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Water in Urban Regions:

Building Future Knowledge to Integrate Land Use, Ecosystem Services and Human Health

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Water in Urban Regions:

Building Future Knowledge to Integrate Land Use, Ecosystem Services and Human Health

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Foreword

Urban regions – comprising urban core areas and the peri-urban hinterlands – in many parts of the world are increasingly facing serious water-related environmental and societal problems, which are posing enormous challenges to the wellbeing of societies and individuals. The current scientific approaches to these challenges often struggle to capture the complexity of urban regions, and thus cannot always provide appropriate answers and solutions.

The Brazilian Academy of Sciences (ABC), the German National Academy of Sciences Leopoldina and Germany's Junge Akademie organised the symposium "Water Issues and Ecological Sustainability in Areas of Urbanisation" from 5 to 8 May 2014 in São Carlos, Brazil, in order to hold a science-based discussion on water-related challenges in urban regions.

The symposium provided a setting for interdisciplinary exchange for 26 young scientists, mainly from Brazil and Germany. It took place within the framework of the "Germany + Brazil 2013/2014" campaign initiated by the German Federal Foreign Office. Inspired by the motto of the bilateral year, "How do we want to live tomorrow?", the young scientists – from the fields of engineering, natural, life and social sciences – discussed and linked up water-related issues in urban regions with regard to land use, human health, ecosystem services, monitoring, data, and policy implementation.

The current report presents research needs, which – according to the participants of the symposium – are important in the research-driven management of water-related environmental and societal problems in urban regions. Extensive scientific research in the identified areas could facilitate the articulation of answers and the formulation of proposals for more viable, sustainable and humane cities in the future.

The report reflects the views of the young scientists participating in the symposium and not necessarily the position of the three academies. A list of authors is available in the appendix.

We, as the organising academies, would like to particularly thank Professor José Tundisi (São Carlos, member of the ABC) and Professor Peter Fritz (Leipzig, member of the Leopoldina) for coordinating and supporting the event.

We would also like to thank the German House of Science and Innovation in São Paulo (DWIH), the Brazilian Agricultural Research Corporation (Embrapa), Finep Innovation & Research, and the City Council of São Carlos for sponsoring the bilateral symposium.

Professor Jörg Hacker
President
German National Academy of Sciences Leopoldina

Professor Jacob Palis
President
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Speaker
German Young Academy

Key Messages

The availability of water is crucial for the wellbeing and development of human societies. Strong trends towards urbanisation are increasing pressure on urban water systems, creating a demand for appropriate management strategies. This position paper focuses on these issues and their links to land use, ecosystem services, human health, monitoring and policy implementation. The key messages below illustrate avenues for future research that may help develop solutions for water-related challenges in urban regions.

Water and Land Use

Close water and nutrient loops within urban regions – the “zero impact” ideal

Devise an ideal concept for guiding decision-making and innovation that separates internal from exchange fluxes and demands that land development has the least possible impact on the surroundings.

Slow down the urban water and nutrient cycles within urban regions

Increase the residence time of water and nutrients, for example by reusing rainwater for essential functions of the city, such as sanitation and irrigation, and recycle nutrients from waste streams as fertilisers.

Improve our understanding of land-use effects in the urban context

Account for unexplored interactions between different physical, chemical and biological impacts as well as between environmental and social systems, and become aware of unexpected systemic responses.

Water and Ecosystem Services

Recognise the full potential of ecosystem services, especially under conditions of limited space

Understand urban regions as living entities and promote the high self-regulatory potential of ecosystems. Integrate green and grey infrastructure, and facilitate the provision of multiple services from green areas.

Create and secure basic conditions for ecosystem services

Understand the basic demands for maintaining urban ecosystems, including connections with more natural hinterlands using green corridors and efficient integration with blue, green and grey water streams.

Integrate ecosystem services in the water-energy nexus

Couple modern technologies with ecosystem functions to promote low-cost decentralised solutions for waste water management combined with energy production and water purification.

Understand ecosystem disservices

Assess the adverse side effects of ecosystem services, as for example the impact of green infrastructures on the spread of waterborne diseases.

Water and Human Health

Reduce environmental and health impacts by preventing water pollution

Re-prioritise the regulation and control of water pollution in policies concerning the core economic activities of agriculture and industry. Promote more environmentally sustainable and responsible production methods.

Improve knowledge, develop technology and enforce measures against water pollutants

Understand mechanisms of pathogenicity and interactions between different pollutants in order to develop suitable emission guidelines. Improve implementation by addressing water pollution in a combined effort between national and international institutions.

Expand water supply and sanitation to the most vulnerable communities, through versatile, contextualised and accessible solutions

Combine alternative decentralised solutions of water supply and sanitation to address the specific needs and capacities of urban and peri-urban populations. This should go along with a paradigm shift from “sewage disposal” to “nutrient recycling”.

Improve local health systems for better reporting and controlling water-related disease, especially in disaster-prone areas

Strengthen risk management policies and the responsible institutions to monitor, communicate and mitigate the spread of epidemics more efficiently and effectively.

Monitoring & Process Analysis

Improve access to water-related data

Allow access to data not only for scientists but for the interested public and other stakeholders in order to facilitate participatory decision-making.

Adapt environmental monitoring and modelling to urban regions

Take into account the high spatial and temporal variation and dynamic changes in the physical and socio-economic environment as typical for urban settings. Adapt the structure of mathematical models (e.g. on water quality or health risks) to better incorporate qualitative data from social sciences.

Develop indicators for healthy urban environments and early warning systems for urban regions

Develop indicators that are suited to defining healthy urban regions reflecting both social and environmental settings, and use them as early warning systems for both naturally-driven and man-made changes.

Society and Implementation

Make efficient use of existing knowledge and technology

Promote inter- and transdisciplinary work to translate and distribute existing knowledge, to test it in the real world, and to take advantage of local knowledge.

Design policies for their specific local context

Pay particular attention to specific local environmental and socio-economic conditions when developing environmental programmes, strategies and policies.

Use impact assessments to design policies

Consider social impacts next to environmental and economic aspects to address concerns such as fairness, social inclusion and gender equality.

Mainstream policies

Develop and implement environmental policies jointly with all affected agencies and departments.

Integrate policies across spatial scales

Coordinate policy decisions across different administrative levels and choose scales that are in concert with natural units and processes such as watersheds and pollution flows.

Develop and apply bottom-up, participatory approaches

Involve local government institutions and authorities, civil society organisations, the scientific community, the business sector and the affected population in decision-making processes.

Use local knowledge to promote education and provide local opportunities for learning

Use experimental learning and participatory approaches to increase people's commitment and responsibility towards environmental stewardship.

Promote long-term thinking and implementation

Design policies to be able to adapt to the temporal scale and dynamics of environmental and socio-economic processes, such as the duration of natural cycles or demographic and economic trends.

1 · Introduction

Today, for the first time in human history, most people are living in urban rather than rural regions. The growth of these areas – a process of land-use change called urbanisation – is projected to continue in many places in the future[1]. Societies are increasingly dealing with urban regions, comprising urban core areas (i.e. dense human settlements) and the peri-urban hinterlands (i.e. areas of fragmented rural and urban land use). Thus the health and wellbeing of an increasing number of people depends on the way urban regions are developed and managed.

Water is of particular importance, and many cities are facing water-related problems including pollution, eutrophication, and scarcity of clean water. Water-related diseases are still widespread, especially in developing countries, where sewage systems are often insufficient, while efforts to address these issues are far from being successful[2]. In many parts of the world, resources are still used in an unsustainable and inefficient way and the potential for re-using industrial and household waste as well as waste water to extract energy and nutrients, is rarely fully exploited. In addition, ecosystem services, which are the benefits and goods humans receive from bodies of water, green spaces and other natural areas in urban regions, are often underutilised and usually not fully considered in planning and policymaking due to poor understanding and evaluation[3].

The land-use change caused by urbanisation often depletes ecosystems' ability to provide services and impacts on human health. Already, many urban environments depend on external natural resources, especially water, making them vulnerable to long-term changing framework conditions as well as sudden disturbances[4]. In the face of population growth, climate change and increasing urbanisation, sustainable water management will become even more urgent.

Urban regions can play an active role when it comes to addressing these challenges[5]. Therefore we, as young scientists, envision resilient cities that reduce their environmental impact and their dependence on natural resources coming from afar, and that have the ability to respond to external changes and stresses. Resilient cities should be well integrated into their surrounding hinterlands through green and blue infrastructure (i.e. forests and other natural areas, rivers, lakes, parks, green roofs, etc.), providing people with the opportunity to reconnect with nature despite ongoing urban growth[6]. Ecosystems within urban regions should be restored and managed in order to guarantee the supply of ecosystem services, such as the provision of fresh water, groundwater recharge, and evaporative cooling, as well as recreational opportunities that improve human wellbeing. In that respect, functioning urban water systems are especially important for healthy and attractive cities.

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1 United Nations Population Division (2012): "World Urbanization Prospects: The 2011 Revision Population Database." Online: http://esa.un.org/unup [last viewed July 2014].

2 World Health Organization and UNICEF (2013). *Progress on sanitation and drinking-water – 2013 update.* WHO Press, Geneva.

3 Andersson, E. et al. (2014): "Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services", *Ambio 43:* 445–453.

4 Ahern, J. (2010): "Planning and design for sustainable and resilient cities: theories, strategies and best practices for green infrastructure", Novotny, V., J. Ahern & P. Brown (Eds.), *Water-centric Sustainable Communities.* John Wiley and Sons, Hoboken, 135–176.

5 Robrecht, H., L. Lorena & P. Mühlmann (2012): "Ecosystem services in cities and public management", Wittmer, H. & H. Gundimeda (Eds.), *TEEB – The Economics of Ecosystems in Local and Regional Policy and Management.* Earthscan, Abingdon and New York, 99-128.

6 Tzoulas, K. et al. (2007): "Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review", *Landscape and Urban Planning 81:* 167-178.

However, the reality in many countries is far removed from our vision. Surface sealing and other ecosystem degradation, intensive peri-urban agricultural land use, and unsustainable water and resource exploitation are having a negative impact on the water system. In addition, due to social segregation within urban regions, disadvantaged societal groups are even more systematically marginalised and excluded from access to green spaces and clean water. Held back by current management approaches, tenure right situations, and unsustainable and inefficient decision-making, the urban green and blue infrastructure is underutilised. In contrast, what is needed are enhanced inclusiveness, equality and transparency for the processes that shape our urban environment and the distribution of water resources.

In the face of the mismatch between emerging urban challenges and our vision of sustainable water management in and near cities, substantial demand for advances in science is becoming obvious. In this paper we have three objectives, outlined in Figure 1:

1. We present crucial research topics that address land-use management, ecosystem service provision, and human health in the context of urban water systems.
2. We elaborate relationships and interdependencies between these three fields, aiming at pathways to more sustainable, resilient and liveable future urban regions.
3. We expand on horizontal cross-cutting issues related to all three aspects, i.e. the formulation of research requirements related to indicators, data and methods as well as interaction with society and implementation.

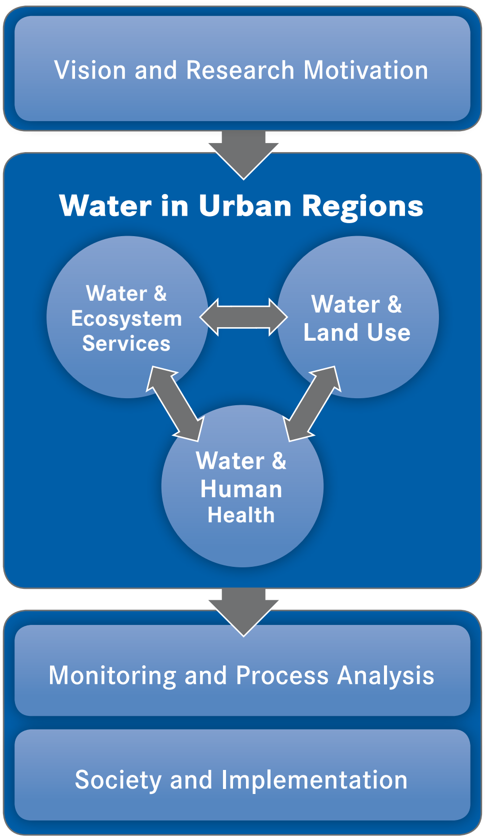

Figure 1: *Research Framework for Sustainable Water Management in Urban Regions. After our vision and motivation is presented in Section 1, Sections 2, 3 and 4 cover Water and Land Use, Water and Ecosystem Services, and Water and Human Health, respectively. Monitoring and Process Analysis can be found in Section 5, while Section 6 is dedicated to Society and Implementation. Each section identifies specific problems and challenges as well as avenues for further research.*

2 · Water and Land Use

On the global scale, urban and metropolitan regions are characterised by an ever-increasing water footprint and a great dependency on resources from rural hinterlands[7]. While urban populations increase, services such as hygienic sanitation, erosion control and sustainable waste water management are lagging behind, and land development is happening in a largely uncontrolled manner. As a result, we are noticing phenomena such as water quality degradation, growing flood risks, and water-borne diseases. Some of these concerns are directly related to anthropogenic activities that interrupt and bypass natural cycles[8]. For example, nutrients are imported in the form of food, but instead of being returned as fertiliser to agriculture they are directed into rivers as polluted water. Other concerns are related to the close proximity of strongly contrasting land uses, for example industrial areas that pollute ground water alongside residential areas with increasing demands for clean water.

Close water and nutrient loops within urban regions – the "zero impact" ideal

The "zero impact" ideal is a planning approach that can be applied to guide decision-making and innovation with regard to conflicting land uses and the development of urban regions. In the water resources domain, "zero impact" means that exchange fluxes with the surroundings are required to be the same as the original or pre-development ones, and only internal fluxes and budgets (water, sediments, nutrients, etc.) may be modified by human action[9]. Thinking "zero impact" or "low-impact development" in the planning processes enforces bookkeeping of input and outputs of a system and devising options for internal (re-)cycling that would reduce both. Implementation has so far focused on the water cycle, restricting the outflow of a developing area to the amount of the existing outflow in the pre-development condition. Solutions are required that further promote the use of this concept and allow for it to be expanded to water quality issues, for example by recycling the nutrients from waste. Here, the concept of urban farming in particular offers opportunities in densely built-up areas for improving the water resources and nutrient cycling and even food production, thereby reducing the need for external supplies while at the same time increasing sensitivity of knowledge regarding food production and nature. As one of the largest water consumers in urban regions, urban and peri-urban agriculture are also important land-use actors that can protect non-sealed surfaces from encroachment and enhance water infiltration into the soil, thereby slowing down the urban water cycle in densely populated areas. This, however, requires new technology for cleaning water from urban runoff to fulfil the high standards for safe irrigation water.

> **Building Future Knowledge:**
> **How can we further implement the "zero impact" ideal focusing on the water cycle and expand it to the nutrient cycles in urban regions?**

7 McDonald, R. I. et al. (2011): "Urban growth, climate change, and freshwater availability", *Proceedings of the National Academy of Sciences of the United States 108(15):* 6312-6317.

8 Kennedy, C., J. Cuddihy, et al. (2007): "The Changing Metabolism of Cities", *Journal of Industrial Ecology 11:* 43-59.

9 Dietz, M. E. (2007): "Low impact development practices: A review of current research and recommendations for future directions", *Water, Air & Soil Pollution 168:* 351-363.

Slow down the urban water and nutrient cycles within urban regions

One important issue related to interrupted water cycles in cities is the quantity of rainwater that runs off on sealed surfaces, rinsing off pollutants and rapidly reaching downstream areas. There is a need to identify and implement more strategies for slowing down water cycling within the city. This is related to closing urban loops and can benefit from the "zero impact" concept. Rainwater should be redirected away from streets and drainage networks, because such short-circuiting intensifies floods. Instead, it should be used for essential functions of the city such as sanitation and irrigation. This requires decentralised technologies for drainage, sanitation and water supply to be acknowledged as essential in city planning processes. Especially where water is scarce, the possibilities of water harvesting and reuse should be reassessed, as has been done for example in the One Million Rain Tanks project in Brazil's semi-arid regions[10].

Although such technologies are currently not considered the state of the art, they have the potential to provide easier access to inexpensive, inclusive and water-saving sanitation. At the same time, decentralisation allows for local decision-making and solutions that are close to local realities. These are more flexible than large-scale infrastructures and allow for stepwise implementation depending on available funds, for example first making sanitation safe from a health perspective and secondly implementing recycling techniques to recover resources and lessen environmental impact. Techniques already available range from low to high tech. For example, pit toilets can be made much safer with simple adaptations that bear almost no additional cost; more complex solutions include in-house water treatment plants or constructed wetlands, which rely on ecosystem services and can be integrated into recreational space for the city. Technological development and cooperation should be targeted towards efficient treatment in densely populated areas, particularly in terms of energy efficiency and recycling of nutrients. Furthermore, an important step forward would be the widespread implementation and testing of available technologies in pilot projects in order to gather more experience of their application on the urban scale.

Figure 2: *Ulaanbaatar, Mongolia. The banks of the Selbe River are covered with litter. Latrines, such as the one in front of the yurt in the foreground, are often constructed in the floodplains and cause water contamination. This is precarious when surface water is used for drinking.*

Photo by Daniel Karthe.

10 Gnadlinger, J. (2007): "P1MC and P1+2, Two Community Based Rainwater Harvesting Programs in Semi-Arid Brazil." Brazilian Rainwater Catchment and Management Association (ABCMAC). See also: http://www.asabrasil.org.br/Portal/Informacoes.asp?COD_MENU=1150 [last viewed July 2014].

The lack of sanitation systems in many urban sprawl areas may be a great opportunity for capacity building. Newly industrialising countries provide a forum where innovation on decentralised management of nutrient and water fluxes, with the particular aim of closing loops in the city, can find fertile ground. This is, on the one hand, because centralised techniques are not yet established and, on the other, because the flexibility of decentralised systems is well suited to a quick development pace that is to some extent unpredictable. This provides the potential for educating and inspiring developed nations to restructure towards decentralised concepts and slow-cycling cities.

Building Future Knowledge:

How can we efficiently slow down and close water and nutrients cycles within the urban areas and their peri-urban surroundings? How can the concept of a decentralised infrastructure in urban regions be enhanced and implemented with local support?

Improve our understanding of land-use effects in the urban context

Urban environmental systems are subject to a particularly wide range of impacts. While system responses to individual impacts are partially understood, little knowledge exists about interactions between different impacts. For example, eutrophication and contaminant pollution may have antagonistic effects on the primary productivity of urban aquatic systems, increasing and diminishing it, respectively. In contrast, eutrophication and riparian clear-cutting may have positive synergy effects, increasing primary productivity of the system. Thus, a better understanding of closely interacting processes is needed in order to also improve our predictions and evaluations of how urban systems react to different impact scenarios.

Figure 3: *Sulejowski Reservoir, Poland. Restoration of plant riparian zone for buffering the non-point source pollution from agricultural land, combined with establishing of denitrification wall under the road, action funded by EU Project Life+ EKOROB.*

Photos by Katarzyna Izydorczyk.

Moreover, urban regions are characterised by a complex and dynamic pattern of urbanised and green spaces, such as housing, commercial areas, industrial zones and transportation infrastructure, but also farmland, forests, etc. These land-use types have different functions in the urban water system; they might act as sinks and sources of water, contaminants and nutrients (see also Chapter 3). In turn, these functions may be strongly modulated by the spatial distribution of patches, and by mutual interferences, and are not fully understood yet. This makes whole-system responses very difficult to predict, but may also bear unexpected advantages. For example, urban areas often negatively affect the functioning of neighbouring ecosystems and agricultural areas, even on a small scale. On the other hand, this patchiness provides multiple opportunities to close nutrient cycles in cities, for example by recycling nutrients from human waste (after treatment) through their use in inner-urban or peri-urban agriculture.

Currently, much of the understanding of processes is derived from natural systems. However, strongly disturbed and modified systems, such as unnaturally stratified soil or urbanised aquatic ecosystems, have markedly different dynamics. The functioning and the responses of the urban region's water systems, including the importance of close interactions between the different land use patches, are not fully understood so far. Particular attention should be paid to the temporal and spatial coevolution of urban expansion with social and demographic changes. New modelling approaches are required to provide a better basis for planning and management. Modelling philosophies in the different related disciplines, for example social and water sciences, are so separate that their true reconciliation within a single modelling and prediction framework has not yet been achieved (see also Chapter 5). An interdisciplinary effort is necessary, translating model parameters and mathematical formulations into a common language, rephrasing model formulations, and looking together at historic urbanisation processes in order to explore new ways of analysing patterns in data that are helpful for the input and validation of interdisciplinary models.

Building Future Knowledge:

How can we improve system knowledge and prediction capacity in the urban context? Which new model structures allow the prediction of those intensified and variously interacting small-scale processes, while permitting the inclusion of social sciences and other disciplines?

3 · Water and Ecosystem Services

Ecosystem services are the goods and services humans receive from ecosystems and which contribute to human wellbeing and health. Urban ecosystem services are provided by a diversity of green spaces and bodies of water that are known as the "green infrastructure" of urban regions[11]. The name reflects the fact that they can be just as important for the functioning of urban regions as "grey" infrastructure like roads or pipes. Ecosystem services provided by green infrastructure are considered to increase the resilience and reduce the environmental footprint of urban regions. However, the links between green infrastructure and the provision of ecosystem services in urban regions are not well understood. In this section, we discuss future research fields that will promote the integration of natural and anthropogenic domains in order to fully exploit the potential of ecosystem services in urban regions. In so doing, we are also aiming to address the provision and management of ecosystem services, and potential trade-offs between green infrastructure and ecosystem services.

Recognise the full potential of ecosystem services, especially under conditions of limited space

The concept of ecosystem services in urban regions has been present in scientific research for more than a decade[12]. However, its consideration in planning, policymaking and design still lags behind. Regarding urban regions as living entities can be an important asset in the integration of green and grey infrastructures across spatial scales. An additional challenge in urban regions is the lack of space for green infrastructure. Possible solutions are: 1) facilitating the provision of multiple ecosystem services from one component of the green infrastructure[13]; 2) provision of ecosystem services from the surroundings of urban areas, such as recovery/restoration areas along bodies of water[14]; or 3) the transformation of existing structures into green spaces, e.g. roofs into green roofs and walls into green walls[15]. Green infrastructures that provide multiple ecosystem services and make use of the connectivity of urban areas with their surroundings are crucial future research topics. Ecosystem services and supportive biotechnologies can become an interesting element of the urban landscape and its multi-functionality, merging the green-grey system, providing resources, serving education, human health, local economic growth and revitalisation of space.

> **Building Future Knowledge:**
> **How can the self-regulatory potential of ecosystems be transferred into the green-grey system? How can the potential of ecosystem services be optimised under conditions of limited space?**

11 Bolund, P. & S. Hunhammar (1999): "Ecosystem services in urban areas", *Ecological Economics 29*: 293-301.

12 Haase, D. et al. (2014): "A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, Models, and Implementation", *Ambio 43:* 413–433.

13 The Chartered Institution of Water and Environmental Management (CIWEM) (2010): "Multi-Functional Urban Green Infrastructure." Online: http://www.ciwem.org/media/878347/MUGI%20Briefing%20report%20FINAL.pdf [last viewed July 2014].

14 Sundermann, A. et al. (2011): "River restoration success depends on the species pool of the immediate surroundings", *Ecological Applications 21(6):* 1962-1971.

15 Gill et al. (2007): "Adapting cities for climate change: the role of the green infrastructure", *Built Environment 33(1):* 115–133.

Create and secure basic conditions for ecosystem services

Current approaches mainly aim at quantifying ecosystem services that directly relate to benefits for humans from nature, for example in terms of goods provided and improved health[16]. A neglected aspect, critical for urban regions, is securing basic conditions that allow ecosystems in those areas to deliver ecosystem services in a sustainable, efficient, and low-cost way[17]. This might not only be important for existing ecosystems, but also for artificial ones, serving particular services, such as constructed wetlands[18]. Hence, it is essential to understand the basic prerequisites for maintaining ecosystem services in green infrastructure, such as water, space and soil. This includes linking ecosystems with blue (surface and groundwater), green (water in agriculture) and grey (kitchen and bath water) water streams through spatial planning as well as considering interdependencies between urban regions and the hinterlands, thus the continuity of ecological processes within the whole watershed. Furthermore, the collective awareness and understanding of the relationship between ecosystem services and public policies is the basis for embracing the protection or reintroduction of green infrastructure in urban regions.

Building Future Knowledge:
What are the basic conditions for the development and maintenance of ecosystem services in urban regions?

Integrate ecosystem services in the water-energy nexus

Urban areas tend to consume large amounts of energy, water and nutrients, and to emit large amounts of greenhouse gases. Ecosystem services should be used to both produce energy and reduce the consumption thereof as well as to decrease water usage, by means of the water-energy nexus and biotechnology. New technologies, such as second- and third-generation biofuels, can allow the transformation of waste into energy and the use of limited spaces in urban areas for

Figure 4: *Belo Horizonte, Brazil. Revitalization of urban space with storm and rainwater harvesting parks, example of multifunctional spaces using ecosystem services for increasing social and environmental security of poor districts.*

Photo by Kinga Krauze.

16 Tzoulas et al. (2007): "Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review", *Landscape and Urban Planning 81:* 167-178.

17 Pataki, Diane E. et al. (2011): "Coupling biogeochemical cycles in urban environments: ecosystem services, green solutions, and misconceptions", *Frontiers in Ecology and the Environment 9(1):* 27-36.

18 Mitsch, W.J. et al. (2012): "Creating wetlands: Primary succession, water quality changes, and self-design over 15 years", *BioScience 62:* 237-250.

producing energy in smaller decentralised units. For example, high loads of nutrients in (waste) water could be used for biomass production, serving as a local sink for CO_2 and a source for energy in urban areas at the same time[19]. Integrating biomass and related energy production on the outside of buildings, such as in algae-producing tanks[20], can present space-efficient solutions that minimise energy loss caused by long transportation routes. In a similar way, ecosystem services can also be integrated in decentralised water-treatment systems, contributing to efforts to recycle water close by or on the spot where waste water is produced, offering low-cost solutions[21]. In doing so, the amount of waste water collection can be reduced and nutrient loops closed. These are not new concepts, but they need to be further developed and integrated in new combined solutions, increasing their effectiveness to a point where they can be broadly applied.

Building Future Knowledge:
How can ecosystem services reduce the import of water and energy to the peri-urban and urban areas, and reduce greenhouse gas emissions?

Understand ecosystem disservices

Green infrastructures in urban regions deliver a multitude of ecosystem services, including provision of clean water, usually scarce in urban regions. In addition, zones where ecosystem services are provided may also include recreational areas, thus improving human mental and physical wellbeing. Even though substantial public health benefits from the provision of high-quality water and other ecosystem services have been demonstrated in many cases, exact assessments of how such health benefits can be achieved are still in their infancy[22]. On the other hand, provision of some ecosystem services may also have adverse side effects. For example, open bodies of water and green spaces can create breeding sites for disease vectors[23] and provide habitat for undesired and potentially dangerous wildlife[24]. One especially important future topic will be assessing the role of green infrastructure on the spread of waterborne diseases and pathogens affecting humans and biota (see also Chapter 4).

Building Future Knowledge:
What are the interactions between green infrastructure and human health and wellbeing and how can we balance them?

19 Shi, B. et al. (2012): "A New Approach of BioCO2 Fixation by Thermoplastic Processing of Microalgae", *Journal of Polymers and the Environment 20:* 124 – 131.

20 Fabris, L. M. F. (2013): "More than living. The IBA Hamburg prototypes", *Środowisko Mieszkaniowe – Housing Environment 11/2013:* 109-113.

21 DuPont, A. (2013): "Best practices for the sustainable production of algae-based biofuel in China", *Mitigation and Adaptation Strategies for Global Change 18:* 97 – 111.

22 Myers et al. (2013): "Human health impacts of ecosystem alteration", *Proceedings of the National Academy of Sciences of the United States of America 110:* 18753-18760.

23 Alirol, E. et al. (2011): "Urbanisation and infectious diseases in a globalised world", *Lancet Infectious Diseases 11:* 131 – 141.

24 Allen, B. L. et al. (2013): "Dingoes at the doorstep: Preliminary data on the ecology of dingoes in urban areas", *Landscape and Urban Planning 119:* 131 – 135.

4 · Water and Human Health

Inadequate use and management of environmental resources and particularly of water not only create ecological problems but also result in health risks, for which solutions are urgently needed. Besides the quantitative scarcity of this resource, the reduced quality of water due to contamination with nutrients, harmful chemicals, pathogens and toxins poses a serious problem. Universal access to clean water can be a challenging issue, and thus human health is often at risk. Some of the most important impediments to the prevention and control of water-borne diseases are related to water management and issues such as deficits in water supply, water treatment and sewage disposal. Other core problems involve functions of the health systems, as there is a clear need to advance medical definitions, to reconsider some of the most widely used indicators of health and wellbeing, and to improve the collection of health data (see also Chapter 5). Looking at the context of urban water management and public health, the following six areas in the nexus of water and health are deemed to require the particular attention and the combined efforts of both researchers and policymakers.

Reduce environmental and health impacts by preventing water pollution

Human activities produce large amounts of effluents, which, if not adequately treated, seriously contaminate surface and groundwater. Despite past efforts to control and regulate industrial activities regarding this matter, problems of water pollution persist and cannot be over-emphasised. The intake of hazardous substances, such as toxic metals, organic compounds or pharmaceuticals and their metabolites (e.g. hormones or antibiotics), can occur either directly, by drinking or having skin contact with contaminated water, or indirectly, by consuming polluted food products. Given such health risks, it becomes clear that the assessment of environmental and health consequences should precede legal permission and promotion of new industrial products and production methods. This specifically includes provisions for ensuring sufficient waste and waste water treatment. Intensive agriculture that relies heavily on chemical fertilisers, pesticides and high animal densities – and that typically surrounds urban areas – is also often the

Figure 5: *Parelheiros, São Paulo, Brazil. Peripheral communities commonly lack access to a public water supply and sewerage systems. The inhabitants of these areas must make use of excavated wells to provide their water needs, and cesspits for domestic waste water disposal. These onsite sanitation systems can release pathogens and nutrients into shallow groundwater.*

Photo by Alexandra Suhogusoff.

source of water pollution. Soil degradation, erosion and the run-off of concentrated nutrients into aquatic environments are some of the direct consequences, and these create health concerns. Cyanobacterial blooms, for example, are a growing environmental health problem, since the toxins they produce are very difficult and expensive to remove from water. In this light, the prevention of water pollution through regulation and control of the two core economic activities (agriculture and industry) is essential for the protection of human health in urban regions.

Building Future Knowledge:
How can the core economic activities of agriculture and industry be regulated and controlled in a way that foresees and prevents human health risks related to water pollution?

Improve knowledge, develop technology and enforce measures against water pollutants

There is a need for more specialised and efficient treatment of household, medical and industry sewage in urban areas. Water treatment faces many challenges due to the complex variety of pollutants, some of which are persisting and some of which are emerging. Apart from the multitude of immediate and long-term health problems caused by individual water pollutants (e.g. diarrheal diseases, skin diseases, cancer), there are a number of interactions and pathogenicity mechanisms that develop between pollutants and that are still unknown in many countries and contexts around the world. Due to the shortage of globally available information and the uncertainty that exists around the potential health impacts of some pollutants, there are no specific emission guidelines for a large number of them. As one result of this, for example, water that carries viral pathogens is often declared safe because safety assessments are based on conventional bacterial and not viral indicators. It is worth noting that even in places where adequate water quality standards are established, there can be a lack of practical enforcement. On a global scale, such governance deficits add significantly to problems caused by knowledge gaps or unavailability of suitable technologies (see also Chapter 6). In a globalised world, the protection of vital water resources requires the joint efforts of both national and international institutions.

Building Future Knowledge:
How can we effectively organise, share and advance our scientific knowledge in order to assess, in a timely manner, the health risks involved in the production/release of existing and emerging pollutants? How can we apply this knowledge to create water quality and pollution control regulation with a higher implementation priority?

Expand water supply and sanitation to the most vulnerable communities, through versatile, contextualised and accessible solutions

The role of water supply, sanitation and hygiene (WASH) solutions is crucial in the prevention of disease. Though such solutions exist, they are yet to be adopted in all places, as they are often not available, not accessible and not contextualised within local socio-ecological environments. People without access to centralised systems commonly end up extracting water from wells or collecting surface water or rainwater for their drinking, irrigation and watering needs. They also frequently employ household-based sanitation, such as septic tanks, pit latrines or open defecation. On-site sanitation systems, however, often release pathogens and nutrients that include nitrates and phosphates into the surrounding rivers, lakes, canals and shallow groundwater reservoirs. Combined with the use of untreated collected water, the health risks are aggravated for both these

Figure 6: *Manila, Philippines. Poor drainage is a frequent problem in Manila's slums, which are constructed parallel to the suburban railway line.*

Photo by Daniel Karthe.

communities and for the inhabitants of surrounding areas. In areas connected to a centralised water supply and waste water disposal infrastructures, a key concern is poor maintenance leading to water loss and waste water leakage. In many parts of the world, the latter contaminates soil and groundwater and may even enter drinking water distribution systems. Along with strengthening the expansion and maintenance of central systems, a combination of alternative, decentralised solutions of water supply and sanitation could better address the different needs and capacities of urban and peri-urban populations. Moreover, WASH solutions need to be holistic and consider both local and larger-scale perspectives. A paradigm change from "sewage disposal" to "nutrient recycling" could turn such solutions into self-sustaining "green growth" strategies (see also Chapter 2).

Building Future Knowledge:
How can we move from one-size-fits-all WASH solutions towards systems of water extraction, use and disposal that ensure human health and that are socio-culturally informed, locally adjusted and integrated?

Improve local health systems for better reporting and controlling water-related disease, especially in disaster-prone areas

Officially reported incidence rates for some water-related diseases reflect only a fraction of actual cases and consequently lead to an underestimation of health risks. Such underreporting of disease can be due to multiple factors, including low institutional capacities (e.g. insufficient clinics or unspecialised staff), cultural constraints (e.g. taboos or social stigma of disease causing its "silencing") and methodological limitations (e.g. reliance on "passive case detection", counting only self-reported cases, lack of diagnostic techniques). Aside from the de-prioritisation or public unawareness of a disease that this underreporting creates, it also contributes to the spread of epidemics. This is especially true and noticeable in areas prone to natural hazards such as extreme flooding (e.g. in densely occupied urban coastal areas). Such events often result in a deterioration of water quality due to pollutant influxes into infrastructure for drinking water supplies, as well as the inaccessibility of safe WASH, for example in relocation settlements. These conditions facilitate the emergence of water-related diseases. In some cases, such long-term effects outweigh the initial direct health burden of physical damage. Moreover, local healthcare institutions are often poorly prepared to deal with the multiple challenges posed by such situations and are not able to adequately provide disease prevention, treatment and healthcare.

Building Future Knowledge:
How can the actual spread of diseases be identified more efficiently and effectively and how can we emphasise the need for this in emergency situations and risk management policies?

5 · Monitoring and Process Analysis

Quality-assured, spatially and temporally explicit data representing real-world problems are the backbone of democratic decision-making and scientific assessments and are the prerequisite for scientific models. In the context of research on sustainability, models are essential tools for predicting possible outcomes of environmental modifications and an important basis for decision-making.

Improve access to water-related data

Today, access to water-related environmental and socio-economic data is often restricted, even though public funds are provided for data collection by governmental, administrative and research institutions. This is a hindrance for scientific research projects and objective decision-making processes. A structured open-access database for water and related environmental and health information should be created at both the national and international level, providing easy access not only for scientists but for the interested public and other stakeholders as well. Practical obstacles not only include restrictive data policies, but also the scattering of information over numerous scientific and administrative institutions and NGOs. In order to guarantee and strengthen the input of water-related research results in the databases, scientific journals should require authors to provide a link to their data uploads. For environmental (and environmental health) data, the international GenBank[25], an open-access genetic sequence database provided by the US National Institute of Health, could serve as a best-practice example. Since most relevant scientific journals in this field require authors to provide a link to their data uploads in the GenBank, this resource is now being widely used. The recent introduction of DOIs (Digital Object Identifier) for datasets could serve as an acknowledgement and incentive for individual scientists and scientific institutions to make water-related data available to a larger community.

> **Building Future Knowledge:**
> **How can we implement and maintain standardised open-access databases for water-related research results? How can we guarantee that information in the databases would be displayed in a way that all readers can understand? Which institutions should administrate the databases?**

Adapt environmental monitoring and modelling to urban regions

With a research focus on urban regions, data collection needs to take into account the high spatial and temporal variation and dynamic changes in the physical and socio-economic environment that are typical for such settings. Hydrological models, for example, require high resolution and up-to-date input data to characterise urban catchments. Recent and ongoing advances in remote sensing are one promising source of spatially explicit (near) real-time information. Moreover, the links between environmental and human health problems in urban settings create the

25 Benson, D. A., M. Cavanaugh, K. Clark, I. Karsch-Mizrachi, D. J. Lipman, J. Ostell & E. W. Sayers (2013): “GenBank”, *Nucleic Acids Res. 41(D1):* D36-42. doi: 10.1093/nar/gks1195.

Figure 7: *Grimma, Germany. Early warning systems, significantly improved after the devastating 2002 flood, helped to reduce damages during the recent 2013 flood in Germany. In the picture, the river Mulde is flooding the city of Grimma, which was evacuated timely in advance.*

Photo by André Künzelmann/UFZ.

need for integrated datasets. Today, information in different fields (e.g. land use, ecology and human health) is typically collected separately, resulting in spatial and temporal mismatches. Harmonised collection and storing of data would allow for more holistic research approaches and more sustainable interventions. This requires closer cooperation on different levels between different sectors, administrative bodies, organisations and scientific institutions.

One important characteristic of urban environments is the important role of anthropogenic activities. Analyses and models of the water cycle in urban areas should adequately represent socio-economic information, which is not always quantitative. To date, however, models aiming at the prediction of environmental or health impacts are still typically numerical and tend to exclude qualitative data. For a more holistic representation of reality, strategies need to be developed to include such information in models. This is particularly relevant in urban settings, where the behaviour of people can only partly be documented by quantitative or categorical indicators. Solutions to this challenge require closer cooperation between modellers and social scientists than is presently the case (see also Chapter 2).

Building Future Knowledge:
How can high spatial resolution data on urban catchments and water-related challenges be collected in an integrated way and provided in (near) real time? How can mathematical models (e.g. on water quality or health risks) be adapted in order to better incorporate qualitative data from social sciences?

Develop indicators for healthy urban environments and early warning systems for urban regions

Indicators that are currently used to characterise urban ecosystems and urban health need to be reconsidered. Many ecological indicators, for example, are based on the reference condition of pristine nature and are poorly suited for characterising environmental deficits or improvements in urban environments. Understanding the role of ecosystem services in improving the quality of life for people and biota requires the development of indicators that can help to quantify interactions and flow of services, and eventually initiate progress towards a healthy city. Attempts have already been made to derive such indices, assessing either citizens' happiness or the integrity of ecological systems. Our new vision for urban areas that are well connected to the landscape and form a part of the ecological system of the watershed imposes the challenge of developing new and integrated indices that allow us to assess: 1) the dependency of the urban area on local and external ecosystem services; 2) the integration of social and ecological systems; and 3) the sustainability of economic development based on ecosystem services (see also Chapter 3). Although the idea that ecological and social systems are in fact one single co-evolving entity has been present in literature since the 1990s, the assessment of socio-ecological system integration as such requires further elaboration. Future research needs to identify reference values for variables that will be used to define "healthy" urban regions, reflecting both social and environmental settings. This reference line will be the basis for the selection of ecosystem services to increase the adaptability of urban areas to global changes. Once the line is set, a great step forward will be the use of these indicators as early warning systems for both naturally-driven and man-made changes. Examples of such indicators for monitoring excessive exploitation or recovery include – alongside technical monitoring devices – pollution-sensitive sentinel species for the quality of water resources, and plant species sensitive to groundwater level changes. In the context of WASH, some currently used indicators are based on problematic assumptions. For example, categorising water supply as "unimproved" or "improved" is often based on the distinction between surface and non-surface water sources or between decentralised supply infrastructures and centralised distribution systems. However, what is ultimately relevant in public health terms is the quality (and not source) of the water consumed. In particular, equating "improved" with safe water sources is problematic and in some cases misleading.

Building Future Knowledge:

What indicators can be used to assess the sustainability of urban development and effective WASH strategies? How can these be incorporated into early warning systems?

6 · Society and Implementation

Besides the needs described in the previous chapters regarding research directions, questions of implementation arise regarding the management of water systems and the use of water resources for the enhancement of human health and wellbeing in urban regions. Often, local and expert knowledge is not adequately integrated and the participation of all stakeholders and affected groups is not guaranteed. Disregarding these vital elements in the planning and implementation process of water developments has rendered many of the envisaged solutions ill equipped to make efficient use of locally available water resources and to safeguard equal access for all societal groups. As a result, projects often fail to be cost-effective, ecologically sensitive and socially relevant. In the following sections we highlight some key issues relating to aspects of implementation and the social inter-linkages that we have identified.

Make efficient use of existing knowledge and technology

Comprehensive knowledge is not necessarily new or external. In fact, there is a body of knowledge that has been developed and accumulated in the past, in various geographic and cultural contexts, and which is useful in making water management more efficient. One might expect that the policymaking and implementing process would take into account this existing "treasury" of both scientific and lay knowledge in order to generate the best solutions in an evidence-based way[26]. However, these different types of knowledge are often used insufficiently, if at all. The reasons behind this failure to translate comprehensive knowledge into successful policy can be multifaceted and include the unequal power relations between different stakeholders, and various types of institutional and organisational mismatches. They also often include a clash between new types of knowledge (unusual, low-tech) and local perceptions of what constitute useful solutions. To enhance our understanding of why particular projects may not be successful, their monitoring should integrate both social and technical points of view. Neither the available local (indigenous, community, lay) knowledge, nor the conflicting interests around water systems are fully considered in the decision-making processes. Moreover, it is often the case that scientific knowledge cannot effectively reach stakeholders and planners due to disciplinary and linguistic barriers.

Building Future Knowledge:
How can the existing technical and local knowledge be facilitated within the process of implementing water management solutions?

26 Dicks, L. V. et al. (2014): "A Transparent Process for 'Evidence-Informed' Policy Making", *Conservation Letters 7(2):* 119-125.

Design policies for their specific local context

Figure 8: *Irregular settlement in Parelheiros district, Municipality of São Paulo, Brazil. Densely-populated peri-urban communities commonly lack access to a public water supply and sewerage systems. The inhabitants discharge their waste water effluents into streams or pit latrines. The exploitation of water wells, which are usually installed in close proximity to these onsite sanitation systems, can induce rapid transport of effluent to drinking water sources.*

Photo by Alexandra Suhogusoff.

When environmental and natural resource policies are developed, decision-makers often aim at adopting what is known as existing "best practices". While it generally makes sense to rely on solutions that have proved effective in the past, careful consideration of the specific local conditions is crucial when knowledge is to be transferred. The performance of environmental policies, programmes, strategies and measures crucially depends on the local situation in which they are being embedded. In the case of water-related issues, it is eminently relevant when designing and implementing policies and measures to define the capacity and functioning of ecosystems and to specify the societal demands and affordances. Moreover, it is important to take into account the managerial and distributive capacities that exist in order to bring together demand and supply, considering environmental (e.g. climate, geology, land cover), socio-economic (e.g. population, economic performance, welfare) as well as institutional (e.g. civil society, institutions, regulatory system) conditions.

Building Future Knowledge:
What drives the variability of policy performance and what are the local factors crucial for implementation success?

Use impact assessments to design policies

When environmental policies and planning processes are evaluated, they often focus strongly on environmental and economic impacts, but ignore the distributions of their costs and benefits in society. Consequently, a more comprehensive consideration of such aspects is required prior to, alongside, and in the aftermath of the planning and implementation process. The application of assessment procedures in terms of social, health or sustainability impacts can address concerns of fairness, social inclusion and gender equality, as well as economic performance. Such an approach provides a broader picture of possible impacts and synergy effects. It is fundamental for ensuring efficient and cost-effective design and implementation of environmental policies. Moreover, carefully carried out impact assessment processes can provide a platform for enhancing the participation of a much broader spectrum of stakeholders and affected groups. This inclusion and involvement in turn facilitates the acceptance of decisions[27] and thereby the potential success of their implementation. In this respect, we see an emergent need to substantiate our knowledge on the meaningfulness and applicability of assessment processes and monitoring systems (see also Chapter 5).

Building Future Knowledge:
What forms of impact assessment are available and suitable for informing planning and decision-making processes and how can they be implemented?

27 Dalal-Clayton, B. & B. Sadler (2014). *Sustainability Appraisal: A Sourcebook and Reference Guide to International Experience.* Routledge, New York.

Mainstream policies

Water policies and plans to address environmental problems and human health sometimes lack consideration of other policy fields and administrations. This may impair their implementation and can also lead to adverse incentives and unintended negative effects in other fields. Consequently, in order to guarantee their success, environmental and human health policies need to be mainstreamed in all affected agencies and departments, including those involved in agriculture, economy, and social, security or education matters[28]. This means that in order to achieve more harmonised decision-making, the policies of other sectors also need to include environmental and health considerations. Further research is required in particular into how new institutional arrangements and new arenas of horizontal communication and coordination can be developed. Some examples of horizontal approaches are already more commonly applied in fields such as gender issues and rural development, but not without shortcomings. New approaches in environmental and water policymaking could be even more successful, taking advantage of the lessons learnt from such previous examples of mainstreaming in other fields.

> **Building Future Knowledge:**
> **What are the barriers and the opportunities for mainstreaming water-related human health and environmental policies, especially in urban regions?**

Integrate policies across spatial scales

Policies can be adopted by local, regional, national and international governments and organisations, but overlapping or unclear responsibilities might hamper their performance. Moreover, policies implemented at the local level may neglect interdependencies that occur between regions, while national policies can fail to properly take into account local particularities[29]. In addition, the spatial scale of policies often does not correspond to that of natural units and processes, such as watersheds or pollution flows, but also not to urban regions that strongly depend on ecosystem services provided by their hinterland, e.g. water supply. Consequently, clear spatial information about human and natural systems and new modes of coordination and cooperation between administrative bodies are both necessary to ensure the success of policies.

> **Building Future Knowledge:**
> **What is the appropriate degree of responsibility sharing across administrative levels, e.g. for water management in urban regions or for water pollution control beyond national borders?**

Develop and apply bottom-up, participatory approaches

Urban policies and planning efforts are often implemented as top-down approaches, which do not take into account local realities, challenges, and problems and which often result in limited inclusiveness, oppositions and conflicts. Therefore, it is crucial to promote and allow

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28 UNDP/UNEP (2011). "Mainstreaming climate change adaptation into development planning: a guide for practitioners", United Nations Development Programme (UNDP)/United Nations Environment Programme (UNEP), Nairobi.

29 Cumming, G. S., D. H. M. Cumming & C. L. Redman (2006): "Scale mismatches in social-ecological systems: causes, consequences, and solutions", *Ecology and Society 11(1):* 14.

bottom-up, community-based and collaborative approaches to decision-making processes[30]. Apart from the involvement of actors in local government, civil society organisations, the scientific community and the business sector, bottom-up decision-making also needs the inclusive participation of the affected population. One specific strategy could be the formation of working groups bringing together stakeholders from all the above groups in a conversation on an equal footing. Within such groups, participators could collaboratively make use of available knowledge, exchange opinions, and negotiate around their different interests in a preparatory way prior to decision-making. This reduces the risk of hollowing out planning processes through exclusively serving private interests, of being governed by powerful economic players, or of ideas being rejected due to not-in-my-backyard (NIMBY) motivations. Therefore, it is necessary to find planning and policy processes capable of balancing community-based and larger-scale society interests.

> **Building Future Knowledge:**
> **How and under what conditions can bottom-up, participatory approaches contribute to improving environmental policy design and implementation, e.g. on water management in urban regions?**

Use local knowledge to promote education and provide local opportunities for learning

Tackling many human health and environmental problems depends on the ability to spread key behavioural messages and raise the public's awareness, while also shedding disease-related taboos and stigmas. However, environmental and public health education systems often suffer from being too abstract, not easily applicable and far from people's real-life everyday concerns. Adapting expert information to a cultural and social context can considerably improve the effectiveness of such educational approaches. On the one hand, local knowledge can provide insights on how to design more impactful educational messages. Furthermore, participatory approaches can ensure acceptance by a wider public. Experimental learning, on the other hand, can help increase public understanding of how people influence and depend on ecosystems. Examples in this respect include offering people the opportunity to experience urban wildernesses, participate in environmental conservation projects, and witness pilot technologies close to where they live. Such local opportunities for learning can increase people's commitment and responsibility towards environmental stewardship. Considering that the cyclic processes related to water vividly demonstrate the interdependence of ecological and social systems, water in particular provides far-reaching educational opportunities, which should be promoted throughout the entire educational system.

> **Building Future Knowledge:**
> **To what extent can local knowledge and environmental education contribute to the creation of resilient cities? Which elements can adequately characterise health education in its various stages and forms (target group identification, content design, implementation methods, outreach strategies) in order to raise public awareness?**

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30 Healey, P. (1997). *Collaborative Planning. Shaping Places in Fragmented Societies.* Macmillan Press, London.

Promote long-term thinking and implementation

Policies and programmes are typically formulated and implemented by short-term projects. However, environmental problems are complex and call for long-term thinking and long-term strategies. Post-project monitoring and evaluation must be foreseen in project planning, and necessary budgets must be provided. Moreover, long-term thinking points to the need for policies to be designed in such a way that they can adapt to changes in environmental and socio-economic conditions. In this regard, the duration of natural cycles, but also dynamic demographic or economic trends, have to be taken into account. Such adaptive management requires flexible administrative bodies and the continuous involvement of stakeholders, science and interested parties.

Building Future Knowledge:
How can policies be designed so that they can continuously be adapted to changing framework conditions? What indicators are appropriate for informing adaptive management?

7 · Concluding Remarks

Dynamic developments and spatial heterogeneity continue to be specific characteristics that are shaping urban environments. Therefore, contextualised solutions for future water management require: 1) spatially integrated concepts for the urban – peri-urban – rural continuum; 2) multi-functional technologies; and 3) a high degree of flexibility as realised by decentralised strategies. Besides this, urban regions in different parts of the world are facing different challenges. Differences arise especially when we look at the socio-political situation, climate conditions and the economic development of the distinct regions. Hence, the overall approaches mentioned above have a higher chance of succeeding on a long-term basis if the local context is taken into account through the adaptation of case-specific measures. In this regard, the retrospective analysis of previous urban planning projects worldwide related to water supply or waste water present a valuable knowledge store for prospective concepts.

Independently of the location, sustainable solutions to water-related challenges in urban regions require integrative transdisciplinary approaches between and beyond natural sciences, social sciences and policymaking. A common understanding of processes and good communication between scientific fields and the public is a prerequisite for their successful development and implementation. Supporting joint knowledge and (public) awareness enables the balancing of different and even contrasting interests regarding land use, ecosystem services and human health (such as nature conservation, human wellbeing, agriculture, industry, economy). Along with this, the effort to define a reference line for healthy urban regions is very beneficial for combining different expectations for the future of urban regions. This allows for the identification of integrative indicators, and platforms facilitating holistic data acquisition, management and analysis can be created.

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