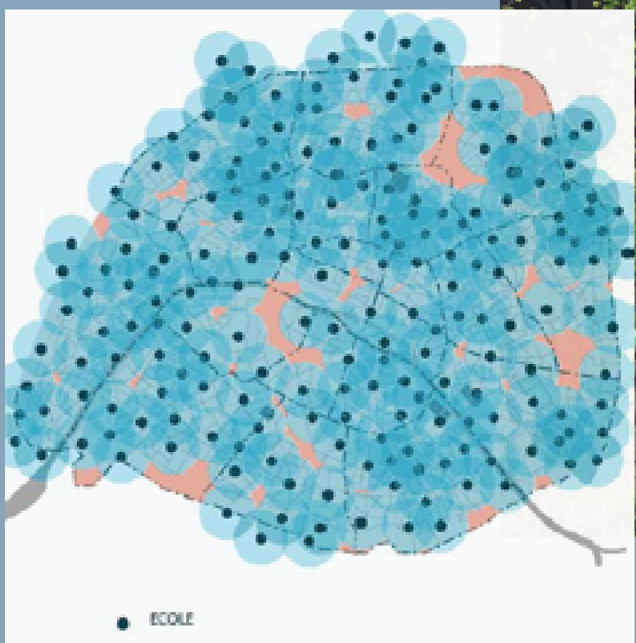
Climate region
Marine West Coast
source. Kopper-Geiger

Description



Indicators

Multiscalarity
Integration with the context
Multifunctionality
Knowledge creation
Replicability, efficacy, sustainability
Participation and governance
Special criticism
Benefits Ecosystemic Social Economic



Context

Paris is the largest urban area in France and one of the largest in Europe. The Greater Paris Region population is about 12.1 million, with a demographic density of 20,000 inhabitants for km2. The city is so dense that it has been estimated that no one lives further than 200 metres from a school.

The Oasis Schools Programme, a climate adaptation interventions program, aims to create more green areas all over the city. In the project are included green walls, plants, permeable and soily surfaces and water features.

The purpose is to protect the most exposed and sensitive groups, the children and at the same time, mitigate the climate change effects. In fact, these interventions would help to reduce the heavewaves' risk to which Paris is increasingly subjected. It would be helpful also in the protection from floodings and heavy rainfalls. The vegetation would be watered directly by the rainwater harvested and would not need particular maintenance interventions.

Outcomes

Furthermore, it would contribute to the public greening of the whole city, benefiting the whole community and increasing social cohesion. Indeed, the schools' green areas are expected to be open to the public, outside school hours or in case of emergency for heatwaves.

1.2 Best practice: Copenhagen

CONTEXT

Copenhagen, the capital of Denmark, is located almost entirely below sea level, with the highest point of just 173 meters above sea level. From a climatic perspective, the region is constantly affected by perturbations from the Atlantic, although it is difficult to record large peaks of intensity, as well as strong winds that sometimes cause sudden swells.

Although bathymetric and morphological conditions do not characterize the Copenhagen area as one of the most exposed to changes in sea level within the Baltic Sea, the fact that it has to balance itself with the North Sea level means that statistically, with a return time of 100 years, rise phenomena close to 2 meters occur. This without considering the risks of global warming, which should probably raise the average sea level by 68 cm, or at least certainly between 29 and 162 cm. Related to the phenomenon, but perhaps more worrying, is an increase in the total number of sea storms along the Baltic Sea coast, with an increase from 4.4 to 6.5 events per year at the Gedser survey station in southern Denmark in the period 1960-2010.

DRIVERS

In general, although the situation is worse for the west coast, it is noted that the Danish east coast, compared to the inland and deep parts of the Baltic Sea, is more exposed to the risk of storm surges and subject to significant fluctuations in average sea level, which could tragically change its geography in the coming decades. Specifically, regarding the city of Copenhagen, it is statistically unlikely that a sea storm will exceed 2 meters, below which it is possible to prevent possible adverse effects.

Historical episodes of extreme flooding are the followings. In 1872 a 3-meter swell hit the Baltic Sea coast, but there are no precise data regarding the level reached by sea. In 1902/1921, the sea level rises more than 150 cm in Copenhagen, but there are no reports of any damage. In winter 2006/2007, a storm started in Iceland descends the Norwegian coast towards the Baltic Sea. In the Oresund Strait, masses of water were forced down, causing a rise of 1.3 meters in sea level. Despite this, no damage has been detected in the city. In 2011, an extreme cloudburst hits Copenhagen, causing damage of around one billion euros. The social impact is devastating most of the citizens no longer feel confident about the risks of climate change. This event will be the stimulus to draw up the Copenhagen Adaptation Plan in 2013.

PLANNING

The Danish planning system is articulated on three governance levels: national, regional, and municipal. The main national planning's aim, handled by the Environmental Minister, is to create general directives for the regional development and for the local planning. The regional level takes care of strategic planning through the regional spatial development plans, while at local level there are the municipal plans and local plans. The municipal plans are strategic documents with the function of land use regulation too, both for urban and rural realities. The local plan, though, is a tool for managing the transformations (Danish Ministry of the Environment, 2007).

Regarding the assignation system of land use rights, Denmark has a neo-performative model: the plan is prescriptive as for conformative systems, but the approval follows the collection of projects, their evaluation and sequent negotiations with operators (Rivolin, 2016).

Planning Act, the most important Danish spatial planning's low, is divided in sections and one of these is dedicated to the Greater Copenhagen's area (the Capital Region of Hovedstaden and other 12 municipalities). Moreover, the Environmental Minister impose to the municipalities to follow the directives given by the

Finger Plan. The Finger Plan is a national strategic document for the development of the capital, in force since 2019 (Danish Ministry of the Environment Nature Agency, 2015).

In the plan, several reminders were included referring to urban resilience and climate change adaptation (*klimatilpasning)*: encouragements to use as much green as possible, to be mindful of resilience transition in the moment of planning new infrastructures, and several interventions for climate change adaptation were prescribed. Among them, the plan has imposed to design water retention squares and channels to improve the safety, the environmental quality and as well the accessibility.

The Municipal Plans have therefore adopted the prescriptions of the Finger Plan and the Copenhagen's one has properly integrated the climate change adaptation: "*We must be prepared to confront climate challenges in a way that takes Copenhagen to a higher level of growth and of quality of like"* and "*Together with the people of Copenhagen, we will develop good, climate-adapted solutions that improve everyday life and quality of life in the city as much as possible. It is important that all of the city's projects focus on climate adaptation, especially those relating to urban renewal, courtyards, schools and institutions"* (Københavns Kommune, 2015).

Copenhagen's example is emblematic also from a participatory process point of view: inhabitants are always consulted, asked to participate and give ideas before, during and after the planning process. This approach causes, among the inhabitants, a feeling of ownership in the regards of the new choices and spaces.

This was one of the first steps of the admirable path that the country, and Copenhagen in particular, have done towards a multifunctional and resilient approach to climate change adaptation. Indeed, the integration among inhabitants needs, risk reduction and environment conservation are the pillars of the danish planning scenario. Although it has to be said that Denmark has a long tradition, especially starting from the 80', of urban requalification prioritizing population's quality of life.

Then, over time, the city of Copenhagen has integrated the theme of the climate change's adaptation in different ways: reduction of energy consumption, innovation in sustainable mobility, develop general awareness on the topic and much more. For these sectoral legislations the city delegates the responsibility to the *Climate Plan,* while the *Municipal Plan* keeps the role of general coordination.

Figure 16 Copenhagen and the adaptation to climate change process

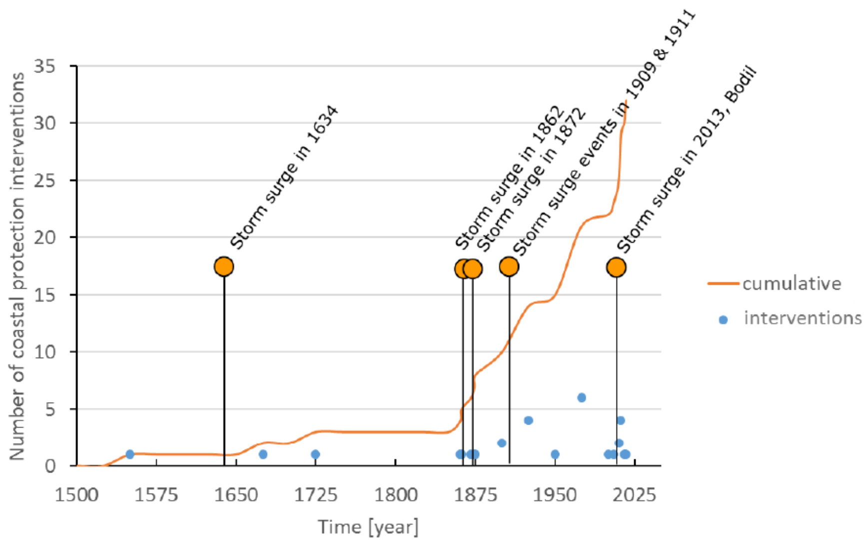


Figure 17 Coastal protection interventions from the year 1500 up to current years.
Source: (Faragò et al., 2018)

PRACTICE

In 2012, the city of Copenhagen drew up a cloudburst management plan (Cloudburst management plan), which complements the city's climate adaptation plan. The plan outlines priorities and recommended measures for adaptation to climate change, including extreme precipitation. The Municipality has carried out an overall assessment of the costs of several feasible measures, the cost of the damage despite the measures and the resulting financial impact. This research showed that continuing to invest in traditional sewerage systems is both inefficient and inconvenient: despite the large investments, the economic damage caused by the floods would remain higher. A combined solution was, therefore, opted for, consisting of the extension of the sewerage system and the implementation of around 300 projects focusing on water lamination and drainage, in order to avoid overloading the sewerage system and at the same time to try to exploit the water resource.

1. San Kjeld and Soul of Norrebro

55°41'19"N 12°32'54"E

In case of heavy rainfall, the Nørrebro district can collect up to 18,000 m3 of water. Excess rainwater can be led via the Korsgade road to the neighbouring lakes. Along the way, the water is purified by the natural biotopes present in flowerbeds of the street. The big park guarantees to inhabitants not only recreative space and mitigation actions but also reduction of flooding risk. Moreover, the project was created in participation with the population, taking care of the needs and wishes of those directly and indirectly concerned.

2. Amager Strandpark

55°39'16"N 12°38'57"E

Amager is an artificial island built to the south of Copenhagen with the function of preventing coastal erosion and at the meantime nature conservation and regeneration of ecosystems. It is occupied in the northern part by a suburb with a total of 160,000 inhabitants, the airport, and a long beach park along the west coast. The intervention guarantees to the city the coastal protection, recreation and accessibility for the population and nature conservation through dunes.

Amager Strandspark is now a seaside public park, which was founded in 1934. It an area of 60 hectares and in total it provides 4.6 Km of beaches. In 2005, an artificial island of the length of about 2.5 Km was added to increase the accessibility of the waterfront. The intervention, that can be considered a soft solution for coastal protection, has a shape created to catch and break the waves originating both the South and the North. The site is a multifunctional park and it provides other recreation functions, as it can be used from swimmers, kayakers, surfers, families.

3. Enghaveparken

55°40'01"N 12°32'31"E

The park, inaugurated in 2020, was developed by Tradje Natur to combine the neighbourhood's recreational needs with the needs of risk reduction for disasters. Indeed, the square is located on the slopes of the neighbourhood with an higher elevation, which means that water is naturally channelled into the spaces specially designed to collect up to 26,000 cubic metres of rainwater. For particularly extreme events, which have never occurred so far, the square, in addition to the areas that can be flooded, is bordered by walls that can be closed off to create one huge basin.

4. Private solutions (Hothers Plads Karrè)

The city of Copenhagen, with multiple policies, awareness campaigns and fiscal advantages, encourages the private initiative for climate change adaptation. This has led to the spread of bottom-up solutions even in private spaces, most of them nature-based and with low maintenance commitment. For instance in the city are always more common private raingardens, to reduce the impact of floodings, slow the runoff increasing the ground permeability and so recharging the groundwater, and also greenroofs, to reduce heatwaves, collect and filter water and also reduce the heat dispersion.

5. Scandiagade

55°38'58.4 "N 12°32'17.5 "E

In Scandiagade, the Landskad 1:1 studio has designed an urban space that can collect considerable amounts of rainwater and at the same time it provides to the population a recreational space. The street, located near the Teglværkshavnen harbour, is designed to collect water from neighbouring streets and, thanks to its slope, collect it in basins. The space is divided into eight basins that can hold up to 1,500 cubic metres of rainwater to slow it down so as not to burden the sewer system. During the dry season, the basins are designed for different recreational activities and more than 120 different species of plants have been planted for ecosystem conservation.

6. Sankt Annae Plads

55°40'53 "N 12°35'32 "E

The long square, located in the very centre of the city and historical aggregation point, connects the centre to the harbour. It is designed to convey water through large pipes, dug underground along its entire length. In case of extreme rainfall, the centre of the area can be transformed into a river leading to the neighbouring port. The rainwater, instead of being directly covey to the canal, is used first for watering the vegetation, which in turn filters the water before to release it. In case of deep rainfalls, the long square can become a natural river to stream rapidly the water out of the centre, protecting the population and the building present in the area.

Sankt Annae Plads was one of the first intervention for climate change adaptation and after years the area seems to be completely self-reliant, with low maintenance commitment.

7. Tasinge Plads

55°42'36.1 "N 12°34'04.6 "E

The Tåsinge Plads square, the first urban space adapted to the climate, was designed to delay, collect and reuse water in different ways. The slope of the pavement collects the runoff from the surrounding streets towards the central area, preventing flooding downstream of the square. Water flows easily towards the green flowerbeds, also thanks to the non-blocking kerbs, which allow rainwater to be used directly for watering the vegetation. In addition, umbrella installations have been positioned to collect rainwater and convey it to basins beneath the pavement. Using manual pumps, designed as part of a children playground, the water from these cisterns can be pumped into the surrounding flowerbeds. With these simple measures, the square functions as a reservoir, a self-sufficient green space and public space.

8. Sidewalks and pavements

In order to slow down runoff, recharge the groundwater and guarantee to the population as much green as possible, the city of Copenhagen has intervened with widespread, if seemingly minor, solutions. Most of the sidewalks of the city, where it was possible, are flanked by flowerbeds, watered by the roofs' water. This allows an initial and instant water biofiltration. The pavements are mostly in permeable or porous materials, that guarantees the water percolation and groundwater recharge. In addition, green sidewalks transformed into flowerbeds collect water from roofs and the road and filter it through the vegetation.

9. Bike lanes

In Copenhagen, the bicycle infrastructure covers approximately 350 km. Every street, both of the centre and in the hinterlands, has a part of it designed for bikes. In some cases, the bicycle's part is even bigger than the one for cars. The municipality is trying to pave all cycle paths with soils that allow water percolation. In this way, there is a reduction in runoff and a minimisation of water congestions. Furthermore, It was also planned to install pipes under each cycle path to speed up the runoff in case of extreme events.

10. Water channels' quality

However, the Copenhagen climate adaptation plans do not only treat water as a mere resource to be stored, slowed down and disposed of. Large sums of money have also been earmarked to make canal water swimmable. Following the achievement of this goal, several floating bathing facilities have been "installed" so that in the warmer season, and not only, citizens can also use the water as a source of entertainment and cooling.

1.3 Database examples

In order to investigate state of the art regarding databases, and especially to look for interesting case studies and good practices, the following examples were found and analysed:

11. Floodsite

The present database was aimed to develop a strategy for the data collection regarding the floodings events. The analysis has been carried out for four pilot areas in Europe with an excellent hydrometeorological station density (Hammond et al., 2015). The aim was to enhance the efficiency of collection, forecasting, response and above all preparedness actions. The project had great potential, but it seems not to have overcome the pilot stage.

Especially from a planning perspective, it would be crucial to have rapid and available information on floods and extreme events worldwide. There is, of course, some data, but the coverage is far from being global.

12. Nature4cities

Nature4Cities is a database funded by the European Union's Horizon 2020 that collects data regarding Nature Based Solutions from all over the world. They collected strategies, actions (management and monitoring), objects (green equipment and infrastructures). The solutions are divided in five macro-categories: Climate, Environment, Resources, Economy and Social. The platform is targeted to policy makers and public urban planners, civil society and urban professionals. It considers different steps of urban development as planning, design, implementation and management.

The platform can certainly be defined as very complete. The weakness, however, is the complicated structure of the database itself, which does not make the paperwork easy and straightforward.

13. WATER Best Practices

In Water Best Practices network they collected good practices in addressing water challenges. The practices are divided between: Extreme weather events, Reduce in water consumption, Quality of water, Water conservation variables. In addition to the area of "Featured Best Practices", there is also "Community Contribution Area", where visitors and stakeholders can contribute to upload data and participating in the debate. This network is also very efficient, with a good number of examples already available. However, it is not possible to search for solutions according to other criteria than those listed above.

14. BlueSCities and Urban Water Atlas for Europe

This report, fundend and published by the European Union in 2017, collects several practices adopted worldwide in water management. In particular, related to storm water management, energy recovery from wastewater, water distribution systems, water reuse and recycling, water's collective memory. Moreover, the *Urban Water Atlas for Europe* provides a reference point for about 40 European cities, enhancing them to tackle water related challenges wih local solutions.

This platform can make numerous insights and suggestions, but is lacking in the field of data sharing.

15. WWF PANDA

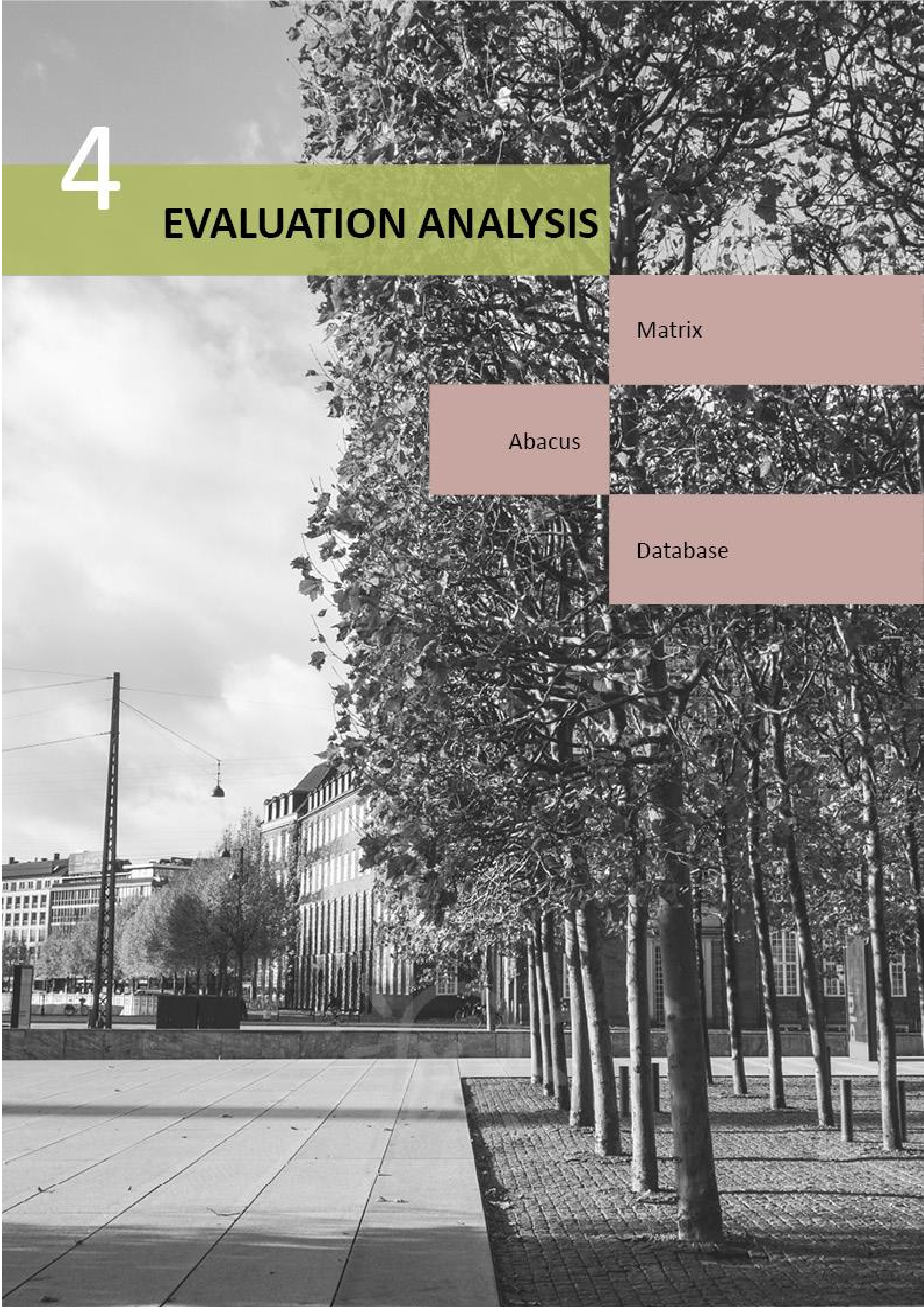
The present WWF's database collects urban solutions for addressing a different type of climate-related challenges. The case studies are divided within the topic they address, as energy, food, mitigation, water or waste. The graphics are also very effective, solutions can be located on the map and the colour distinguishes the category. There is access also to The Knowledge Hub with the latest publications and reports. Despite this, however, only two solutions have been identified in the water sector.

4 EVALUATION ANALYSIS

Matrix

Abacus

Database



Matrix of practices, evaluation through theory

3.1 Matrix presentations

Regarding the practical solutions to cope with climate change, a general difficulty in finding examples was seen it was found generally difficult. Many reports, list and collections of water management interventions have been realised, some of which are very comprehensive and informative. There are also some databases, as before mentioned, that report solutions adopted on different scales and time.

However, there seems to be a lack, or at least a shortage, of a database, platform or search engine that could collect all solutions adopted so far worldwide and facilitate their dissemination.

For this purpose, a research sample of 40 case studies was collected and through a matrix they have been evaluated and compared.

The matrix has been structured as simply but comprehensively as possible, in order to gather all the necessary information. Indeed, the general aim was to create a replicable tool.

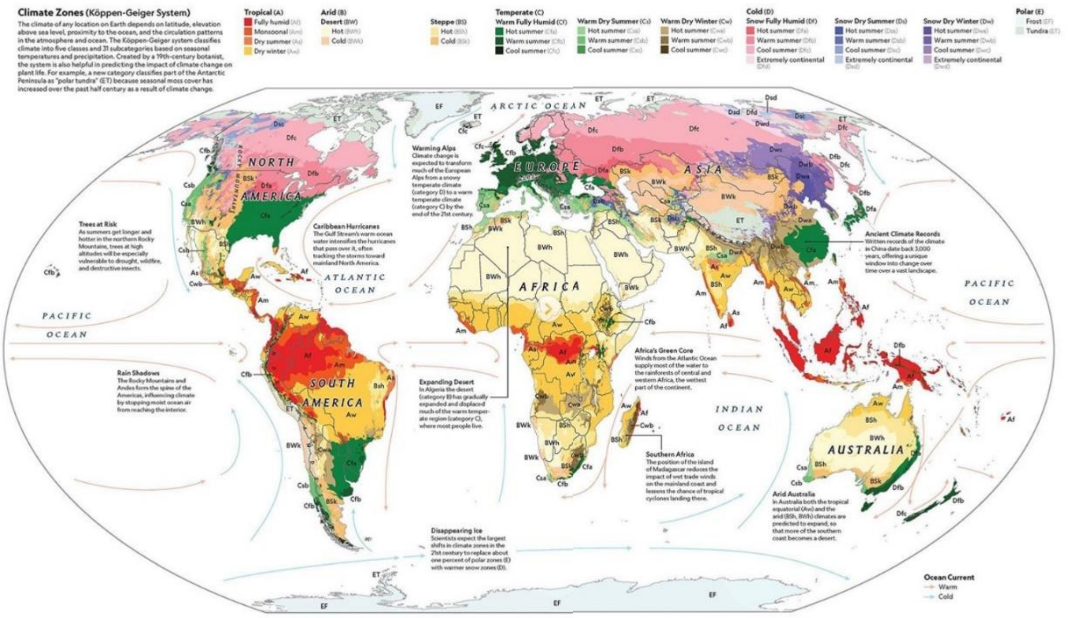
3.2 Indexes

The indicators identified through research of similar studies, based on literature review, are both general and intervention specific. Reference was made to the series of information provided by comprehensive international reports given about the solutions. For instance, WWF with "*Urban solutions for a living planet" (2000);* C40 CITIES with "*Cities 100 solutions for climate action in cities" (2015);* UNESCO with "*Water and Climate Change"* (2020).

In addiction to describing and characterising the entity of the problem and the specifics of the solution, it has been considered important to include indicators that qualify the context where the solution is located.

All the indexes were structured for Yes or No answer, to facilitate the final score and comparison between them. Future research could go deeper giving scores to every index, but in this occasion, it has been considered more appropriated and more objective stay with binary responses.

3.2.1 Features of the context



Map 3 The Climate and latitudes.
Source: National Geographic Atlas of the World, 11th Edition.

The climate of any location on Earth depends on latitude, elevation above sea level, proximity to the ocean, and the circulation patterns in the atmosphere and ocean. The Köppen-Geiger system classifies climate into five classes and 31 subcategories based on seasonal temperatures and precipitation. Created by a 19th-century botanist, the system is also helpful in predicting the impact of climate change on plant life. For example, a new category classifies part of the Antarctic Peninsula as "polar tundra" (ET) because seasonal moss cover has increased over the past half-century as a result of climate change.

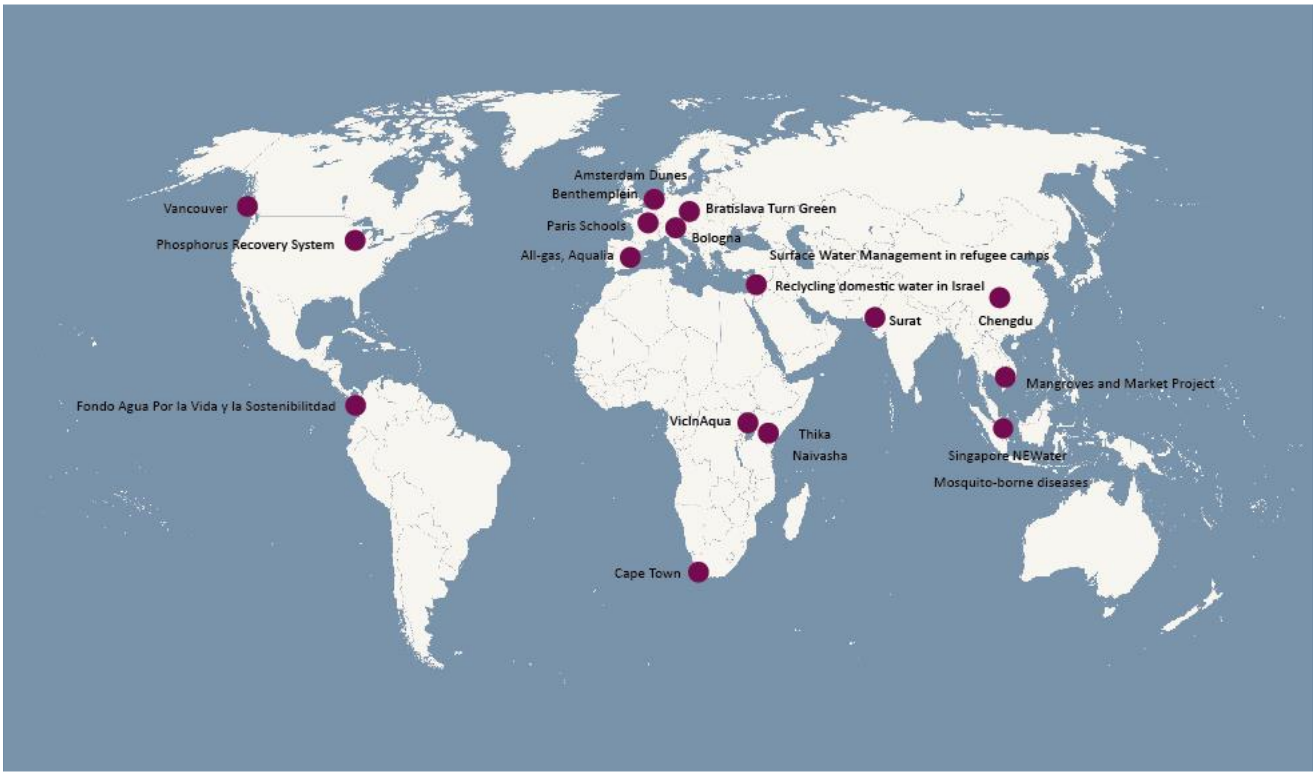


Figure 18 Map of the case studies. (Source: Personal elaboration).

3.2.2 Features of the problem

Regarding the problem, first indicators describe the extent of the exposed elements. The climate change hazards, indeed, can affect human capital, natural capital, physical capital, financial capital and cultural capital.

The extreme events and environmental imbalances can often have consequences on other sectors as well. The main related sectors reported are urban health, transport system, housing, energy and industry.

The impacts that the case studies had to face are:

- Flooding
- Storm events
- Environment loss
- Heatwaves
- Droughts
- Sea Level Rise
- Coastal erosion
- Land Degradation
- Health and vector-borne disease
- Pollution (of water and/or air)
- Wastewater

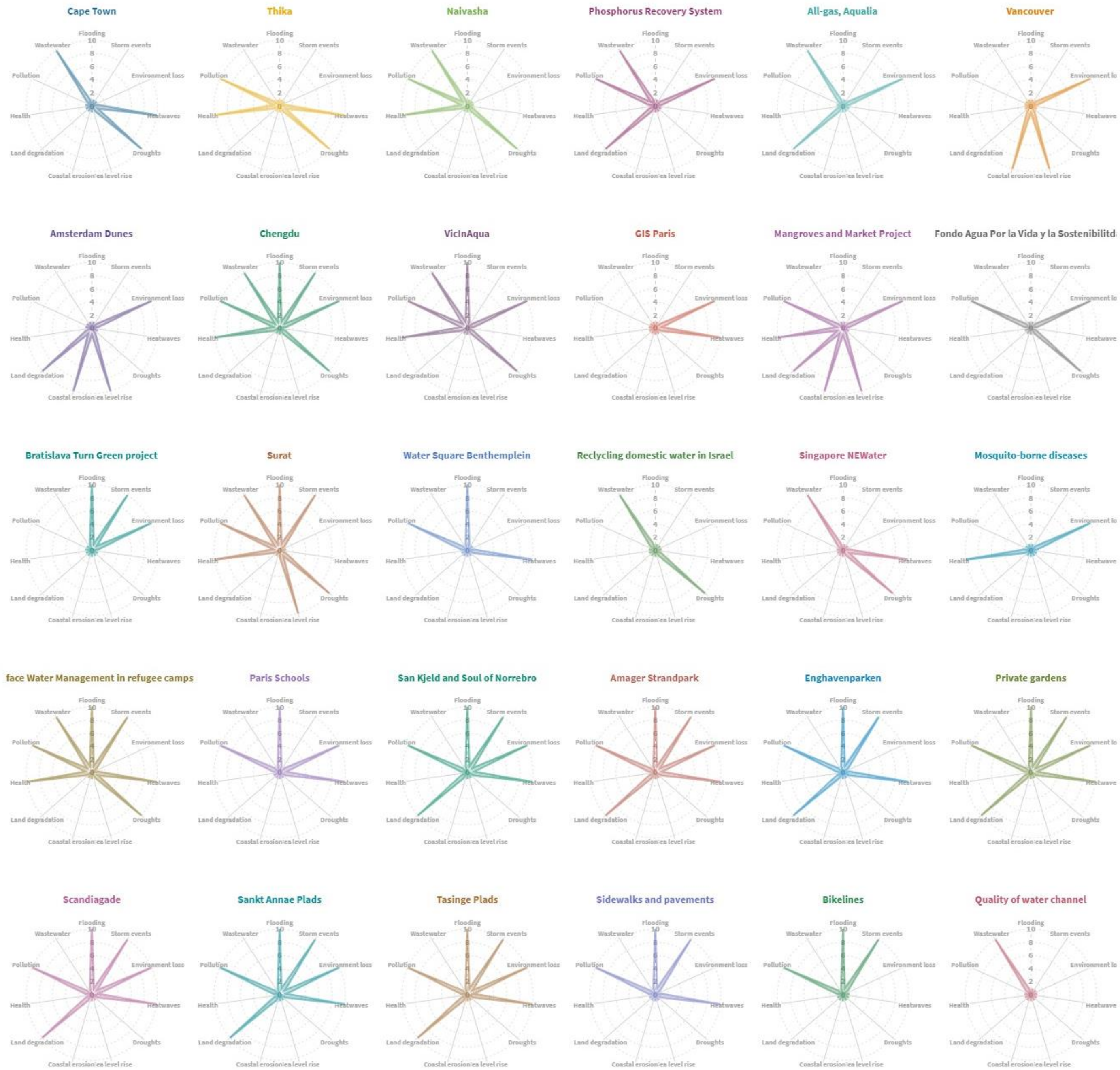


Figure 19 The problems faced from the case studies. Source: personal elaboration

3.2.3 Features of the solution

Regarding the solution, first indexes defined the type of climate change challenge response that the city or entity is adopting with that measure: preparedness, indirect mitigation, adaptation and resilience.

The type of water intervention that can be used are: engineering intervention; planning intervention; Nature Based Solution; reduction in use; management of excess; management of scarcity; pollution treatment; distribution; collection and delay; alternative water source; wastewater management and acceleration of runoff.

The project or intervention can be multiscale, and integrated with the context from a social, environmental or design perspective. For a more comprehensive and effective solution, it is recommended that the project is multifunctional.

All these features contribute to making a solution replicable, effective, and sustainable from all points of view.

Important key enabling factors are the participation level, the public and private contribution, the level of governance involved and the strategic planning behind that.

The main criticisms that can affect the efficacy of a solution are the maintenance commitment and the cultural or historic bounds.

Nevertheless, the final scoring of each indicator could be justified by the descriptions that are provided for each score and the additional reasoning made by the practice partners, whenever possible, and all partners were aware of the subjectivity of the scores. Several practice partners reflected on this during the scoring process, for instance by highlighting the areas where they can collect data in the future to quantify the scores in a more objective way. Given the common understanding that the scores would not be used to compare the cities' success or performance, the partner cities mainly used the scoring process to diagnose their status and learn from each other's weaknesses and strengths on the multiple dimensions of urban climate resilience.

In the following table, the authors Jarraud and Steiner, in 2012, analised the possible adaptation approaches to manage and reduce the risks related to climate change. They also pointed out that these approaches should be considered as overlapping and simultaneously pursuing. The table is reported because it has been relevant for the realisation of the matrix.

Overlapping Approaches	Category	Examples
Vulnerability & Exposure Reduction through development, planning & practices including many low-regrets measures	Human development	Improved access to education, nutrition, health facilities, energy, safe housing & settlement structures, & social support structures; Reduced gender inequality & marginalization in other forms.
	Poverty alleviation	Improved access to & control of local resources; Land tenure; Disaster risk reduction; Social safety nets & social protection; Insurance schemes.
	Livelihood security	Income, asset & livelihood diversification; Improved infrastructure; Access to technology & decision-making fora; Increased decision-making power; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
	Disaster risk management	Early warning systems; Hazard & vulnerability mapping; Diversifying water resources; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements.
	Ecosystem management	Maintaining wetlands & urban green spaces; Coastal afforestation; Watershed & reservoir management; Reduction of other stressors on ecosystems & of habitat fragmentation; Maintenance of genetic diversity; Manipulation of disturbance regimes; Community-based natural resource management.
	Spatial or land-use planning	Provisioning of adequate housing, infrastructure & services; Managing development in flood prone & other high risk areas; Urban planning & upgrading programs; Land zoning laws; Easements; Protected areas.
Adaptation including incremental & transformational adjustments	Structural/physical	***Engineered & built-environment options***: Sea walls & coastal protection structures; Flood levees; Water storage; Improved drainage; Flood & cyclone shelters; Building codes & practices; Storm & wastewater management; Transport & road infrastructure improvements; Floating houses; Power plant & electricity grid adjustments.
		Technological options: New crop & animal varieties; Indigenous, traditional & local knowledge, technologies & methods; Efficient irrigation; Water-saving technologies; Desalinisation; Conservation agriculture; Food storage & preservation facilities; Hazard & vulnerability mapping & monitoring; Early warning systems; Building insulation; Mechanical & passive cooling; Technology development, transfer & diffusion.
		Ecosystem-based options: Ecological restoration; Soil conservation; Afforestation & reforestation; Mangrove conservation & replanting; Green infrastructure (e.g., shade trees, green roofs); Controlling overfishing; Fisheries co-management; Assisted species migration & dispersal; Ecological corridors; Seed banks, gene banks & other *ex situ* conservation; Community-based natural resource management.
		Services: Social safety nets & social protection; Food banks & distribution of food surplus; Municipal services including water & sanitation; Vaccination programs; Essential public health services; Enhanced emergency medical services.
	Institutional	***Economic options***: Financial incentives; Insurance; Catastrophe bonds; Payments for ecosystem services; Pricing water to encourage universal provision and careful use; Microfinance; Disaster contingency funds; Cash transfers; Public-private partnerships.
		Laws & regulations: Land zoning laws; Building standards & practices; Easements; Water regulations & agreements; Laws to support disaster risk reduction; Laws to encourage insurance purchasing; Defined property rights & land tenure security; Protected areas; Fishing quotas; Patent pools & technology transfer.
		National & government policies & programs: National & regional adaptation plans including mainstreaming; Sub-national & local adaptation plans; Economic diversification; Urban upgrading programs; Municipal water management programs; Disaster planning & preparedness; Integrated water resource management; Integrated coastal zone management; Ecosystem-based management; Community-based adaptation.
	Social	***Educational options***: Awareness raising & integrating into education; Gender equity in education; Extension services; Sharing indigenous, traditional & local knowledge; Participatory action research & social learning; Knowledge-sharing & learning platforms.
		Informational options: Hazard & vulnerability mapping; Early warning & response systems; Systematic monitoring & remote sensing; Climate services; Use of indigenous climate observations; Participatory scenario development; Integrated assessments.
		Behavioural options: Household preparation & evacuation planning; Migration; Soil & water conservation; Storm drain clearance; Livelihood diversification; Changed cropping, livestock & aquaculture practices; Reliance on social networks.
Transformation	Spheres of change	***Practical***: Social & technical innovations, behavioural shifts, or institutional & managerial changes that produce substantial shifts in outcomes.
		Political: Political, social, cultural & ecological decisions & actions consistent with reducing vulnerability & risk & supporting adaptation, mitigation & sustainable development.
		Personal: Individual & collective assumptions, beliefs, values & worldviews influencing climate-change responses.

Figure 20 Approaches for managing the risks of climate change through adaptation.
Sources: (Jarraud and Steiner, 2012)

Finally, getting to the results of the matrix survey, case study scores are given below. Denmark and its interventions seem to be on the top of the list. This may be due both to the effectiveness of the policies pursued by the Danish government, and partly to the proximity of this case study to the researcher. It is important to remind that these values were obtained from the fulfilment to the requirements of the matrix, all normalised so that the answer was binary, yes or no.

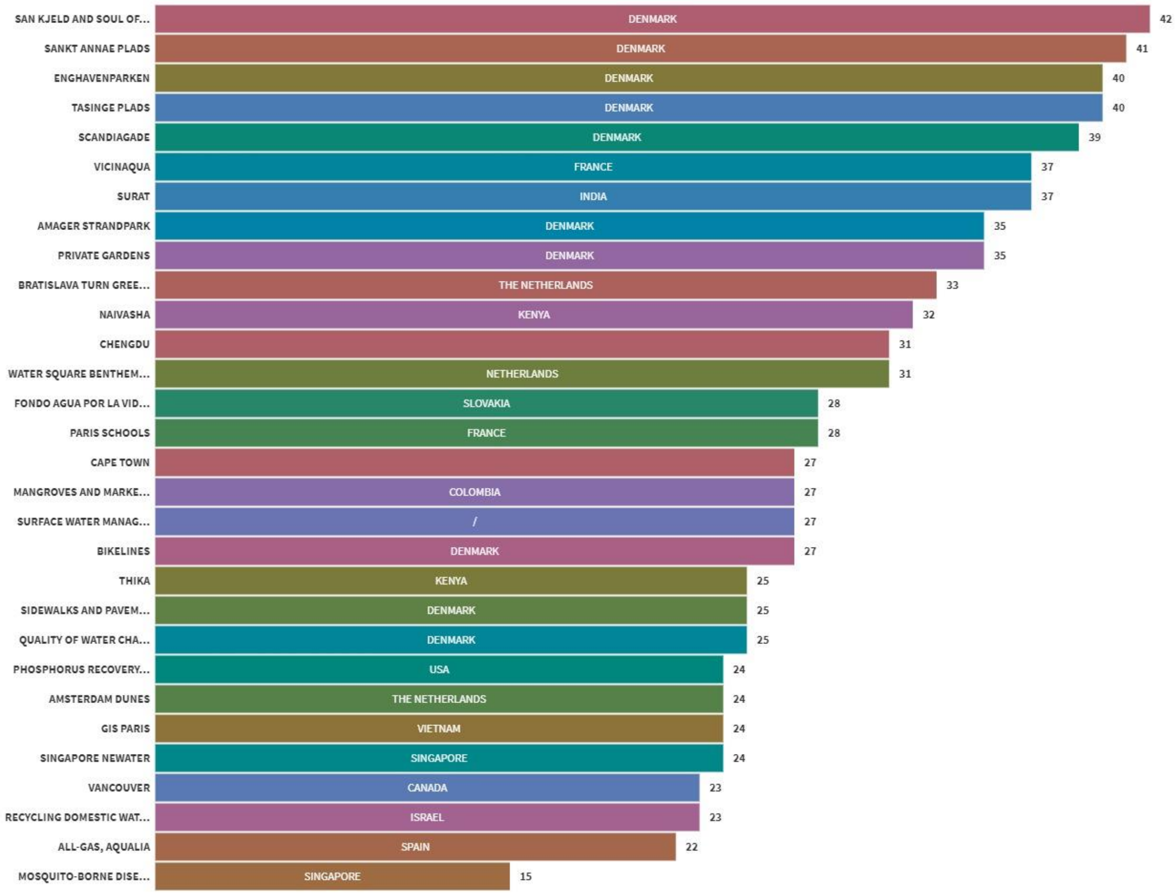


Figure 21 Case studies and their scores (Source: personal elaboration).

In the following representation, we can notice that al most all the problematics water-related that our case studies had to face and all the solutions that they have adopted are related. Indeed, every intervention is usually made by the overlapping of different solutions. Moreover, every solution can address different type of challenges, sometimes even totally opposite, as shown for instance from the correlation between floodings and management of scarcity. Indeed, there are several examples of utilisation and retention of surplus water for times of shortage.

In addition, great importance is given to policies and strategies, which are indispensable for almost every type of intervention, and to NBS, which demonstrate their simplicity and effectiveness.

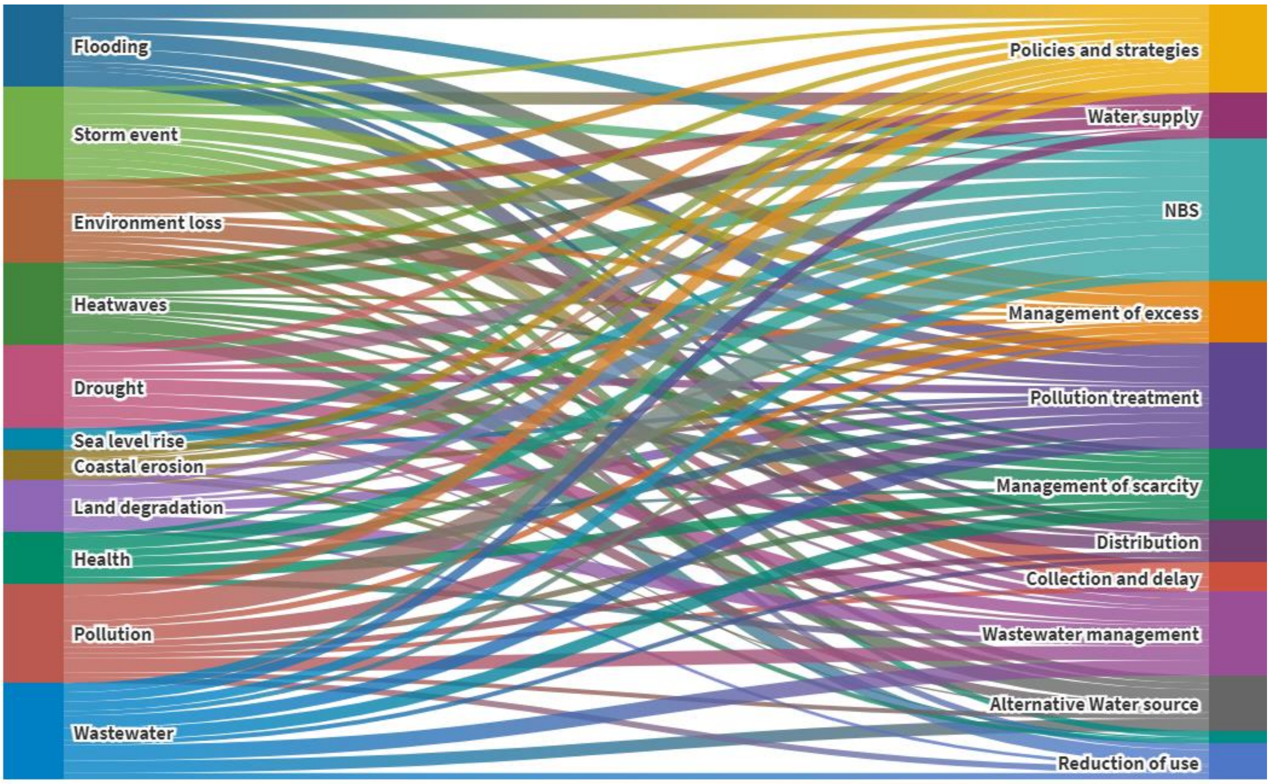
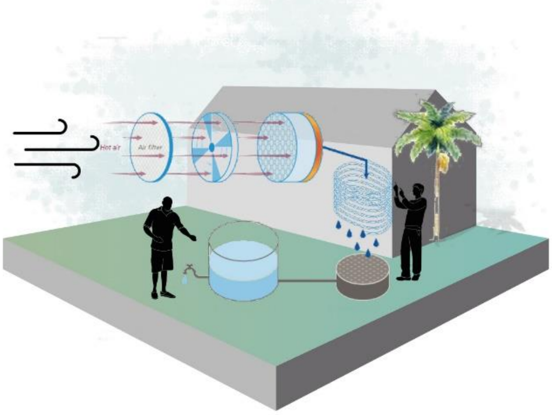


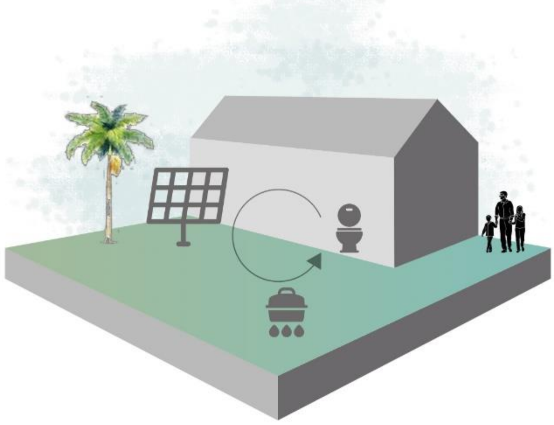
Figure 22 Relations between challenges and solutions of the case studies. Source: Personal elaboration.

3.3 Abacus

Cape Town, South Africa
Policies and strategies



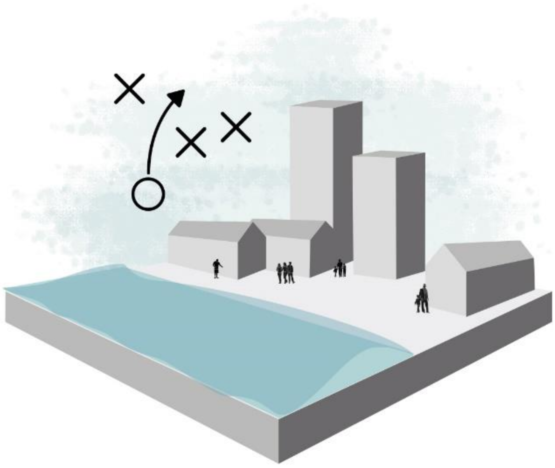
Thika, Kenya
Alternative water source



Naivasha, Kenya
Wastewater and energy

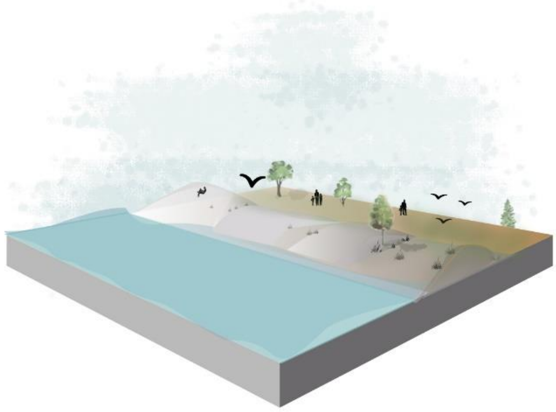
Chicago, USA
Wastewater and agriculture

Cliclana, Spain
Wastewater and energy



Vancouver, Canada
Sea level rise strategies

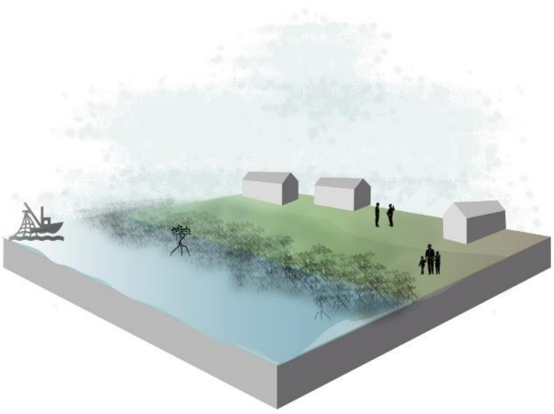
Amsterdam, The Netherlands
Coastal protection and alternative water source



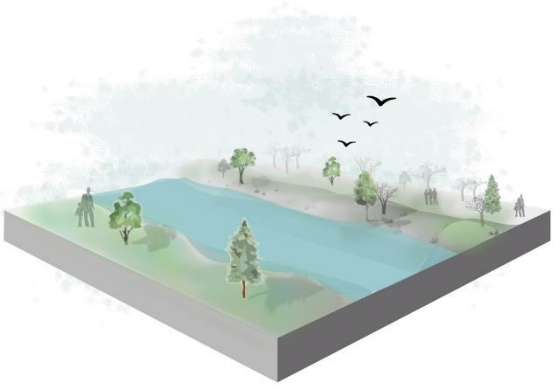
Chengdu, China
River's water quality

VicInAqua, Victorial Lake
Alternative water source and aquaculture

Bologna, Italy
CC strategies and water squares

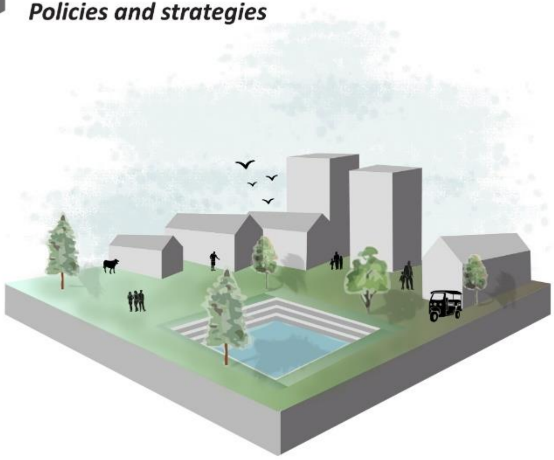


Mekong Delta
Mangroves conservation and aquaculture

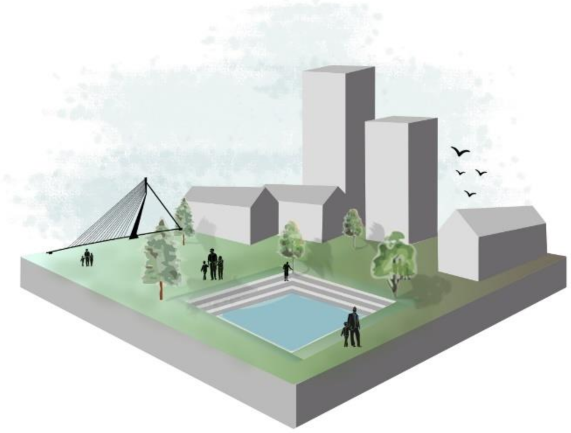


Cauca Valley, Columbia
Foundation for water conservation

Bratislava, Slovakia
Policies and strategies



Surat, India
Policies and strategies



Rotterdam, The Netherlands
Policies and strategies

Negev desert, Israel
Wastewater and alternative water source

Singapore
Wastewater and alternative water source

Singapore
Fight agaist mosquitoes

Refugee camps
Water Management education

Paris, France
Schools as oasis vs heatwaves

3.4 Database proposal

The research carried out so far led to the proposal of a new open-source database for best practices in water management related to climate change adaptation.

The overall objective is to share climate change adaptation achievements more fluent and more manageable, and thus speed up the transformation to resilient cities.

The database could start with a primary repertory of best practices, uploaded with standardised information, as outlined above in the matrix. The data would be stored according to context, problem and solution information.

In a second phase, best practices could be added by the actors themselves (for instance decision-makers, stakeholders, technicians) by filling in a form that the database's curators then analyse. This structure is inspired by the system of databases such as the *Metabolism of Cities*. In this way, the spectrum of archived practices would be much more comprehensive and continuously updated.

A researcher, an engineer facing a problem, a mayor of a small municipality, a decision-maker or an individual citizen could search by:

- **related geographical, social or economic contexts**
- **nature of the problem(s)**
- **features of the solution**

The requirements that in our opinion the database should have are:

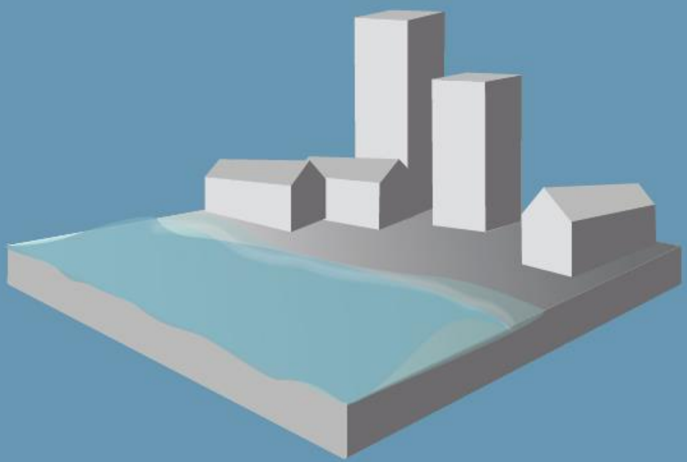
- **Simplicity,**
  Some of the databases analysed, although comprehensive and fascinating, turned out to be somewhat difficult to read.
- **Exhaustiveness**
  The database must provide as much information as possible both to inform and to help find the most suitable solution to the context or problem.
- **Open access**
  There is a strong belief in the right to information regardless of income, education or field of occupation.

The present idea is currently under discussion with UNESCO-IHP, R3C and SDU.Resilience, and is expected to be part of the UNESCO's Water Information Network System WINS, an open-access database collecting data about the global water cycle.

DATABASE PROPOSAL

CONTEXT

- **Country**
- **Continent**
- **Demography**
- **Urban or rural**
- **Size of city**
- **Economic type**
- **Climate type**



CHALLENGE

- **Drivers of impacts**
  - Flooding
  - Storm events
  - Environment loss
  - Heatwaves
  - Drought
  - Sea level rise
  - Coastal erosion
  - Land degradation
  - Health
  - Pollution
  - Wastewater
- **Exposed elements**
- **Related sectors**

SOLUTION

- **Benefits**
  - Ecosystemic
  - Social
  - Econimic
- **Type of answer**
  - Preparedness
  - Mitigation
  - Adaptation
  - Resilience

- **Type of intervention**
  - Engineering
  - Planning
  - Policies and strategies
  - NBS
  - Reduction of use
  - Management of excess
  - Management of scarcity
  - Pollution treatment
  - Distribution
  - Collection and delay
  - Alternative water source
  - Wastewater management
  - Acceleration of runoff

- **Multiscalarity**
- **Multifunctionality**
- **Integration with the context**
- **Participation level**
- **Knowledge creation**
- **Replicability**
- **Economic effort**
- **Mainenance effort**
- **Cultural bounds**

RESULTS

State of the art of the theories

An overview regarding the state of the art on resilient cities, climate change adaptation and water management has been done. In particular, through the literature review on Water Urban Metabolism carried out, the state of the art on the topic of Water Urban Metabolism has been investigated and analysed. Although there are numerous studies, there is a need for coherence and cross-sectional research between theories.

Indicators for Water Urban Metabolism

Starting from the literature review and the analysis of the indicators used in the field of Water Urban Metabolism, a series of indicators were proposed to summarise and facilitate the evaluation and comparison of metabolic analyses.

Matrix indicators for the evaluation and comparison of case studies

A series of matrix indicators were proposed for the evaluation and comparison of case studies regarding water management. The indicators are divided between features of the context, of the problem to face and on the solution adopted. The aim is to facilitate and encourage the collection, diffusion and comparison of good practices worldwide.

Database proposal

We now arrive to the proposal of a best practices database as a new UNESCO "Heritage for the Future" list, that can help create a sharing platform to collect, in the clearest, simplest but most comprehensive way possible, the interventions implemented so far to tackle climate change.

CONCLUSIONS

The present research moves from the values and aims of the sustainable development goals introduced by the 2030 Agenda, known as SDGs, with particular reference to number 6: "*Ensuring the availability and sustainable management of water and sanitation for all*" (*Agenda 2030*, 2015). These values have guided the research through theories and practices that are not easily understandable, with the final porpoise of identifying easy solution as replicable as possible.

In fact, in structuring the methodology, the attempt was to make it replicable and at the same time adaptable to changing needs.

Exploring water and climate change issues, the greatest difficulty was to remain detached from the challenging picture that awaits us. Although climate change challenges are numerous and daunting, with the right balance of passion, rationality and foresight we can ensure a more equitable and dignified survival for present and future generations, both human and ecosystem.

The problems associated with water resources are becoming more worrying by the day, both in terms of accessibility and exposure to the risk of extreme events. Especially in a time of crisis, such as the one we are currently experiencing, we should avoid diverting the attention from these issues and rather redouble the energy and resources invested in tackling climate change.

Developing this thesis, the relation between urban systems and water was explored. Urban water demand rises daily, both due to population growth and urbanisation, and in terms of litres per capita, but what emerges from recent studies is that water may also need the city. In fact, through good planning, optimisation of all internal and external processes, systematic maintenance, implementation and regeneration of infrastructure and appropriate social awareness, cities can no longer just be the main factor in water pollution and consumption, but also the solution to its problems. Water would therefore leave urban systems in better quality than it entered them.

However, the gap between theory and practice does not facilitate these projects' implementation nor timely responses. Indeed, theories appear to be articulated, in-depth but rarely applied to practice, at least not directly. On the other hand, practices are often the result of local needs, exceptionally part of a broader plan, and even less frequently based on theoretical evidence. On the theoretical level, this leads to a vastness of studies and research that is often as interesting as it is an end in itself. Despite this, some of the theories with the greatest potential for practical application have been identified, including Urban Metabolism, Water Sensitive Cities and Water Sensitive Urban Design. However, none of these theories is exhaustive in all its components, although they are multi-disciplinary, on different levels and in an integrated manner.

In practice, there has been a fair amount of action taken around the world to address water-related climate change, although these are not always natural solutions or direct translations of theoretical studies, and there is still a long way to go to transition to urban resilience.

Collating these practices and analysing them, it was noted that the Global North has more climate change adaptation interventions, although it is the Global South countries that are most affected. However, Nature Based Solutions in terms of economy, maintenance and efficiency do not impose any geographical limits on replicability. The role of governance and planning is key to designing, implementing and replicating interventions, building on the operational knowledge that sharing best practice can activate. The city of Copenhagen, the case study of this research, represents an excellent example not only for the quantity and quality of interventions carried out and for the progress made in the transition to a Water Sensitive City, but also for the ability demonstrated to trigger knowledge and awareness, without which the solutions would have remained punctual engineering interventions.

Considering the above, a suggestion that we can make from the theory point of view is to avoid remaining strictly within the bounds of a single theory but to prefer a multi-theoretical approach to overcome, as quickly as possible, the serious obstacles that we have to face, with the help of all the valid theories and their contributions. Urban Metabolism, and Urban Water Metabolism, for example, can be an excellent means of carrying out comprehensive and detailed analyses of systems in their entirety, to be able to understand strengths and weaknesses on which to intervene. For its part, the Water Sensitive Cities theory clarifies the pillars a city must work on in order to be defined as a water sensitive city. These pillars, strategies or key points as they are called, should be kept in mind when drafting strategic plans and directives to ensure that social, ecosystem and active learning aspects are an integral part of our future cities. Finally, Water Sensitive Urban Design can make this happen through integrated urban regeneration interventions for climate change adaptation.

By integrating some aspects of each theory and with evidence-based solutions, it is to believe that the theoretical part can take a step in the direction of the practice and vice versa to bridge the gap.

From the practice perspective, it is considered necessary to move away from the perspective of a single intervention carried out by the architectural firm or promoted by the particular political campaign, to a slightly more urgent but above all community-based approach. To this end, sharing any kind of progress and insight should be encouraged as much as possible. Learning from and with others is an excellent strategy to gain efficiency and save increasingly precious time.

Hence, the proposal of a best practice database as a new UNESCO "Heritage for the Future" list, which can help create a sharing platform to collect, in the clearest, simplest but most comprehensive way possible, the interventions implemented so far to tackle climate change.

The replicability of interventions is linked to different factors, but good ideas often trigger chain reactions needed more than ever these days.

SUGGESTIONS

Best governance level for planning

Understand which government level is the most appropriated and efficient in handling the climate change's adaptation, depending on the different realities (International level, national level, regional level, local and municipality level).

Economic benefit

Encouraging policies of financial and tax benefits for sustainable practices (economy is often the main barrier).

Sharing

Encouraging the share of problems and solutions (there can be already a solution for the same problem).

Sustainability networks and platform

Encouraging participation in sustainability networks and platforms.

Databases

Encouraging to collect and share data that can help understand trends and dynamics to implement climate change mitigation and adaptation (as C40 database, Metabolism of Cities Hub, UNESCO-UCCN, etc.).

Top-down as Bottom-up

Solutions both top-down, starting from international policies or calls, and bottom-up, came from local problematics and local solutions.

Replicability, simplicity, and durability

Take care of the replicability of the solutions, if not at an international level, also just at a local level. The most effective and durable solutions are often the simplest ones, nature based and self-sufficient.

Too much and too little

Linking water surplus and water shortage events is a traditional and efficient way of optimizing the economic resources in designing infrastructures with a dual purpose.

Retrofitting

It is never too late for retrofitting blue-green measures (especially in infrastructures and buildings renovations).

Bibliography and references

A New Era in Global Health (2018) Transforming Our World: The 2030 Agenda for Sustainable Development. DOI: 10.1891/9780826190123.ap02.

Bhaskar AS and Welty C (2012) Water balances along an urban-to-rural gradient of metropolitan baltimore, 2001-2009. *Environmental and Engineering Geoscience* 18(1): 37–50. DOI: 10.2113/gseegeosci.18.1.37.

Blanca Jiménez-Cisneros; Alexandros K. Makarigakis (2019) UNESCO's Contribution to Face Global Water Challenges.

Brunetta G, Caldarice O, Tollin N, et al. (2019) *Urban Resilience for Risk and Adaptation Governance*.

Burn S, Maheepala S and Sharma A (2012) Utilising integrated urban water management to assess the viability of decentralised water solutions. *Water Science and Technology* 66(1): 113–121. DOI: 10.2166/wst.2012.071.

Climatecon., Minx J, Creutzig F, et al. (2011) Approach To Assess Urban Metabolism in. 240(1): 1–83.

Dijst M, Worrell E, Böcker L, et al. (2018) Exploring urban metabolism—Towards an interdisciplinary perspective. *Resources, Conservation and Recycling* 132(October 2017): 190–203. DOI: 10.1016/j.resconrec.2017.09.014.

Encyclopedia of Science (2020) Encyclopedia of Science.

Faragò M, Rasmussen ES, Fryd O, et al. (2018) Coastal protection technologies in a Danish context.: 1–74.

Farooqui TA, Renouf MA and Kenway SJ (2016) A metabolism perspective on alternative urban water servicing options using water mass balance. *Water Research* 106. Elsevier Ltd: 415–428. DOI: 10.1016/j.watres.2016.10.014.

Fratini CF, Geldof GD, Kluck J, et al. (2012) Three Points Approach (3PA) for urban flood risk management: A tool to support climate change adaptation through transdisciplinarity and multifunctionality. *Urban Water Journal*. DOI: 10.1080/1573062X.2012.668913.

Hammond MJ, Chen AS, Djordjević S, et al. (2015) Urban flood impact assessment: A state-of-the-art review. *Urban Water Journal* 12(1): 14–29. DOI: 10.1080/1573062X.2013.857421.

Huang CL, Vause J, Ma HW, et al. (2013) Urban water metabolism efficiency assessment: Integrated analysis of available and virtual water. *Science of the Total Environment* 452–453(February 2019). Elsevier B.V.: 19–27. DOI: 10.1016/j.scitotenv.2013.02.044.

Jarraud M and Steiner A (2012) *Climate Change 2014, IPCC*. DOI: 10.1017/CBO9781139177245.003.

Juan Godoy Chacha (2015) Harvesting rainwater in households a strategy in short term to improve the current water metabolism in Cuenca, Ecuador.

Kennedy C, Cuddihy J and Engel-yan J (2007) The Changing Metabolism of Cities. 11(2).

Kennedy C, Pincetl S and Bunje P (2011) The study of urban metabolism and its applications to urban planning and design. *Environmental Pollution* 159(8–9). Elsevier Ltd: 1965–1973. DOI: 10.1016/j.envpol.2010.10.022.

Kenway S, Gregory A and McMahon J (2011) Urban water mass balance analysis. *Journal of Industrial Ecology* 15(5): 693–706. DOI: 10.1111/j.1530-9290.2011.00357.x.

Lucertini G and Musco F (2020) Circular Urban Metabolism Framework. *One Earth* 2(2). The Authors: 138–142. DOI: 10.1016/j.oneear.2020.02.004.

Meerow S, Newell JP and Stults M (2016) Defining urban resilience: A review. *Landscape and Urban Planning* 147. Elsevier B.V.: 38–49. DOI: 10.1016/j.landurbplan.2015.11.011.

Musango JK, Currie P and Robinson B (2017) Urban Metabolism for Resource-Efficient Cities. *Paris: UN Environment*: 1–40. Available at: www.sustainabilityinstitute.net.

Newman PWG (1999) Sustainability and cities: Extending the metabolism model. *Landscape and Urban Planning*. DOI: 10.1016/S0169-2046(99)00009-2.

Omojola A, Dettinger MD and Diego S (2011) Climate change, water, and wastewater in cities. *Choice Reviews Online* 49(07): 49-3876-49–3876. DOI: 10.5860/choice.49-3876.

Renouf M, Kenway SJ, Serrao-Neumann S, et al. (2016) Urban Metabolism for Planning Water Sensitive

Cities: Concept for an Urban Water Metabolism Evaluation Framework. *Cooperative Research Centre for Water Sensitive Cities*: 1–43. Available at: http://watersensitivecities.org.au/.
Renouf MA, Serrao-Neumann S, Kenway SJ, et al. (2017) Urban water metabolism indicators derived from a water mass balance – Bridging the gap between visions and performance assessment of urban water resource management. *Water Research* 122. Elsevier Ltd: 669–677. DOI: 10.1016/j.watres.2017.05.060.
Serrao-Neumann S, Renouf MA, Morgan E, et al. (2019) Urban water metabolism information for planning water sensitive city-regions. *Land Use Policy* 88(February). Elsevier: 104144. DOI: 10.1016/j.landusepol.2019.104144.
Thériault J and Laroche AM (2009) Evaluation of the urban hydrologic metabolism of the greater moncton region, New Brunswick. *Canadian Water Resources Journal* 34(3): 255–268. DOI: 10.4296/cwrj3403255.
Tollin N (2020) Urban Resilience & Water:Research, Policy and Practice.
UN DESA (2015) World Population Expected to Reach 9.7 Billion by 2050.
UNESCO (2020) *Water and Climate Change*.
UNESCO IHP (2014). Available at: https://en.unesco.org/themes/water-security/hydrology/IHP-VIII-water-security.
Voskamp IM and Van de Ven FHM (2015) Planning support system for climate adaptation: Composing effective sets of blue-green measures to reduce urban vulnerability to extreme weather events. *Building and Environment* 83. Elsevier Ltd: 159–167. DOI: 10.1016/j.buildenv.2014.07.018.
WHO/UNICEF (2017) Progress on Drinking Water, Sanitation and Hygiene - Joint Monitoring Programme 2017 Update and SDG Baselines. *Who*: 66. Available at: http://apps.who.int/bookorders.%0Ahttp://apps.who.int/iris/bitstream/10665/258617/1/9789241512893-eng.pdf%0Ahttp://www.wipo.int/amc/en/%0Ahttp://www.wipo.int/amc/en/.
World Bank (2017) Reducing Inequalities in Water Supply, Sanitation, and Hygiene in the Era of the Sustainable Development Goals. Synthesis Report of the WASH Poverty Diagnostic Initiative. *World Bank Group*.
WWDR (2020) *The United Nations World Water Development Report 2020: Water and Climate Change*.
Zhang Y (2013) Urban metabolism: A review of research methodologies. *Environmental Pollution* 178: 463–473. DOI: https://doi.org/10.1016/j.envpol.2013.03.052.

List of figures and tables