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Review

Urban Stream and Wetland Restoration in the Global South—A DPSIR Analysis

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Abstract: In many countries of the Global South, aquatic ecosystems such as streams, rivers, lakes, and wetlands are severely impacted by several simultaneous environmental stressors, associated with accelerated urban development, and extreme climate. However, this problem receives little attention. Applying a DPSIR approach (Drivers, Pressures, State, Impacts, Responses), we analyzed the environmental impacts and their effects on urban hydrosystems (including stagnant waters), and suggest possible solutions from a series of case studies worldwide. We find that rivers in the Global South, with their distinctive geographical and socio-political setting, display significant differences from the Urban Stream Syndrome described so far in temperate zones. We introduce the term of 'Southern Urban Hydrosystem Syndrome' for the biophysical problems as well as the social interactions, including the perception of water bodies by the urbanites, the interactions of actors (e.g., top-down, bottom-up), and the motivations that drive urban hydrosystem restoration projects of the Global South. Supported by a synthesis of case studies (with a focus on Brazilian restoration projects), this paper summarizes the state of the art, highlights the currently existing lacunae for research, and delivers examples of practical solutions that may inform UNESCO's North–South–South dialogue to solve these urgent problems. Two elements appear to be specifically important for the success of restoration projects in the Global South, namely the broad acceptance and commitment of local populations beyond merely 'ecological' justifications, e.g., healthy living environments and ecosystems with cultural linkages ('River Culture'). To make it possible implementable/practical solutions must be extended to (often poor) people having settled along river banks and wetlands.

Keywords: rivers; lakes and wetlands; socio-ecosystem; environmental impacts; restoration; urban sprawl; Southern Urban Hydrosystem Syndrome; River Culture; social connectivity; ecosystem services

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1. Introduction: Urban Freshwater Hydrosystems of the Global South—A Socio-Ecological Pandemonium

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A person travelling through tropical and fast-developing countries (the so-called "Global South" (GS), according to the UN and UNESCO definitions) will very probably find a similar situation when looking at urban streams and wetlands. Many hydrosystems have been transformed into concrete canals and/or dammed to form reservoirs, the water quality of urban streams is uniformly bad, banks and riparian zones are used as dumping sites (relying on the next flood to flush away waste products), and the people living near or passing by the waterbodies perceive them negatively because of the water appearance, foul smell and the suspicion that they harbor vectors of water-borne diseases. This situation used to be prevalent throughout the Global North (GN), but with policy changes such as the Clean Water Act in the United States [1] and the Water Framework Directive in Europe [2], urban waters have recovered considerably in the past four decades. Moreover, the riparian zones in the GS are often inhabited by the poorest part of the population, which has neither the political power nor the technical skills to manage or develop them in a sustainable way. Moreover, the local population is rarely involved in problem analysis, or in identifying possible solutions, not to mention decision-making. Many urban hydrosystems cannot be seen any more, because they have been buried and covered by asphalt to make space available for transportation infrastructure.

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In rare instances, however, while water quality is generally quite bad, hydrosystems have become part of public green space. Urban greenery projects often involve the transformation of river banks and the planting of trees, but these 'elements of greenery' rarely fulfil any kind of provisioning and regulating ecosystem services, such as sustaining a substantial part of biodiversity typical of natural habitats, contribution to biogeochemical processes such as water purification or carbon storage, or buffering of floods and droughts, as they could potentially be delivered by a restoration project. There is also some debate as to which degree urban river restoration may restore natural structures and functions, and certainly every project is different. However, we want to make a plea here to integrate as much natural habitat dynamics and water quality as possible into urban river restoration. We use the term 'restoration' in this study, defined as reclamation, rehabilitation, mitigation, ecological engineering and various kinds of resource management by the Society for Ecological Restoration [3].

Freshwater ecosystems have suffered the strongest decline of global biodiversity, while their vertebrate populations alone have declined by 83% between 1970 and 2012 [4], with maximum values of 94% in the Neotropics [5]. Freshwater hydrosystems are most often literally overlooked or even obliterated by urban planners, especially in the Global South. Cities grow, often beginning with the most appropriate sites for human settlements, which are close enough to a river system to profit by the transport, food, and water-delivering ecosystem services but sufficiently elevated to avoid flood problems. At a given moment, urban expansion reaches the borders of the hydrosystems, but the specific nature of the different freshwater ecosystems is often ignored by the urban development process. This has severe consequences for the well-being of the citizens, and for the biological and cultural diversities that are linked to water, and for ecosystem services by the hydrosystems that are the life support systems for humans even far outside the urban perimeter.

The impacts of urbanization on streams has been analyzed in detail, described by some authors as the 'Urban Stream Syndrome' [6]. Most of these phenomena have been described for river systems of the temperate zone, although they also occur in tropical countries [7,8]. There are, however, additional stressors for ecological integrity of the aquatic ecosystems in the tropics [9,10]. But only few comprehensive articles about urban stream ecological restoration have been published from this part of the world (see [7–10] and citations therein). In this paper, we explore the characteristics of urban rivers and streams in the Global South, and review examples of restoration efforts to date.

By using the term 'urban freshwater hydrosystems' we purposely bring urban wetlands and lakes into consideration, which have suffered similar ecosystem deterioration, and for whom the socio-ecological aspects of restoration, and specifically the motivation for taking action, parallel those for streams. We do acknowledge the differences of the characteristics of lotic and lentic water ecosystems that must be accounted for in engineering aspects of restoration, as reflected in system-specific suggestions presented below, including special cases such as freshwater hydrosystems of the marine littoral zone.

This paper is based on research and field experience of authors from a wide range of countries across the globe. As an overall framework, we adopt a DPSIR approach: Drivers, Pressures, State, Impacts, Responses [11], augmented by more explicit integration of participative decision-making [12]. We have expanded the "response" component with an analysis of the social background of decision-making on Southern Urban hydrosystem restoration.

Applying this expanded DPSIR approach, we intend to answer the following questions:

1. Driving forces: Which are currently the main urban development trends negatively impacting freshwater hydrosystems in the Global South and which must be considered in the context of their restoration? Which major societal and political phenomena are linked to hydrosystem restoration in the Global South?
2. Pressures and Impacts: Which biophysical phenomena of the Urban Stream Syndrome are particularly problematic in freshwater hydrosystems in the Global South? What are the main impacts (positive or negative consequence of state variables) for ecosystems and for society?
3. State: What is the state of urban hydrosystems in the Global South?
4. Societal responses: Which steps can be taken to motivate the stakeholders to act and to overcome administrative hurdles for hydrosystem restoration?
5. Technical responses: Which practical engineering approaches can be devised to overcome the specific biophysical problems and meet socio-economic goals?

Focusing on case studies mostly located in tropical-warm and moist-to-seasonal areas, the objectives of the contribution are to (i) deliver a detailed analysis of the problem, (ii) propose general approaches for problem-solving and (iii) present positive examples of case studies using an upscaling approach that may encourage future restoration actions promoting the North–South–South dialogue as advocated by most international agencies including UNESCO. Furthermore, the relationship between humans and hydrosystems and the inspiration by nature for cultural activities, which have been termed as "River Culture" [13] is addressed as one of the central elements in urban hydrosystem restoration. Purely technical or ecological argumentation alone rarely succeeded in a positive decision for restoration actions. Processes of dynamic decision-making and of inducing citizen participation are crucial and must not be neglected when dealing with urban hydrosystems [12,14], even if this may not be feasible in all political systems. Here we combine both these aspects into one interdisciplinary approach.

In fast-developing countries, the time for still preserved ecosystems to become strongly impacted ecosystems is often shorter than in long-existing industrialized or post-industrial regions where several generations have often been brought up among strongly altered ecosystems and consider such altered environments as the as the 'norm'. In the context of the Global South traditional forms of land-uses, community experiences, emotional linkages between humans and nature, etc., remain often quite vivid in the memory of the people, a situation which can be built upon to re-create the social connectivity of urban rivers [15,16]. Moreover, less strict regulation of administrative processes is generally favorable for habitat destruction, but this also may allow the development of novel, 'Southern paths' of urban hydrosystem restoration. Therefore, we suppose that creative solutions revitalizing human-nature-relationships from the Global South may also deliver important aspects for urban hydrosystem restoration in the industrialized countries of the Global North.

Finally, we wish to encourage practitioners and scientists to improve the documentation of urban hydrosystem restoration projects in the Global South. Documentation and efficiency analysis of river restoration projects have been strongly neglected in the Global North for a long time (e.g., Europe [16–19], Australia [20] and North America [21,22]). Consequently, restoration techniques were often applied without knowing their impacts, restoration targets were not precisely defined (or refined), and the interactions between different restoration activities remained unknown. Since hydrosystem restoration in the Global South is in its infancy, this situation opens the chance for a systematic documentation from the first projects onwards.

2. Materials and Methods

This paper is based on discussions that took place during the session "River and the City" of the Integrative Sciences of Rivers Conference (IS Rivers), Lyon, France, June 2018, the session "River Culture" during the 2-nd Great Rivers Forum, Wuhan, China, October 2018, both attended by academic researchers and planners and managers, collectively with broad experience implementing restoration projects, and coming from very different disciplines such as ecology, sedimentology, social and physical geography, architecture, and urban planning. All contributors to this study revised their personal datasets on urban hydrosystem restoration projects, as many of them have not yet been published. They also performed literature backsearches and selected adequate literature. Due to differences in the individual backsearches, classical bibliometrical data are not presented here. Assessments (e.g., types of pressures, Table 1) are the result of expert opinions, and were not based on quantitative analyses for lack of data. The currently best overview of stream restoration projects in the Global South (in our view) comes from Brazil (especially the State of Minas Gerais), therefore, our analysis is biased to this area. More comprehensive studies are needed to complete the picture. This paper is considered to be a pioneer approach to Southern Urban Hydrosystem Restoration, and it is our intention to motivate further studies on this issue in the Global South.

Table 1. Types of pressures and their occurrences.

Impact Type (Specific Agent)	City Center	Outskirts	Rural Zones
Water Pollution			
Tanneries (chrome)	xx	x	0
Chemical industry (pesticides, side-products, acids)	xxx	x	0
Slaughterhouse organic pollution (proteins),	x	xx	0
Breweries and paper mills (cellulose)	x	xxx	x
Hospitals wastewater (pathogens)	xxx	x	0
Household wastewater (fecal bacteria, BOD)	xxx	xx	x
Agriculture (nutrients, pesticides)	x	xx	xxx
Physical Impacts on Habitats			
Solid waste (plastic bags, cans, tires)	xxx	x	0
Canalization (loss of hydromorphological diversity)	xxx	xx	0
Construction of buildings on the banks/shores	xxx		
Construction of roads on the banks/shores	xxx	x	
Low head dam construction	xx	xx	xxx
Large hydropower reservoirs	0	0	xxx
Sand removal for habitat construction	x	xx	x
Agriculture and gold mining (siltation)	x		xxx
Agriculture (water abstraction for irrigation)	x	xx	xxx
Terrestrialization or removal of wetlands	xxx	xx	x
Direct Impact on Aquatic Biota			
Hunting aquatic birds, mammals, or reptiles	x	xx	xxx
Fishing	xx	xx	xx
Invasive species	xxx	xx	x
Deforestation of riparian vegetation	x-xxx	xxx	xxx
Light pollution and road kills	xxx	xx	x

3. Results and Discussion

3.1. Driving Forces: Which Current Urban Development Trends Make Freshwater Hydrosystem Restoration Particularly Difficult in the Global South

Cities of the Global South, i.e., in so-called 'developing countries', show a very different growth and development pattern from those in the Global North, which generally date back to centuries of urban planning, and present relatively low population growth rates [23]. In terms of freshwater ecosystem management, this means that countries of the Global North could adapt step by step to the different impacts brought by human civilizations (see [13] for details), whereas in the South, all these impacts occur at the same time, which makes mitigation strategies difficult. The climatological-hydrological and the societal-political background within the GS is widely variable, ranging from poor or war-shaken to very fast-developing countries, and from strongly seasonal (monsoon-driven) to permanently dry-hot and even temperate climates [24]. Many cities in the Global South lack both appropriate governance frameworks to manage urban development and technologies, as well as resources to invest in needed physical and social infrastructure (drains, sanitation and solid waste collection including public toilet, embankments and levees, pumping systems, further flood prevention mechanisms such as early warning systems and models, sensitization and community-building) and in planning, implementation, monitoring and evaluation (skilled personnel and equipment). The point is that, to be effective, urban hydrosystem restoration requires attitudinal challenges in terms of behavior by the citizens, urban practitioners, and decision-makers, while one must simultaneously cope with fast and sustained urban growth (due to population growth and in-migration) and very sensitive climatic and ecological conditions.

With climate change, stronger and more frequent floods and droughts reduce the predictability of hydrological cycles, and overall global warming exacerbates the problems caused by often unplanned and badly managed urban hydrosystems. Worldwide, conflicts about water use between cities and their surroundings are increasing, with the most intensive conflicts in semi-arid and arid areas such as the Brazilian Sertão [25]. It is not surprising that seven out of eleven global cities that are most likely to be running out of water are situated the Global South [26]. Another important factor to be considered is water quality. Urban water bodies, such as the Tietê in São Paulo, or the Bogotá River in Colombia's capital, have a very poor quality.

We identified below a range of driving forces that make the conservation of water-bound diversity (both in biological and cultural terms) particularly difficult.

3.2. Urban Sprawl and Environmental Injustice

Even under 'normal conditions', i.e., without additional immigration flows to cities due to the occurrence of war or to climate change (climate refugees), urban growth proceeds rapidly in the Global South if compared with advanced economies of North America, Europe or Japan. Mass migrations usually result from limited labor absorption capacity and new developing industries and markets in the metropoles, coupled with high fertility rates (but not in some upper middle-income countries). This – together with the reclassification to 'urban' of formerly rural areas due to densification – leads to annual growth rates of urban populations of 2.4% per year (47 large cities in Africa and Asia are growing by 6%), [23]), or even the establishment of completely new towns *ex nihilo*. More than 100 Chinese cities were above 1 million people in 2017, and this number is likely to double by 2025 [27]. Worldwide, the quota of city dwellers will rise from 51% in 2016 to 70% in 2030, and most of them live in cities with high natural disaster risk, mostly due to flooding [23]. Urban sprawl is not caused by population growth alone but by a wide range of factors, and it unleashes a series of socio-economic and environmental problems, such as increased public service costs, energy inefficiency, disparity in wealth, impacts on wildlife and ecosystems, loss of farmland, increase in temperature, poor air quality, impacts on water quality and quantity, as well as impacts on public and social health [28].

Environmental quality of river valleys can be decisive for the living conditions of social groups establishing in new urban areas. We observe a global trend for two divergent situations: Areas with a low flood risk, bordering hydrosystems with more or less unpolluted water, are attractive settling grounds for citizens with better education, higher incomes, and stronger political influence. Here, the nearness to an aquatic ecosystem (accompanied by ecosystem services improving human well-being such as buffered air temperatures, singing birds, options for leisure activities, etc.) is regarded as an asset, resulting in higher property values. This more influential part of the population has the opportunity and the means to campaign for river restoration, although they rarely do. For example, on the outskirts of Bogotá, several developments catering to high-income clients have recently been established without any provision for wastewater treatment [29].

On the other hand, areas with a higher flood risk and stronger polluted water bodies have lower market values. These are often squatted by poor migrants from rural areas with sometimes experienced one or more unsuccessful migration(s) to the city. Slum development very often echoes the ecological status of the area and vice versa: the worse the environmental quality, the lower the social/educational level of the squatters and the lower their ability to change the situation they live in. Moreover, the borders of the hydrosystems are used for waste dumping and wastewater inlets, which additionally lowers water quality and hygienical conditions. Despite severe degradation of water quality, water withdrawal for small-scale use is still common, representing a great risk of public health [8,30,31]. Thus, the economically and socially most vulnerable part of the population colonizes areas with greater hazards, as illustrated in Buenos Aires [32]. The term 'marginalization' applies in two senses: the socially marginalized settle on river margins.

Urbanization of hydrosystems proceeds simultaneously with profound changes in land and waterbodies uses and shape. Before becoming urbanized, riverbanks were often traditionally used for wharfs, quays/piers for storing, loading, and unloading commodities, fisheries, pottery workshops, drawdown agriculture, dyeing, or extraction industries, etc. This leads to the structuration of space and architecture according to the social and occupational groups and communities deriving their livelihoods from the river corridor and working or living there [13]. These forms of occupational use are rarely maintained when these systems become overgrown by urban sprawl, but become replaced by other uses. Cultural linkages to the hydrosystem [13,15] get lost, the new (generally: poor) settlers rarely show cultural adaptations to the Flood Pulse, and risk losing all their material belongings during floods.

Often, improvised uses of the stream banks develop, e.g., in the rural-urban gradient of African cities. In the case in the fluvial port city of Mali in the Inner Niger Delta, specific ethnic groups significantly encroach on the Niger or Bani rivers by practicing forms of landfilling in the city core area. They compact garbage and other materials along the existing riverbanks, thereby extending the banks and creating new land, which they sell for income. In the Ekozoa stream valley within the City of Yaoundé, Cameroon, the riverbanks are used for subsistence horticulture by poor residents nearby ([33], Figure 1). The farming is unpermitted, but the Cameroonian government tolerates and even encourages this subsistence agriculture as an important 'safety valve' against social unrest [34]. For the authorities, these agricultural areas play the role of a 'tactical reserve' for occupation, which becomes cleared and secured at low cost if needed. The farmers do not enjoy tenure and can be easily evicted under the pressure of urbanization in a context of land scarcity.

Figure 1. Urban gardening along the banks of the Ekozoa stream valley (City of Yaoundé, the capital of Cameroon (photo by JL Yengué).

We have observed that urban development commonly follows an opportunistic pattern integrating the functions of streams and their riparian zones in the urban ecosystem. With the election of the city of Cuiabá to become one of the sites of the World Soccer Championship in 2014, more urban streams and their riparian zones became covered by asphalt to avoid massive traffic jams (Figure 2). This disappearance of urban water bodies is alike for running and standing water ecosystems; therefore, it is not surprising that most wetlands have vanished from the urban perimeter. For example, Dakar, Senegal, has lost a good part of the urban wetlands, mostly due to irregular urban growth [35]. The surface of those wetlands declined from 35.84% in 1942 to 5.44% in 2003 [36]. The wetland of Technopole shrank to about 1/3 of its original size, due to conversion of farmland into residential areas [37]. Urban lakes are especially affected. Lake Mbeubeuss (Dakar, Senegal) is estimated to receive 500,000 tons of domestic waste per year, and on the shores of the lake systems of Wouye, Warouwaye, and Thiourour, built space doubled from 410 to 879 ha between 1999 and 2014 [38]). In St. Louis (Northern Senegal), saltwater floodplain mud flats were filled by deposit of garbage, consolidated over time to allow the installation of settlement ([39], Figure 3).

Figure 2. *Cont.*

Figure 2. Urban streams in Cuiabá, Brazil (**above**) 'Barbado Stream' before being filled up 2014 (photo by Karl M. Wantzen), (**middle**) Channelized 'Prainha' stream, 1970 (photo by Almanaque Cuiabá), (**below**) Buried 'Prainha' stream (today's downtown main road), 2008 (photo by Thiago Foresti).

Figure 3. Urban sprawl in the lowlands in Saint-Louis Guinaw rail district, Senegal (Modified after Coly and Sall, 2015).

Maybe the most iconic case of loss of a hydrosystem is Mexico City. Before the Spanish conquest, 2000 km^2 of the valley of Mexico were covered by 5 interconnected lakes (Figure 4a, [40–42]). Lake Texcoco, Zumpango, and Xaltocan were brackish, while Xochimilco and Chalco in the South contained fresh water. The Mexica (or Aztec) had built and maintained several large-scale hydraulic features to control the water level and to separate brackish from fresh water [43]. With the Spanish conquest, the lake was drained over the following centuries, starting in 1607 with the Tajo de Nochistongo and finally in 2015 only 35 km^2 of water bodies was left (Figure 4c, [40]). Since the beginning of the 20th century modern hydraulic infrastructure has been built and is still ongoing, with the 62 km of the Eastern Discharge Tunnel being built since 2009. This situation has created a contradiction: to control the flooding, aquifer recharge is prevented, and Mexico City is now one of the megacities in the world with the highest risk of running out of water.

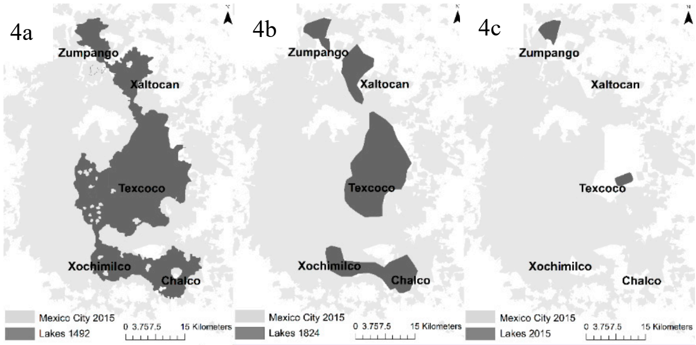

Figure 4. Drainage of the 5 lakes in the Valley of Mexico over the last 500 years [42,44]. 4a = pre-Hispanic (1492 AD), 4b = post-colonial (1824 AD), 4c = modern (2015). Graph by M. Kolb with data from 42 and 44.

In many cities of the Global South, there is a permanent immigration of fugitives from politically instable areas due to war and terrorism (examples: Kabul, Afghanistan; Amman, Syria) and, from areas that have become inhabitable due to climate change and agricultural mismanagement, especially in Africa and Asia [45]. In addition to the above-mentioned problems (especially groundwater pollution), the demands for riverine ecosystem services such as drinking water and wastewater disposal are skyrocketing. In Kabul, the population is expected to double to 9 million until 2057, and groundwater-level declines may reach tens of meters in the next years, risking a collapse of the urban water supply [46]. Immigration and climate change effects worsen the already-existing groundwater problems all over the Global South. Intense and unsustainable water abstraction due to irrigation [47] and other anthropogenic uses have already depleted groundwater storage, e.g., in the North China Plains, northwest India, Bangladesh, and Brazil [48–51].

3.3. Local Governance Problems Make Integrated River Management and Restoration Projects Difficult

Some of the so-called 'developing and emerging countries' have actually far advanced environmental policies. While the use of the watershed unit for planning and management of the river was introduced in Brazil in the 1990s [52], this was much later formulated in the European Water Framework Directive [53]. The protection of a 50–250m wide, fully protected buffer strip in the riparian area has been integrated into the Brazilian "Codigo Florestal" as of 1965, but which has been "softened up" stepwise in recent decades [54]. Moreover, even if adequate laws exist, there is often an "implementation gap" [55] between technical and/or administrative features and their application is wide in most cities of the Global South. Moreover, there is often an 'institutional gap' [14] when the involved institutions do not cooperate with each other. In the International Master Course on Sustainability and Urban Planning at Poly'Tech Tours, France, in 2017, 20 students from 16 nations were asked the question "why there is no decent integrated management and restoration of urban rivers in developing countries?" and to deliver specific examples from their countries of origin. The most frequent answers from Southern countries were (in decreasing order): lack of public money, lack of legal reinforcement, ignorance of the problem by the politicians, cronyism and lobbyism (KM Wantzen, pers. obs.). These shortcomings are by no means limited to the issue of urban hydrosystem management, but there, they are specifically difficult to overcome.

In the view of urban planners, the major (and often exclusive) concerns about urban river and wetland management are the usability of water as a resource, (i.e., to provide drinking or cooling water or to act as a dilutant for wastewater emissions) and protection from floods. There is hardly any awareness of biodiversity and ecosystem functions (which are considered to be abundant outside the cities), or the linkage between human well-being and ecosystem health (as evidenced by strongly polluted streams in public parks).

Even when efforts were made to improve the quality of urban hydrosystems, the outcomes of projects are often not monitored. Wastewater treatment plants are often assumed to be working fine once the public investment has been made in them, even if the receiving water quality remains very bad. The Bogotá River is a compelling case study. Since 1906, the city of Bogotá, Colombia, and diverse sponsors have made enormous financial efforts in wastewater treatment (summing up to 15 billion USD in 2020, [56]) but the river remains highly polluted. The uppermost 10 out of 230 km river length are unpolluted, but then the next 150 km are polluted by agricultural and industrial discharges, and the next 65 km through Bogotá DC are polluted by sewage. It is one of the most polluted rivers in the world, with anaerobic conditions over 60 km [57]. A hotel at a scenic waterfall downstream of Bogotá had to close due to the putrid stench of the water [29]. The Economic Commission for Latin America and the Caribbean by the United Nations has estimated the externalities due to the restrictions of river water use in the anaerobic 60 km reach, excessive operating costs of the treatment plants, and costs arising from individual and public healthcare measures due to water pollution to more than 550 million USD per year [58]. In 1990, the World Bank rejected a 1.5 billion USD proposal to clean the water in all 3 tributaries to the Bogotá River due to a high risk of inefficiency, but in the 2000 s, a nationally funded wastewater treatment plant was established at the smallest tributary (Salitre) for a similar cost. However, the governmental entity dedicated to the surveillance and control of public administration expenses noted that its capacity reached only 20% of the polluted water of the Salitre River [56]. A new 'decontamination program' is being set up to settle this problem [59], involving the expansion of the Salitre plant (50% of its water to be treated), dredging of the riverbed, the installation of multiple small treatment plants in rural areas tributary to the Bogotá River and construction of a new treatment plant similar to the Salitre plant, engaging a budget of more than 1.5 billion USD [60]. The few existing scientific publications show that the water quality of the river deteriorates along its course but has not changed significantly in the past 20 years (Figure 5), calling into question the utility of the costly measures taken thus far to decontaminate the Bogotá River [57,61].

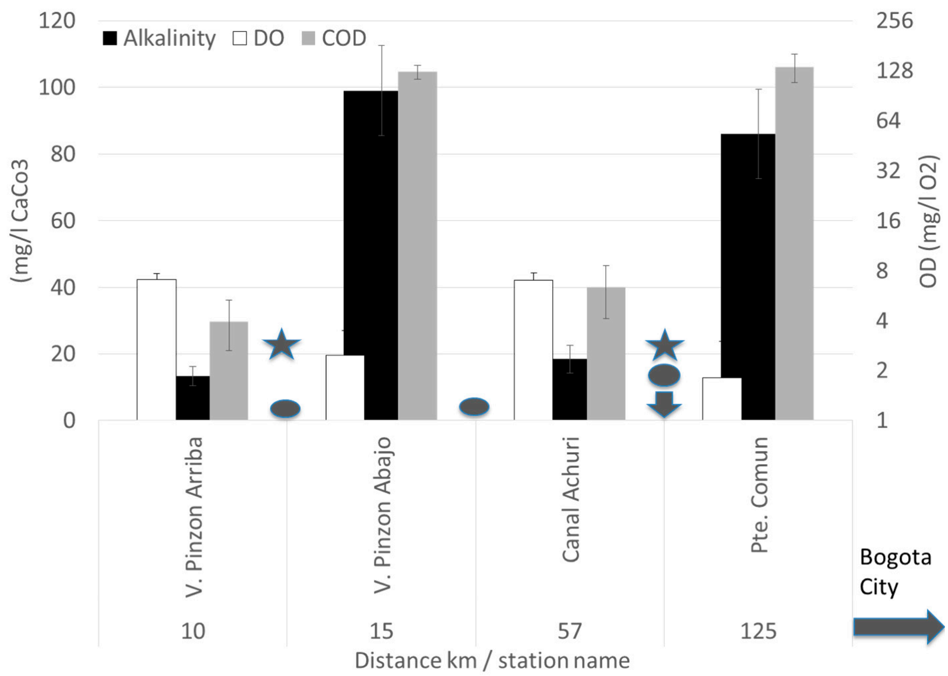

Figure 5. Mean values and standard deviations from Dissolved Oxygen (DO), Chemical Oxygen Demand (COD, both in mg/l, assigned to the right y-Axis, mind the logarithmic scale!), and of alkalinity in the Bogotá River. Symbols indicate: asterisk (*) polluted water inputs by industrial use (more than 50% of the discharge), point (●): municipal wastewater treatment plant, arrow (↓): Water withdrawal for the city of Bogotá (7.5 m^3, corresponding to more than 50% of the discharge). Data from: Secretaria de Salud de Bogotá [62].

Another issue that should be addressed in this context is the linguistic obscurity and ambiguity in public policy discourse in some countries of the Global South. In China for example, higher authorities, instead of clearly articulating their commands, tend to issue orders that are subject to multiple interpretations, due to ambiguities of the Chinese language. Consequently, lower-level officials need to make meticulous calculations and informed conjectures about the true intentions and preferences of their superiors before coming up with specific measures to carry out the "spirit" of the commands [63]. China's domestic law is not always clear whether the national authorities are committed to public participation, or whether they simply let local authorities decide what level of public participation is appropriate [64], which may limit efficiency and impacts of water management implementation.

3.4. Drivers beyond the Catchment Scale (International–National Policies)

The environmental health of urban streams is strongly influenced by socio-political processes that go far beyond the decision range of urban planners. Global market developments and foreign direct investment influence the national/regional land-use policies with consequences for urban streams. Policies to improve the environmental quality in the Global North have emerged in parallel with the frequent relocation of polluting industries to developing countries. This creates a disparate pattern of biodiversity trends: improving trends in the Global North and decrease in poor countries [5]. The two most important spheres of long-distance environmental influence are the agribusiness and the energy market, which are often intertwined. For example, the Brazilian environmental scenario has been dramatically changed due to strong demands for biofuels (alcohol from sugarcane) and for soybean for the meat production in the Global North. The Brazilian Forest Code, which was formerly a model for the protection of natural resources, has been gradually weakened to legalize ex post previously illegal deforestations and to permit intensive land use of riparian zones [65]. Deforestation has been very intensive in Southern Amazonia [54], followed by an increase of agro-combustive plantations and big and small hydropower dam projects, resulting in both greater erosion and pollution, and fewer free-flowing river reaches with the capacity to absorb the pollution [66]. In Asia, the large freshwater wetlands of the Tibetan Plateau, which contain the headwaters for the major rivers of India, Pakistan, Bangladesh, Thailand, Lao PDR, Cambodia, Vietnam and China, are increasingly intensively used to satisfy food demand, with similar effects [67]. These pressures cause different impacts on stream morphology and biogeochemistry [68] long before they arrive in the cities.

The state of many urban rivers depends on transboundary policies. Most of the conflict-prone river basins are situated in the Global South, with tensions in multiple rivers in Sub-Saharan Africa and in South Asia, notably the Himalayan region. Most cities in Pakistan are situated along the Indus River, and depend from the dam management from the upstream in the Himalaya belonging to India and China. While the Indus Water Treaty has worked well to date, the lingering Cashmere conflict may threaten its future effectiveness [69]. Tensions arising from limited water supplies are exacerbated by political factors, as illustrated in the Middle East [70]. Dams under construction in Turkey on the Euphrates and Tigris may have severe consequences for the river water budget of cities in Iraq [71–73].

These impacts, which are driven by international and national policies on the regional scale have a deep impact on urban hydrosystems on the local scale. They include reduced discharges due to upstream reservoir storage and extractions, unnatural high peaks below hydroelectric dams during high-energy demand periods, siltation, and increased water temperatures due to lacking shading and reduced flows. The lack of inter-basin cooperation in the Global South is especially acute in relation to flood risk governance [74,75]. In many river basins of the Global South (e.g., Juba–Shibeli, Han, Kura–Araks, Maritsa, Aral Sea, Ganges, Golok, Han, and Indus) urban flooding has occurred due to upstream actions and lack of transboundary policies that could have prevented the problems [76].

3.5. Perception of the Problem: What Makes Citizens Feel that They Need to Restore Urban Hydrosystems

Fast development in the Global South results in the synchronous occurrence of technological developments that occurred over a longer time span in the Global North. Moreover, there may be a long delay between the identification of an environmental problem and the moment when adequate mitigation policies are adopted. Often, political steps were taken only after the occurrence of catastrophic events such as floods had happened [77]. In the case of the Rhine River, pollution peaked in the 1960s, but it was not until the well-publicized Sandoz chemical accident at Basel in 1986 that public opinion forced a substantial change in environmental policies [78,79]. This accident happened at a time when the economy of the Rhine abutter states was running very well, and enormous amounts of money could be mobilized to enact water protection activities. Moreover, the political willingness to improve the environmental situation was very strong in this time (the Green Parties had just been founded in several European States). The example of urban river management of the Ebro at Zaragoza, Spain, gives an impressive example of how societal attitude towards the river may changes the local policies from the roman to post-industrial times [80]: *"The sensitivity of the society of Zaragoza evolved from a utilitarian and disdainful vision, which had transformed river courses into marginal areas and oblivion . . . to a new vision transforming them into meeting places. Finally, the river becomes visible as an organic element, with its prerogatives and its spatial needs."* (translated by the senior author).

The situation in many countries of the Global South is quite different, as neither the economic nor the political situation are favorable for acting, and even far-ranging environmental accidents are hardly perceived by the public or result in adequate political changes. If urban freshwater hydrosystems are strongly polluted, they are seen as a problem rather than an opportunity for restoration that can create a place for an encounter with nature, a well-functioning ecosystem, or a site that contributes significantly to human health. Humans tend to perceive polluted water as ugly, smelling, or dangerous [81], which reduces their interest in hydrosystems and impedes the development of an attitude of "care" for ecosystems (see Section 6.4.1, below). The control of water pollution therefore appears to be a *conditio sine qua non* for the restoration of physical habitats in the water bodies and on its banks. However, if the efficiency of wastewater treatment is hampered by lack of political motivation and by overly rapid urbanization, most urban hydrosystems of the Global South will remain polluted and the motivation to restore them low. However, a representative interview study with 351 participants about the perception of urban rivers all over Brazil revealed that 67% of the participants considered watercourses important for environment and public health, and 83% consider the river system in their neighborhood as polluted. The willingness in participating in the process of decision-making of rivers was 75–84%, with the highest values in the medium-income group [82].

Burial of streams apparently solves two problems: it provides more space for new constructions, and helps to hide the pollution problem from the public audience, but this 'aesthetic' solution does not solve the sanitation problem [83]. For example, the city of Cuiabá, Brazil, has grown very fast since the 1980s, due to the agrarian boom in the Brazilian central west [84]. At this time, many daylight-running streams were buried or canalized (Figure 2). Today, only few citizens know that the central avenue in Cuiabá, called 'Prainha' (Brazilian for: 'little beach'), covers a stream that once served for laundry-washing and bathing to the local population. Streams and wetlands that cannot be seen any more, certainly have the lowest potential to raise attention for restoration measures.

3.6. Concepts for Urban Hydrosystem Restoration in Developing Countries Are Virtually Absent

The examples of river restoration projects in developing countries studied here indicate that the relatively few projects existing to date have focused on water pollution and hygiene. The river is seen as a source of water rather than as an ecological or socio-ecosystem, and conceptual approaches such as the "Stream and its Valley" [85], the Flood Pulse concept [86], Environmental/ecological flows [87,88] or the River Culture Concept [13] have not yet been considered in the objectives of restoration.

Moreover, just as it was the case with the establishment of biological water quality indicators [89], there is a dominion of ideas, concepts, or technologies for restoration that were developed in the Global North, but which do not always fit to the specific types and setting of problems in developing countries. This could be interpreted as an 'intellectual imperialism' of the Global North, which hampers the development of original solutions in the Global South. We hypothesize that urban hydrosystem restoration projects are relatively rare in developing countries for the following reasons.

One of the major problems is that the responsibilities for restoration projects are in the hands of very different administrative units, and these, in turn, often belong to different regional political units. As a result, there is no synopsis of these problems or a coordinated action applying a catchment perspective as a baseline for all territorial policies (as claimed in the River Culture Concept [13]). This lack of transboundary action (catchment perspective) is by no means an exclusive problem to the GS, but in our study we have seen some specifically severe (see example from Argentina).

If we assume that the sequence of economic development and subsequent awareness of environmental quality and societal investment in ecological restoration observed in the Global North will play out similarly in the Global South, it should come as no surprise that restoration is only nascent in the Global South, where economic development is still underway.

The aging of concrete structures may prompt re-consideration of conventional engineering approaches, especially in the Global North, where this infrastructure is older and reaching the end of its life sooner. Removal of dams is an increasingly important issue in Europe and in the USA [90], but not yet in the Global South, where a "gold rush" of hydroelectric dam construction is underway [91]. In many cities of the Global North, many buildings on the banks of rivers and wetlands have become obsolete in recent years, and can now be repurposed. For example, in the Zaragoza Riverside Park, Spain, corporate buildings that had been built in the early 20th century are now being integrated into environmental restoration projects [80]. These trends could become increasingly important (and used) for urban hydrosystem restoration in the Global South in future.

All these factors contribute to a delay of freshwater hydrosystem restoration concepts in the Global South, although there is a pressing need to implement restoration now.

4. Pressures and Impacts: Which Biophysical Phenomena Are Particularly Problematic for Urban Freshwater Hydrosystems in the Global South

If we compare natural hydrosystems in the temperate zone with those from tropical zones, the basic ecosystem functions are relatively similar [92], although the local diversity often camouflages regional trends [93]. Differences exist, among other places, in the life-cycle length and the phenology patterns of the aquatic fauna, in the food web bases, on detritus [94,95], or on green algae [96,97], and in the generally higher biodiversity [92,98], so that conservation and restoration efforts need to consider these specific characteristics [9,10,99].

There are also large similarities for urban streams of temperate and tropical or hot-arid zones, if basic features were considered. In general, urban water bodies are in worse ecological status than their rural counterparts (EEA 2012; Yuan et al. 2017). Humans impacts include changes the morphological structure of (e.g., channelization) and in hydrography, point source and diffuse pollution, and modified structure of biological assemblages by decrease of the biotic richness and increase in tolerant species, species introduction, loss of sensitive species etc. (see, e.g., [100,101]. These dysfunctions have been described as the "urban river syndrome" [6], and their nature can vary with climatic zones [24]. Urban river restoration (URR) considers these deficits as the baseline for restoration activities (see review in [18]), and most studies published so far have focused on urban streams in temperate zones. There is still a large need for research on ecological requirements for urban river restoration in the GS. Wenger et al. [102] have identified a series of research questions, highlighting major gaps in the understanding of ecosystem structure and functional responses (e.g., what are the sublethal impacts of urbanization on biota?), characteristics of urban stream stressors (e.g., can we identify clusters of covarying stressors?), and management strategies (e.g., what are appropriate indicators of ecosystem structure and function to use as management targets?). These issues need to be addressed in different biogeographical and climatic contexts, but restoration measures will have to be taken before the last scientific problem was solved.

Very similar patterns and processes as in streams can also be found for urban lakes and wetlands [103,104], we therefore we include them into the term 'urban hydrosystem syndrome', with the following differential elements (see further details and citations in the next sections). The stagnant character of lakes and wetlands forces a stronger stratification of the water layers compared with the fast water exchange in streams. Stratification strength (i.e., the difference of density in waters of differing temperatures) increases with heat [105]. Consequently, anoxic zones may develop even in shallow water bodies, and stronger wind events than in the temperate zones are needed to provoke mixing of the water layers of warm lakes [106]. There can be large uncertainty about the extent of wetlands and lakes, as their water level commonly fluctuates seasonally [107], causing large lateral size variations. We observe a current tendency to use only the low-water level expansion of the wetlands for their delimitation [108], or the presence of hydromorphic soils (e.g., in France, [109]), which underestimates the real size (or even presence) of wetlands, reduces their conservation status, and allows their conversion from natural landforms to human use, specifically in cities. Moreover, lakes and wetlands have a depositional character in terms of sediment dynamics, and their waters have a much higher residence time. Therefore, all types of solid and dissolved pollutants remain much longer in the water body and in the sediments than in running water systems, where these may be transported downstream during floods. Conditions for biota and the ecological functions of stagnant water bodies then become strongly impaired, e.g., nutrient removal and the ecosystem service of drinking water provisioning. Water deviation for drinking and irrigation purposes in "thirsty" cities further reduces water levels (e.g., Lake Kinnereth as an extreme example, Zohary and Ostrovsky [110]) and fosters inadequate use of the littoral. Very often, planners overlook the fact that these systems are actually not static, but they communicate with groundwater zones and that their littoral zones are important buffer zones, providing flood and drought mitigation. Neglecting these facts may result a long-lasting pollution of the groundwater as well as more extreme floods and droughts.

In the following, we analyze biophysical pressures that are typical of urban hydrosystems of the Global South, and that need to be considered with special care when developing concepts for urban hydrosystem restoration.

4.1. Hydrological and Morphological Pressures on Southern Urban Hydrosystems

Urban flooding is a significant challenge, which today increasingly confronts the residents of the expanding cities and towns of developing countries [23,111,112]. Hydrological patterns of urban hydrosystems display large regional variation. While most regions of the Global North belong to the temperate zone with relatively balanced precipitation patterns, resulting in lower variations, the mostly seasonal climate of the Global South causes discharge variations that tend to be higher [113]. Torrential ('tropical') rainfall events (>50 mm/h) produce huge amounts of water that need to be transferred somewhere to avoid flooding of parts of the city [114]. This favors the construction of steeply inclined, sealed surfaces, channelization of urban streams [115] and concrete embankment of lakes and wetlands. Channel dimensions and shape are adapted to accommodate maximum flows during rainstorm events, i.e., they have a linear planform, lack any flow obstacles that could sustain sediment accumulations, and have vertical walls that are unsurmountable for the fauna, and may pose a public safety hazard. A strong morphological modification of the freshwater hydrosystems and their banks reduces the self-purification capacity of the aquatic ecosystem. Riparian floodplain zones that could provide essential ecosystem functions such as shading, buffering or habitat effects (see [98,116] for reviews) are generally absent. Urban channels are hostile to any kind of aquatic biota (with few exceptions such as drought-resistant, filamentous algae), and represent lethal traps for terrestrial and amphibious species. For example, large numbers of Southern Anacondas (*Eunectes notaeus*) regularly get trapped and killed during their mating period when migrating upstream into the channelized streams in the city of Cuiabá, Brazil (KMW, pers. obs.).

Surface sealing and channel morphology generally cause a flashy discharge pattern with unpredictable flood and drought pulses of urban channels. This increased flashiness due to urbanization may be lacking when urban and corresponding natural streams occur in steep (naturally flashy) catchments [117]. During the intensive flow phase, biota are stressed by a water-sediment suspension that has strong abrasive effects on biofilms and respiratory/filtering organs. With decreasing flow (reduction of tractive forces), habitats and food resources may become covered by a sand layer (see below). For the local human populations, the flash floods are considered to be an opportunity to discard garbage. Waste material that has been deposited during the dry season is carried away by successive floods. Contrary to liquid pollutants that become diluted during the rainy season, solid wastes tend to have an increased impact on urban hydrosystems then. In canalized urban streams, waste represents the only solid substrate and/or acts as a matrix for the accumulation of sand and organic debris that is often anoxic and thus uncolonizable for metazoans. In wetlands, solid waste increases the terrestrialization process (Figure 6).

Figure 6. Pulau Ketam Creek in Kuala Lumpur, Malaysia. The water surface is completely covered by solid waste deposits. Photograph courtesy by Cathy Yule, Monash University.

In seasonal climates, water level and flow velocity decrease abruptly after floods, and the low water heats up before the channels finally run dry for a longer period. Intermittence of flow has a linear negative effect on aquatic species [118]. Prolonged droughts require the establishment of minimum flows in sewage canals to transport wastewater and solid waste out of the cities to avoid hygienic problems. Small, unpolluted streams flowing into canals therefore become channelized and sealed, as well, to provide this transport water. These measures reduce the infiltration of precipitation into the groundwater, and so they worsen the water problems during the dry season. When the streams finally dry up completely, the concrete surfaces heat up and render survival of metazoan life impossible, with very few exceptions. Migration into the hyporheic zone, which is a common pattern in arid-zone streams [119], is impossible through the concrete fittings.

Urban ponds and wetlands include constructed storm water retention ponds, with vertical concrete walls, in contrast to remnant natural ponds with generally very shallow littoral zones. Natural urban wetlands retain water longer than urban streams and may provide permanent habitats for aquatic fauna and flora, including birds and other mobile terrestrial animals, so that they have a considerable importance for biodiversity [120]; however, their conservation status in Southern cities can be considered even worse than that of streams. Apart from inflowing groundwater, their water budget is defined by surface runoff and evapotranspiration, which increases the concentrations of dissolved solids brought by inflowing water. They are very often abused for garbage and liquid pollutant (e.g., oil) dumping. They generally have high nutrient concentrations favoring intensive plant growth, thus the terrestrialization process, namely the invasion of the land by plants, is very fast. The combination of stagnant, nutrient-rich, and heated water favors the development of water-borne-diseases, which is another cause for the removal of urban ponds (see below). A special case are treatment ponds in semi-arid countries, which are used for wastewater stabilization by evaporation of the water. The deposited sediments are generally too polluted for reuse, reuse of the water is possible but difficult, and ecological targets are generally limited to resource use efficiency but not for biodiversity or other ecosystem services [121].

4.2. Physical Pressures: High Water Temperatures and Siltation

Most of the features described below occur all over the world, but due to the specific climatological situation in tropical and seasonal climates of the Global South, they may be more pronounced there. Due to higher temperatures and higher light intensities, both bacterial and algal productivity are generally higher in the Tropics and Subtropics than in the temperate zone, which has consequences for organic matter turnover, nutrient cycling, and the oxygen regime. Nutrient spiraling lengths generally vary with the presence of biologically active structures, but they tend to be shorter in warm streams [122], i.e., ions of nutrients are taken up faster by the microbiota, which can be interpreted as a quicker "self-purification" of the aquatic ecosystems. However, this interpretation must be taken with care. For example, measurements of free ortho-phosphate ions above, within and below a city bordering a tropical river (city of Cuiabá, Cuiabá River, Mato Grosso, Brazil) showed a fast uptake just downriver the city; however increased concentrations of fecal coliforms could be measured over long distances below the city [123].

Higher bacterial activities in warm water also cause a fast decomposition of organic matter resulting in an increased and fast consumption, whereas the solubility of oxygen decreases with water temperature. At the same time, the oxygen demand by the animals is higher, causing a physiological dilemma for all organisms that require oxygen for their survival. This phenomenon can already be found in natural ecosystems such as the lakes of the Pantanal of Mato Grosso, where huge fish kills occur when the first rainfalls strip terrestrially deposited, organic matter [124,125]. A toxic collateral effect of this phenomenon is the occurrence of cyanobacterial blooms, which is increased by high temperatures, nutrient availability, UV exposure and by scumming up of algal foam at the borders of hydrosystems [126].

High temperatures and high nutrient concentrations make urban hydrosystems likely to be breeding sites for vectors of water-borne-diseases (e.g., the vector mosquitos, *Aedes aegypti* and *Anopheles albipictus*), as well as for the development of hazardous bacteria and protozoa [127], specifically under stagnant conditions. Flood events and climate change increase the risk of water-borne-diseases [128], as they create isolated water bodies that are out of reach of fish, the natural predators of mosquito larvae. Moreover, intermittency of flowing waters can also produce still-water conditions and thereby increase the hygienical risks from urban hydrosystems. Thus, the benefits of biological mechanisms for wastewater treatment such as lagoons and artificial wetlands must be considered and managed considering potential habitat for mosquitos. As their larvae filter-feed on bacteria, which depend on dissolved nutrients and organic matter, nutrient removal by effective wastewater treatment may considerably reduce potential biological hazards from urban hydrosystems.

Urban hydrosystems generally have disturbed hydrosedimentological patterns. In the upper parts of the catchment above the cities, erosion mobilizes large amounts of sediments that scour biological surfaces or cover habitats and natural resources in water bodies (see Wantzen & Mol [129] for a recent review of siltation effects). The high degree of imperviousness in cities speeds up surface runoff in uncovered areas and fosters these effects, especially in canals. Urban ecosystem managers try to remove silt and sand by constructing sand traps from where they can be removed, or to avoid siltation by construction of dams upstream the city. This "too much or too few" distribution of sediments precludes sediments from exerting their functions (ecosystem services) as habitat or site of biogeochemical ('autopurification') processes [130,131].

Light pollution is another physical stressor in urban hydrosystems [132] that can reduce nighttime drift of larval aquatic insects in urban streams by disrupting their circadian rhythms [133]. It is independent of their geographical position [134]; however, in recently developing cities of the Global South, "urban light islands" in the otherwise non-illuminated, surrounding landscape attract very large numbers of phototactical animals (insects, nocturnal birds, etc.) that get killed at the lamp-posts or by cars, with detrimental consequences for their populations especially of large-bodied, insect species (KMW, pers. obs.). As the wavelength-characteristics of the light are crucial for the "attractivity" for insects, i.e., as a trigger for their photophoretic behavior, the choice of specific lamp-types (and of reflectors that emit light down to the street rather than to the sides or the sky) may reduce the negative impact on aquatic and terrestrial biodiversity in cities.

4.3. Simultaneous Occurrence of Different Types of Chemical Pollution: The Hydrosystem as a Sewer

While societies in the Global North had several centuries to "develop and tackle" environmental problems one by one over centuries (Wantzen et al. 2016), these occur practically simultaneously in countries of the Global South; however, without adequate technologies to mitigate them.

Reduction of water pollution is the first step in river restoration. Increased imperviousness of the catchments generally results in increased concentrations of pH, conductivity, bicarbonate, chloride, sodium, potassium, and magnesium (Ramírez et al. [135] and citations therein). In many to most Southern cities, highly polluted effluents become directly drained into urban hydrosystems, such that urban rivers have become sewers. Pollutants resulting from wastewater mainly include organic matter (Biological Oxigen Demand) and nutrients such as phosphate and nitrate, which may cause a strong eutrophication. Nitrate values may be buffered, to a certain degree, by denitrification inside the water body or the floodplain [135–137]. Apart from oxygen-demanding substances from human wastewater or slaughterhouses, more toxic substances from industrial production, heavy metals, and biologically hazardous substances from hospital wastewater often run into the urban hydrosystems without any visible treatment. Despite a paradigm shift regarding wastewater rather as a resource than as "waste", and first successful applications of the new paradigm [138], the reality of most cities of the Global South is different, where 756 million people lacked adequate sanitation and wastewater treatment in 2016 [139].

In most Southern countries the public policies and the sanitation management have not yet succeeded to operationalize an adequate system for the collection of different water types, so that stormwater and wastewater are commonly carried in the same pipes. In treatment plants, the dilution of sludge with rainwater provokes technical problems so that this water cannot be adequately cleaned. Moreover, during heavy rains, sewer canals and treatment plants overflow, polluting urban hydrosystems. Grit filters and pre-treatment of surface runoff from critical drainage areas (e.g., parking areas or car washes, which release polyaromatic substances) are often lacking and result in an additional pollution. If present at all, sewage treatment plants in the Global South are mostly able to provide primary, sometimes secondary, but rarely tertiary treatment procedures. Hardly any sewage treatment plant can reduce hormones, pesticide, organochlorides, or pharmaceutics from urban sewage. Legal baselines to assure that all households become connected to the urban sewage system are often lacking. According to the Brazilian Institute of Statistics, IBGE [140,141], the general percentage of connected households rose from 46% in 2000 to 55% in 2010, and for the three largest urban centers, connectivity rates increased even more in the same time (Belo Horizonte Metropolitan Area 78–85%, São Paulo 79–87%, Rio de Janeiro 65–82%), but also indicate that ca 15% of the urban wastewater was still not connected in 2010. In 2011, only 34.5% of the household wastewaters were actually treated due to lacking sewage collectors in Belo Horizonte City [142].

Badly planned urban growth also results in an accumulation of industrial pollution in the outskirts, which already begins in the river sections upstream of the urban centers. Urban impacts are superimposed with pollutions from agriculture and/or gold mining [129,143] and from damming effects [144] further upstream. This results in a stepwise accumulation of multiple stressors along the stream. As a result, one can observe the co-occurrence of toxic and organic pollution (such as leather tanning (chrome), slaughterhouse organic pollution (proteins), breweries and paper mills (cellulose)), solid waste (plastic bags, cans, tires), along with serious hygienically problematic effluents (wastewater release from hospitals, untreated wastewater containing fecal bacteria and viruses, Table 1).

5. The State of Urban Hydrosystems in the Global South

As a consequence of these intensive and diverse impacts, the state of many urban hydrosystems in the Global South can be shortly described as 'catastrophic' (see introduction). Monitoring parameters such as water quality data (oxygen content, conductivity, pH, etc.), biological parameters (occurrence of species that are sensitive to pollution, biodiversity), or structural parameters (habitat, flow, or sediment diversity), very often display a 'binary' pattern, i.e., a dramatic deterioration as soon as the water enters the urban perimeter. Nearness to the sea may mitigate this problem to a certain degree, as marine fauna may immigrate into urban channels during floods [117]; however, alternating saline and freshwater conditions set limits to osmotically sensitive biota, and outflow of polluted urban streams may severely affect marine ecosystems. Climate has an important but yet understudied effect on the expressions of the Urban Stream Syndrome, e.g., it can affect the direction and magnitude of response of stream flashiness, and the magnitude of the response for losses of sensitive taxa [24]. However, we stress that the man-made impacts of the here-presented "Southern Urban Hydrosystem Syndrome" go far beyond purely climatic effects, while climate change effects are often misused as an excuse for bad hydrosystem management.

The diversity of the types of pressures (Table 1 above), in combination with natural settings (strongly seasonal hydrology and periodically very high temperatures), result in a steep decline in all types of environmental quality parameters as evidenced in several publications, e.g., for Latin America [117,135,136,145–147], for Africa [148–152], or SE Asia [153–155], Japan [103], South Korea [156], India [157] or in the Philippines (Peralta et al., submitted). Even if dams and weirs were absent in rivers crossing a city, the hydromorphological and chemical modifications alone are so strong that they cause discontinuities in faunal distribution patterns. For example, the Velha river in Belo Horizonte, Brazil, is—despite considerable efforts and results in restoration—still not suitable for the majority of migratory fish species of the São Francisco river basin [158].

Summarizing the social drivers and biophysical pressures described above, and based on the existing definition of the Urban Stream Syndrome [6], we define here the "Southern Urban Hydrosystem Syndrome" (Figure 7) as "*the complex consequences of urbanization (increased imperviousness; loss of longitudinal, horizontal, and vertical hydrological connectivity; straightening, reduction and deforestation of riparian habitats; canalization, water and light pollution* etc.*) on habitat structure, hydrosedimentological patterns (including strongly seasonal discharge patterns), chemical (oxygen, nutrients, toxic substances) and physical (light, temperature) conditions, resulting in strongly modified (often reduced) habitat conditions, loss of biodiversity and ecosystem functions and services, combined with socio-political features of the Global South (fast population growth, complex and deficient governance structures, quickly changing cultural approaches, perceptions and valuing of natural resources), resulting in loss of cultural diversity and social connectivity and in difficult conditions for the management of urban aquatic ecosystems such as streams, rivers, wetlands, lakes and estuaries*."

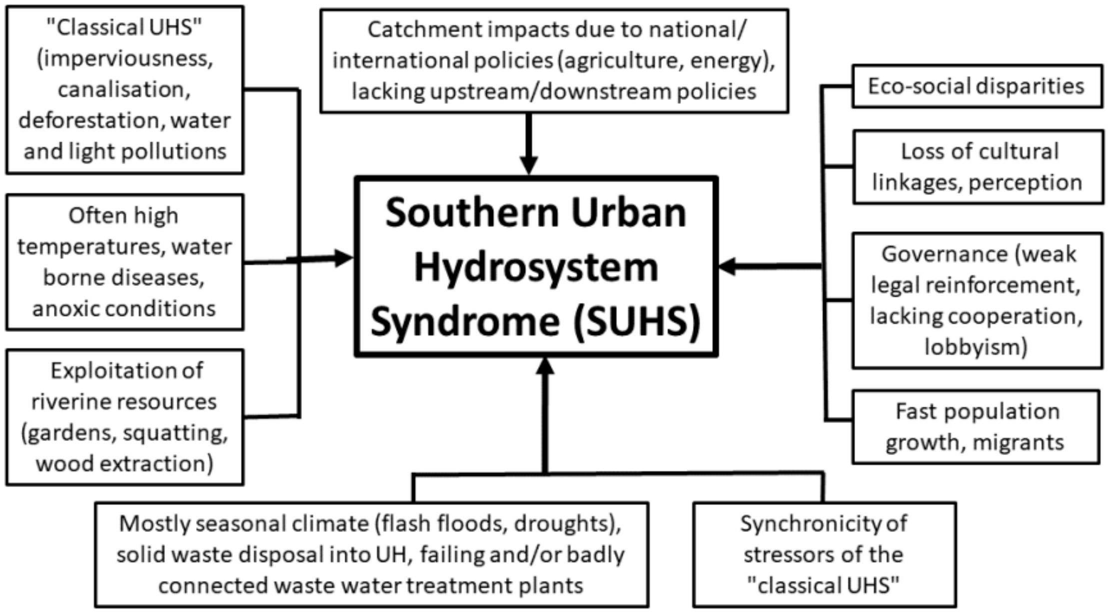

Figure 7. "Southern Urban Hydrosystem Syndrome" (graph by Karl M. Wantzen).

6. Societal Responses

6.1. Which Steps Can Be Taken to Motivate the Local Population to Take Action and to Overcome Administrative Hurdles for Hydrosystem Restoration

Developing countries face a series of societal and governance problems that make the restoration of urban hydrosystems especially difficult: (i) different types of environmental problems need to be solved simultaneously, (ii) many States and sub-national bodies are highly indebted and the financial situation often does not allow large investments for environmental protection, considering that urban restoration projects require larger investments than rural projects, (iii) the institutions responsible for environmental problem-solving are scattered over different geographical units and different hierarchical levels, (iv) environmental education level and degree of political participation by the population are generally low, resulting in a low motivation to take action, (v) the political power of environmental-friendly parties or other political groups is very weak, while political decisions are often taken by ruling clans and lobby groups, and (vi) only few researchers want to dedicate their work to study these problems. As a result, many urban administrations give up when facing this problem, ignore it, or hand it over to future generations.

The degree of engagement by the governing institutions and by the local population in developing urban projects is variable; ideally, lacking initiative by the government can be counter acted by a very active local population and vice versa, but we often witness that neither group takes action for urban hydrosystem restoration. In the background of urban flood protective measures, Hegger et al. [159] have established 5 classes of political engagement of the citizens, respectively the need for governmental engagement (Table 2), based on the following questions: (1) who initiates the project, (2) who coordinates the decision-making process, and (3) who decides in the end? We consider it very important to clarify these questions both in the analysis of existing projects and for the planning of new projects. The upper end of Table 2 represents a 'top-down' governance practically without engagement by the citizens, the lower end a 'bottom-up' governance (see below). These approaches complement each other, with variable proportions (intermediate positions).

Table 2. The government participation ladder and corresponding roles (after [159]).

Roles for Local Governments	Who Initiates, Coordinates, and Decides	Practices of Local Government Roles
Regulating	Government regulates interventions	Policy making, organizing traditional public participation, and sanctioning in case of non-compliance
Network steering	Government (co-)initiates and creates a network of public and private stakeholders; decisions are co-decided in the network	Process coordination, fostering of dialogue, and negotiation among stakeholders
Stimulating	Government actively stimulates; initiatives coordinate and decide independently from government	Provision of structural (financial) support during a longer period of time
Enabling & facilitating	Initiatives are self-initiated, and the government has an interest to make them happen	Process facilitation, helping the initiative to find its way in the municipal organization, providing a limited amount of resources
Letting go	Initiatives are self-initiated, self-coordinated and self-governed without the help of government	None, government is not participating in any way

In the following section we analyze potential drivers for environmental problem-solving concerning urban hydrosystems in the Global South, and cite some positive examples, how restoration projects have come into being.

We present here 3 different types of social response drivers and procedures:

- Bottom-up approach, driven by active urbanites
- Top-down approach, driven by the government
- Interactive approach, driven by societal and economical processes

6.2. Bottom-up Approach: Increasing Participation by the Population

The degree by which citizens are willing to get involved in restoration activities is crucial for the success of any restoration project [160]. A scientific analysis, existing legislation, and the proposal of technical solutions alone are generally not sufficient to solve the problem. The central question for any urban hydrosystem restoration project is therefore: how to motivate/stimulate the citizens so that they support restoration projects? For Southern urbanites, this question has an overlay with the perspective of the local population to be influential on such processes ("Does it matter if I am engaged?"), as many citizens feel that their engagement will not result in action, but there are positive exceptions. Well-functioning and traditional urban communities may mobilize enormous efforts, as for example the 'mingas' (Quechua word for communal work in the Andes), which have resulted in the restoration of the Ortega stream by the local population in Quito, Ecuador [161]. We analyze the motivation process in detail in the following examples.

Manuelzão Project, Minas Gerais, Brazil

The "Manuelzão" urban river restoration project in Minas Gerais, Brazil, occurred thanks to an actively participating population and a well-prepared governance. Being part of the São Francisco basin in Brazil, the Rio das Velhas river basin has a mean annual discharge of 631 m^3/s, drainage area of 27,867 km^2, length of 761 km, and mean width of 38 m. It hosts a human population 4.5 million today. It is one of the few urban rivers of which at least a part of the fish fauna has been studied before the most intensive pollution and modification began, as studies date back to 1850s [162]. The project began in 1997 with a mobilization by the citizens based on the slogan "The return of fish to the river", to express their motivation to change the water quality in relation to human health [163]. By that time, the environmental conditions were in a very bad state, the main channel was highly disturbed (deforestation and siltation), and fish kills were common [164]. Water quality was an important clue, as it may change the appreciation of the local community from negative to positive [165], here; however, the negative attitude against a putrid river could be overcome. Interestingly, the action began with a group of professors of the faculty of medicine, experts in public health, who understood the causality between the environmental crisis and the recurring health problems in that region (specifically that of water-borne-diseases). They formed the core of the movement, which soon included highly diverse social groups (basin committees, private companies, NGOs, and Federal, State and City governments, and local social groups along the basin) and scientists from very different fields (medicine, ecology, botany, journalism, geography, engineering, cultural studies, and others). An important element of success was the creation of committees in every sub-basin, a pioneering initiative at the national level. This allowed the Rio das Velhas Basin Committee to take decisions based on more accurate local information. The support of the project by the citizens was improved in many ways, mostly by means of big Expeditions along the river, cultural festivals, creating a net of "Friends of the River" to alert any changes in its course, fish kills, or other disturbances, as well as public lectures. For example, in 2003, the Manuelzão Project promoted an expedition on boat from the headwaters to its mouth in São Francisco river, mobilizing a great number of people from all participating groups. It became a great media event, reported by television, radio, and internet, showing its importance to the decision-makers. As a result, the local government adopted the formula by the activists "Goal by 2010: to navigate, swim and fish in the Rio das Velhas at the MRBH (Metropolitan Region of Belo Horizonte)", as an official government plan. The program did not only involve the restoration of polluted creeks, but their complete sanitation, risk management (risk of flooding, risk to public health), erosion control at the catchment and river bed, and a housing program addressed to people living in risky areas (improvement of housing conditions, removing people from risky areas) [166]. Moreover, the government of the Minas Gerais state engaged for this mission, and launched a project to build and operate the two biggest wastewater treatment plants of Minas Gerais state (each with a capacity to treatment the domestic sewage of about 1 million people). In this context, the Rio das Velhas were chosen as the pilot basin to develop biological monitoring in the Minas Gerais in 2008, as a result of Federal and State environmental legislation [167,168].

In this case, participative action has different levels of engagement still today. Each citizen automatically becomes part of the process by participating at the Hydrographic Basin Committee and its subdivisions (sub-basins and micro-basins) and in the mutual information process. Elected members are hired by the basin agency and vote on the priorities for action. The basin agency manages the money collected by the water users (hydroelectric and sanitation companies, irrigation sector, mining and industry, and private users). Participating in the basin committees, the legal democratic forum to establish the wide will of the society, seems to be the key to push governors to implement healthy environment decisions. This does not prevent the citizen from participating in other spheres of decision-making, in private or governmental public companies, or independent NGOs.

The measures showed very positive results, which are regularly documented on a homepage and an own journal in the local language (freely accessible), and summarized in peer-reviewed expert journals. Shortly after restoration the number of fish species increased to 107 fish species in 2005 [162], and at least 135 species in 2018 [169]. A direct comparison with the 19th century studies is not possible, as many fish species were described for the first time then, but it could be shown that some species had gone locally extinct during the higher pollution period [158]. Today (2018), the ecological status of the Velhas river is stabilized and in a better condition compared to the past but still far from the desirable or expected state, considering historical data [162]. There is a need for tertiary sewage treatment stage at the bigger treatment plants to reach the desirable state. In the Baleares creek, a 1 km-long tributary to the Velhas River, water quality has considerably improved from pre-(2003–2006) to post-restoration

(2008–2009), dissolved oxygen values increased from 1.2 to 7.5 mg l^{-1}, total phosphorus, total nitrogen, and conductivity decreased 0.5–0.05 mg l^{-1}, 1.4–0.005 mg l^{-1}, and 600–400 µS cm^{-1}, respectively [166]. The same study analyzed the opinion of the riparian urbanites and showed that nearly 80% of them admitted that the restoration success exceeded their expectations concerning improved water quality, esthetics, reduced disease vectors, park construction, improved accessibility, slum removal, and flood control (answers in decreasing order of magnitude).

The Manuelzão Project can be seen as a landmark for tropical urban river restoration and may serve as a "living lab" example for other projects worldwide. Although many achievements have been reached, there is still much to do to bring the stream ecosystem to a minimally disturbed condition. We ascribe its success to different elements (see below), but mostly to the high degree of mobilization of the local population.

Favorable social situation:

- The State of Minas Gerais has an excellent level of education, with one of the lowest degrees of illiteracy in Brazil and a great interest in environmental issues by the population.
- The riverine urbanites have a strong cultural and emotional linkage to "their" river, which motivated them to take action when seeing that their river was "dying" (visible, frequent fish kills that were also reported by the media), the memory of a healthy river was still present in the politically active part of the population.
- There was an emblematic personality ("Manuelzão", a well-respected, old man who was a living testimony for the Velhas River before pollution) who served as a "trademark" for generating an identity of the participants that came from very different social and political groups.
- The driving force was to overcome public health problems, i.e., an issue that touches the entire society (whereas purely biodiversity-driven restoration projects often have difficulties gaining traction with the larger populace).
- An open-minded mixture of academics, local citizens, and government members planned, conceived, and coordinated actions jointly, and active feedback on the technical efforts and on the financial aspects contributed to an efficient project implementation.
- A State Government who was interested in accepting the proposals by the population, who had (or developed) an administrative infrastructure capable of acting on the entire catchment, who found the financial means to realize the projects, and who gave priority to these actions over other thematic issues.
- A period, in which the citizens were strongly engaged in political participation, after with overcome a dictatorship, and which was carried by the spirit of the ecological movement, culminating the first Earth Summit in Rio de Janeiro 1992.

Favorable environmental situation:

- The size of the river precluded it from being buried, as it had happened to many smaller urban streams.
- The restored river system is free of dams, which enables migratory fish to return.
- Some of the tributaries are relatively well-protected and served as species pool for recolonizing the restored aquatic and riparian zones of the river (i.e., the native fauna and flora was able to recolonize the river before this was done by invaders).
- The surrounding ecosystems are relatively well-protected from invasive species so that the restored habitats were re-colonized by native species.

6.3. Top-Down Approach: National and Regional Governance

Integrated River Basin Management (IRBM) proposes the establishment of basin-wide administrations that go beyond the existing governance structures to optimize flood risk management and water supply. However, coherence is often lacking between regional river basin plans and urban water management plans, mostly due to scalar mismatches (see van den Brandeler et al. [170] for a review). Moreover, socio-ecological restoration projects for rivers and wetlands are rarely part of IRBM plans, even less so in cities. In spite that this would be desirable for the future, a realistic scale must be chosen for decision processes to bring back human well-being and environmental quality to urban rivers.

This can be achieved by an urban/regional "top-down" approach, i.e., a superior authority controls the collaboration of the individual institutions of the part of the catchment that is relevant to a city. City planners are often not trained in ecosystem functioning and need to learn about the necessity of riverine ecosystem services, and ecosystem restoration. Gorski [171] has studied the interplay between the different actors, the motivations, and the driving legal directions for several case studies in Brazil. As in the bottom-up approach, the motivation of the participating agents is crucial, as described below.

6.3.1. Urban Drainage, Belo Horizonte

The case of the "DRENURBS" (urban drainage) project in Belo Horizonte [172], attempting to solve the problem of wastewater treatment efficiency in areas with strongly seasonal rainfall patterns. By initiative of the mayor, master plans for wastewater treatment and urban drainage ("Plano Municipal de Saneamento" (2001), "Plano Diretor de Drenagem" (2002)) were established to coordinate the entire management of the urban hydrosystems on the municipal scale [173]. Financial aid to this interinstitutional collaboration coordinated by the Belo Horizonte Sanitation Company was equally shared between the Interamerican Development Bank and the City Council. According to the sanitation plan of the City of Belo Horizonte [174] and assuming an exchange rate of 1 BRL to 0.5 US$, restoration costs ranged from 1.46 to 17.7 million US$ per kilometer of restored stream length. These large variations were caused by the variable area that was restored, and the number of households that became connected to the sewer system.

6.3.2. Rio Barigui

Another (not yet completed) example of a top-down directed project is the very ambitious "Viva Barigui!" project in Curitíba, which is co-financed with 20 million Euro by the French Development Agency (AFD) [175]. The Barigui river is 67 km long, draining a watershed of 279 km^2, just upstream and downstream the capital of Paraná. It obviously suffers from the Southern Urban Hydrosystem Syndrome and is heavily polluted, i.e., with polyaromatic hydrocarbon (PAH) values as high as 2350 ng g^{-1} of dry sediment [176]. Since 2008, a new strategic planning instrument has been implemented to re-connect the riparian river corridor to 5 existing parks and by creating many new conservation units that form the Barigui Linear Park. 30 slum areas, and houses of 750 families that inhabit risk areas by the Barigui river margins and over 100 illegal settlements in existing reserves have been demolished and relocated for conformity with the Brazilian legislation that protects river and lake margins (so-called 'permanently protected areas', area de proteção permanente, or APPs [177]). Some families could remain and will receive road infrastructure and sanitation. Houses for 30,500 families will be built and public buildings installed to prevent new invasions of riparian zones. Actions include the re-establishment of riparian floodplains and their native vegetation, as well as the restoration of polluted and terrestrialized lakes. Specific attention is given to the definition of clear goals for the riparian zones inside and outside the city and to create targeted parks for biodiversity, leisure, and a novel road and bicycle/hiking track system. Connections of the households to the sewage system are controlled using color tracking, new connections made, and a wastewater treatment plant is being built. The local population has been involved since the beginning. Strong efforts are made to increase the interest on urban ecology by establishing an organization that performs public science (Olho d'Agua—Water watch) and that has specific sites for environmental education.

Favorable social situation:

- Curitíba has a long-standing reputation as one of the best-organized and most ecology-driven megacities in the world, including an excellent transportation system, waste recycling, and a high degree of public participation
- The perspective to give the illegal squatters a better housing than their current situation has contributed to the public acceptance. The local government has shown that the demolition of houses did not only affect the poor, but also economically better standing people who had squatted in nature reserves.

Favorable ecological situation:

- The Barigui river has an intermediate size, i.e., it is manageable.
- The river borders were yet only partly colonized so that the riparian continuum can still be visualized.

6.3.3. The River-Chief System in China

The newly established "River-Chief System" in China is another example for top-down approaches. In China, various official departments and parties are involved in river management. A plethora of responsibilities, including flood prevention, irrigation, water transport, and prevention of water pollution has been shared among them [178]. The "River-Chief System" is intended to overcome this problem. Originally established by the Jiangsu provincial government for the management of 15 major lakes and rivers in 2008, it was upgraded from local practice to national action in 2016. By the end of October 2017, all municipalities, 95% of counties and 92% of towns have issued implementation plans for the River-Chief System across the whole of China [179]. By the end of 2018, a thorough four-level River-Chief System has been established by Chinese government, encompassing all provinces, cities, counties, and townships in China [178] and see Figure 8).

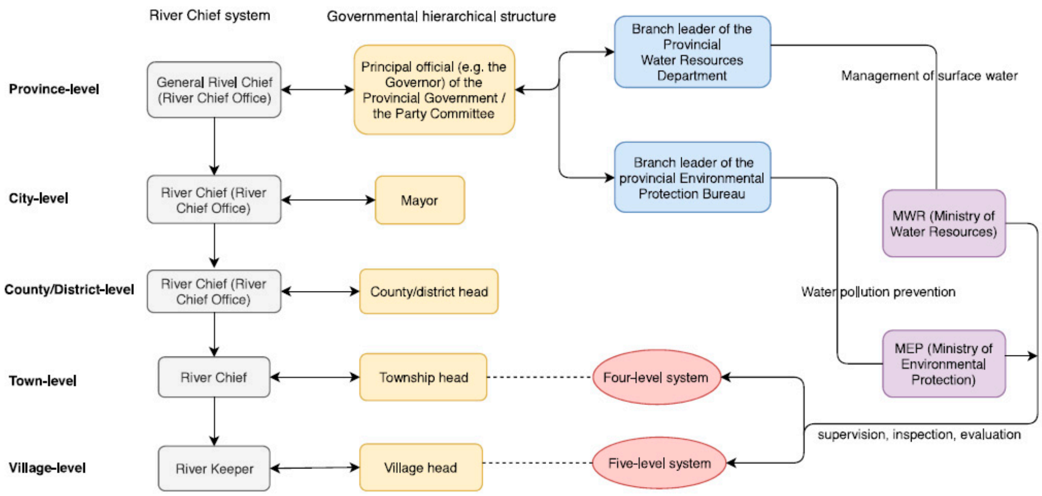

Figure 8. The Chinese the River-Chief System (graph by Yixin Cao).

The River-Chief governance reforms include five mechanisms. The first is the "Conference of River Chiefs", through which all River Chiefs and Keepers responsible for a given river basin convene to identify and resolve critical problems in the management and protection of its rivers and lakes. The second involves "Information Sharing", which will ensure that data and information on river protection and management are shared and will track progress in the implementation of the River-Chief System. Thirdly, "Work Supervision" involves checking and supervising the implementation and performance of duties of River Chiefs and Keepers. This will be supported by the "Accountability, Assessment and Incentive" mechanism, which will reward the achievements of River chiefs, and reproach those who fail in their duties. Finally, "Acceptance" requires regular checks on the timing of interventions, and acceptance of the quality of work undertaken [180].

The “River Chiefs System”, as a practice of Chinese environmental governance system innovation, and still with an essential property of “top-down” system, represents the implementation of chiefs-term protection and management mechanism, it has clarified the responsibility of water pollution management, and strengthened the role of government organization and leadership. It also symbolizes the tentative transformation of Chinese governments: from the economic subject-oriented into service-oriented, by establishing a water control system with Chinese characteristics [180].

6.3.4. Factors Affecting the Success of Top-Down Systems

Not always the collaboration between the institutions runs so smoothly. In Argentina, the case of restoring the Matanza–Riachuelo shows the social and political complexity of governing urban hydrosystems. Since this river crosses different administrative areas, the environmental problems of this territory were not considered by the local and regional authorities, and no plans for restoration were established for a long time. This situation only changed when the Supreme Court of Justice intervened, an interinstitutional authority for the entire river basin could be established [181].

Top-down approaches may not provide the expected results if there was an “institutional gap” between the responsible authorities of river basin, i.e., legislation, such as the Indonesian Water Resources Law and the designation of regions such as Jakarta Special Capital Region (Daerah Khusus Ibukota Jakarta (DKI Jakarta)) as national strategic area with regional spatial plans, exists, but lacking communication between municipalities may still lead to a fragmented spatial development [14].

Favorable conditions for the top-down approach include:

- All involved institutions share a common idea about the targets of the restoration project
- Financial and administrative responsibilities are clear
- Larger areas (even entire catchments) can be dealt with

6.4. Interactive Drivers

It is obvious that Southern Urban Hydrosystem Restoration projects can only be performed with a high degree of participation of the public acting as political supporters, contributing planners, or physical implementers of the restoration activities. Even in the case of top-down approaches driven by regulatory compliance or international agreements, an active participation of the local population is needed to support (and not to counter act) the projects. Grêt-Regamey et al. [12,182] summarized experiences in the Jakarta urban hydrosystem management project [14]. The experiences from the Brazilian projects in Belo Horizonte (Manuelzão) and Curitíba (Barigui) can provide examples of how the hurdles of motivation and administration could be overcome. In all cases, clear goals (such as: “fish back in our river”, “clean water”) encourage public participation and shows the public value of the project. Despite being time-consuming, an iterative decision process with several feedback loops seems to be essential to build support among partners for the project goals, a step that may be overlooked by purely “top-down”-driven approaches. There is a large array of different techniques for this process, including decision analysis techniques [183], confronting the population with the outcomes of their desired endpoints as visualized by 2D graphs, 3D graphs or even 3D prints (Grêt-Regamey, pers. comm. to KMW), participant appraisals of ecosystem services [184], household surveys, monetary choice experiments and ethnographic interviews [77]. All those may reveal the residents’ preferences for future state of the urban hydrosystem, and their perception of cultural and other ecosystem services.

The interactive and transdisciplinary character of the proposed solutions approaches requires the difficult task that terminologies become clearly translated between the widely differing jargons of urban planners, engineers, social scientists, and ecologists. Lack of understanding and lacking credibility may result in lack of acceptance or even opposition by stakeholders, whereas reported experiences from previous, successful projects (and regularly updated evaluations and monitoring) may considerably increase credibility in the feasibility of planned action and in the added values brought by the project (see table of projects below).

While the bottom-up and top-down approaches mainly focused on compliance with requirement of water quality legislation, there are other drivers for urban hydrosystem restoration in the Global South, outside of legal mandates. These include "soft" triggers such as the change of priorities, emotional and cultural relationships to the water body, "hard" triggers such as economic considerations, or intermediate forms, such as the valuing of ecosystem services. Whatever the trigger, these alternatives imply an interactive and evolutive participant process.

6.4.1. Cultural and Emotional Linkages

The participant process depends on the perspective of the citizens towards an urban aquatic ecosystem management/restoration project: to what end may the project lead? What do we want to have? What do we want to have back? Ideally, there are memories or still-existing usages of the services of the ecosystem, which are engraved into a "use culture", enabling humans to develop an emotional affection to rivers [165] and to prioritize the conservation and restoration of aquatic ecosystem functions, which foster both biological and cultural diversities (River Culture Concept, Wantzen et al., 2016 [13]) and to re-establish social connectivity [15]. On the other hand, lacking empathetic relationships between humans and their environment may de-motivate participation. The rediscovery and revival of cultural uses of hydrosystems (e.g., folk festivals that are linked to fish migrations that were previously used as protein sources, rediscovery of ancient river beds or wetlands from old maps or road names) and the (re-) establishment of sites where humans beings can feel the river (e.g., use of beaches [18]), the maintenance or transformation of religious celebrations at the shores (e.g., in India [157]) or of traditional use forms (e.g., willow wattling) may be vehicles to re-establish these linkages (see Wantzen et al., 2016 [13], for further examples). The increasing understanding of linkages between elements of nature and the physical and socio-psychological well-being of humans [185] may further support the linkages with the hydrosystems, e.g., by environmental education [186]. Even the success of small-sized projects results in an increasingly urban local population [187] may advertise new restoration projects.

Urban hydrosystems, mostly rivers and large lakes, may have a structural role to establish or to reinforce the identity during the redevelopment of cities [188]; however, the environmental quality plays and important role in this process. While many cities are still "facing away from the river" (for example, in Chennai, India, buildings are facing away from the Cooum River, which is one of the most polluted in the world, with > 300mg BOD/l-1 [154]), the restored river may be have a central importance for the urban redevelopment. The river parks in Brazil cited here all have in common that they bear the name of the water course, which serves as an element of urban identity.

In general, the targets of urban river restoration differ from that outside cities by integrating more societal goals [16,18] and they may be part of urban redevelopment. One important goal of any urban hydrosystem restoration project should be the creation of encounter sites of humans with nature, where they can experience the sounds, silence, smell, visual and tactile appearances of nature [13,81,189]. The empathic experience of this encounter is elementary for the development of a "care" relationship and may be the driver of future engagement for further restoration projects [190,191]. Apart from sites where the beauty of the landscape is "self-explaining", sustainable efforts are needed for environmental education, i.e., establishment and long-term maintenance of demonstration sites and guidance of the public, as it is the case with the successful "Manuelzão" and "Viva Barigui!" projects in Brazil. The environmental quality of these sites, and the effects of environmental education, should also be used for a long-term monitoring of the effects of the restoration [19,192].

There is a great need to improve environmental education measures, and more specifically, to develop demonstration sites of hydrosystem restoration that can be used to transfer knowledge to future project sites. Further research is also needed to identify natural elements of rivers and lakes, and their empathetic effects on humans.

6.4.2. Economical and Legal Drivers that Are Indirectly Linked to Hydrosystems

Economic and law theories provide different approaches to motivate the participation in public processes. First of all, the water body and its riparian zones are often considered to be common good, thus they do not appear to have an assigned economic value ("tragedy of the commons", [193]). This can encourage illegal garbage dumping and discharge of toxic pollutants. The lower the environmental quality of the area, the lower is the apparent economic value, and the lower is the public concern about further impacts on these areas (the "free rider" phenomenon in public choice theory).

To counteract this vicious cycle, an alternate vision can be presented, emphasizing the economic potential of healthy, restored rivers and wetlands. The example of the Isar River in Munich [18] has shown that citizens owning houses next to the river were engaged in the river restoration project, among others, because they expected that real-estate prices for their houses would increase, once the Isar was restored (and they were right). However, the transfer of examples from the Global North to the Global South always needs to be done with care. There may be some cases in fast-developing countries, where land-owners in well-to-do areas could be motivated in a similar way. In many cases; however, especially in the areas of bad environmental quality, the security of land tenure is low or uncertain, and slum dwellers risk to be chased away as soon as the real-estate prices rise along with the environmental quality, or if larger development projects come into place, such as Olympic Games [194]. This legal uncertainty has very negative consequences on participative processes, and it demotivates the riparian dwellers to preserve nature or to live in a sustainable way. Here, socially acceptable solutions need to be developed. Different scenarios can be envisaged:

Legal protection of urban riparian zones as parks and multi-purpose sites, including transformation of waterfronts into multiple-use floodplains

One solution could be the protection of riparian zones inside or above cities by local laws. Riparian zones of streams and wetlands outside cities are often protected. For example, the Brazilian Forest Code (Codigo Florestal) considers that a riparian zone of 50–100 m aside each stream [177] need to be protected. Some riparian zones of streams and wetlands are protected as nature reserves or parks. Ecuador has been the first country in the world to recognize "Rights of Nature" or ecosystem services in their constitution [195] as a reaction to decades of natural resources exploitation by multinational companies. Since the 1970s, the City of Cuenca has protected an area of "páramo", a wetland ecosystem characteristic of high elevations in the Andes, to ensure a clean water supply and has designated protected zones along the banks of streams and rivers in the periurban areas. The breadth of these zones is defined according to stream order [196].

In Buenos Aires, Argentina, nature reserves protecting freshwater hydrosystems—mostly lakes and wetlands—have existed for decades, but many of them have been created just recently, like Costanera, Santa Catalina or Laguna de Rocha [197], during the discussions about of environmental conflicts that led to the consolidation of an environmental agenda. However, a wetland protection bill that would allow national enforcement, is blocked in Congress due to lobbying from real-estate developers and the forest industry. In Brazil, several projects exist, where new areas were protected in order to link existing parks via the riparian corridors between them, for example in the states of Paraná (Barigui in Curitíba, see above), in Santa Catarina, [198], or Pernambuco [199,200]. The linear extension of these parks makes them sensitive to disruption by buildings or physical structures. On the other hand, it also offers the opportunities to establish longitudinal and transversal connectivity between different types of urban green spaces, sports, and safe and healthy, non-motor-driven transport (bicycle and jogging), it establishes sites for man-river encounters, it connects the margins of the rivers by bridges or by boat passage, and to activate the transformation process of cities, social-political participation, public debates, creativity etc. [199]. Recife was the third city of Latin America to have a sewer system as early as 1873, but the connectivity of the households is far from being satisfactory today, but the linear structure of the park helps to re-organize the wastewater sewage system in the future. The city of Recife considers itself as "aquacentric" and has planned to use the structure of the linear riverine park for the transformation from a city bearing a park into a park city [200]. An adapted and moderate navigability of the urban river sections may be integrated into these parks and may improve the internal transport infrastructure, as it is requested, e.g., for the city of Bogotá (G. Rueda-Delgado, pers. obs.).

Linear parks may integrate riparian zones, urban green corridors and flood mitigation [201]. Win-win situations can develop when designating urban floodplain zones for multiple use, e.g., creating habitat for fauna and flora, providing a reserve area where large volumes of flood water can be stored, and permit human use such as leisure activities (sport, playgrounds, recreation). Care must be taken how these different uses are combined to fulfil the different purposes, and how a clean-up after eventual flood events can be done (flotsam and garbage withdrawal, avoidance of breeding grounds for mosquitos, etc.). This solution is mostly recommended for areas that have not yet been covered by asphalt and concrete; however, it is also necessary to think about demolishing obsolete buildings and those in flood-prone areas on river banks, as increasingly proposed for coastal cities [202]. Insurance and re-insurance companies are less and less willing to cover flood risks in these areas [203], which could be a motivation to transform them into urban, multiple-use floodplains.

6.4.3. Integration of the Local Population into Jointly Used Restored Riparian Zones

The fate of illegal squatters in riparian zones poses several problems. At one hand, they need legal protection against being chased out of the territory as soon as the real-estate prices increase, but on the other hand, the way they colonize the riparian zones is very often highly unsustainable. A possible solution to this dilemma could be to integrate a part of the urban population that is willing to act sustainably on the hydrosystems and their riparian zones by giving them a technical orientation and by establishing a legal sustainability, i.e., to give them the right to live in parts of the restored riparian zones (e.g., in flood-adapted housing) and to act as communicators of the restoration project and of transformed traditional riparian use forms, demonstrating how to use these ecosystems in an appropriate manner. The perspective of legal safety in the long term could become an important motivation for developing responsibility for the used hydrosystem.

Another potential solution to the conflicting interests of the riparian zones of urban hydrosystems could be the delineation of restored urban riparian zones as commonly used grounds. In practice, this would mean that a river section or a wetland would be attributed to a clearly defined number of persons who would jointly establish and apply rules about the use and the maintenance of natural resources. This use form is practiced in traditionally organized societies (e.g., jointly used wood-delivering forests or bread ovens in Switzerland, or in nature reserves such as the Mamirauá reserve [204]), which are all closely connected to natural procedures. Elinor Orstrom, Nobel-prize winner in Economics in 2009 for her lifetime work investigating how communities succeed or fail at managing common pool (finite) resources such as grazing land, forests, and irrigation waters, has established 8 rules for participative use of common goods, so to say as an answer to the "tragedy of the commons" [205]: 1. Define clear group boundaries. 2. Match rules governing use of common goods to local needs and conditions. 3. Ensure that those affected by the rules can participate in modifying the rules. 4. Make sure the rule-making rights of community members are respected by outside authorities. 5. Develop a system, carried out by community members, for monitoring members' behavior. 6. Use graduated sanctions for rule violators. 7. Provide accessible, low-cost means for dispute resolution. 8. Build responsibility for governing the common resource in nested tiers from the lowest level up to the entire interconnected system.

Common pool resources (e.g., water or fish) typically consist of a stock of core resources, which must be protected, while providing a limited quantity of extractable fringe units, which can be used. The open character of urban hydrosystems may pose problems for the delineation of boundaries and the establishment of stock size limits. Adaptations of the rules to the specific situation of a participant and sustainable use of urban riparian zones are needed. "Living Lab" experiences could help to carefully find solutions and to avoid reversion into a riparian slum. To our knowledge, this kind of management is unknown for riparian management in the urban context, but it is known from urban participative gardening [206], which could help to transform rules for usage and to develop social structures in riparian zones. Since in developing countries, urban riparian zones are often still used for gardening and even farming (see examples above), transitional use forms between riparian protection and urban gardening may be developed here. Given that local governments would permit and protect such areas/communities, we consider this option specifically interesting for areas with yet low juridical certainty and low environmental quality because it could trigger bottom-up initiatives and a "demarginalization" of river banks and wetlands, by developing identity and responsibility for the environment the people live in.

6.4.4. Valuing of Ecosystem Services

Ecosystem services (ES) are increasingly used for decision-taking in environmental management, as they promote a deeper understanding of the social-ecological system [182] and as they identify (positive) use options rather than (negative) pressure avoidance as drivers for ecosystem management [14]. A tiered (scaled) approach of ES mapping [182] may help to overcome the scaling problems between Integrated River Basin Management and Urban Water Management [170]. As the process of valuing of ES and integrating them into administrative rules is still ongoing, we put ES here in an intermediate position between "hard" drivers based on existing economical and legal rules and "soft" drivers of yet unestablished, personal wishes by the population.

The types of potential ES deliverable by urban hydrosystems are generally similar to those of streams and wetlands (e.g., [184]) in the open landscape; however, the urban situation (mostly the imperviousness of the catchment and the canalization of the water bodies) may limit ES in number and quality (Table 3). One ES that must be seen critically is navigation. For an effective transport of many persons in a short time, heavy engineering is required. Even without channelization, the effects of ship waves may be detrimental for the ecological integrity of the riparian zone. The establishment of a single transport line may provoke a "tyranny of small decisions" [207,208], and transformation of river or lake banks into piers is contradictive to conservation efforts. Therefore, solution finding must involve very careful studies on the individual urban situation. On the other hand, the wish by the population to establish navigability of urban water bodies and the perception of the river from a boat may be important drivers for the restoration of water quality.

Table 3. Ecosystem services by urban hydrosystems, subject to improvement by restoration projects.

Elements of Ecosystem	Ecosystem Service (Type)	Quantifiable Indicators
Vegetated surface (in the city and in the upper catchment)	Bank protection, erosion control, reduction of siltation (regulating)	Size of area (ha) that does (not) suffer from erosion or siltation, canopy cover (%)
Floodable area	Flood reduction (regulating)	Volume (m^3) of stored water
Water body and aquifer	Drinking water supply, increased base flow (provisioning)	Volume (m^3) of percolated water
Water body and flood plain	Nutrient reduction, carbon fixation (regulating)	Concentration change per surface unit of floodplain (mg (substance) l^{-1} m^{-2})
Vegetated and humid area	Moisturizing and cooling of air (regulating)	Change in °C, %RH (averages and maxima/minima)
Riparian landscape and park space	Benefits of visiting such as stress reduction, health improvement, leisure, sports, creativity, inspiration (recreational, cultural)	Public healthcare costs, revenues by tourism, contentedness (hedonic pricing)
Water body	Transport route (provisioning)	Time saved for transport, number of persons transported
Animals and plants	Biodiversity (provisioning), Control of invasive species (regulating), pollination (provisioning)	Species numbers and abundances (e.g., of rare, sensitive, pollinator, conservation target, or exotic species)
Plants	Use of individual species as food, ornaments, medicine, fodder, construction material, or for handicraft such as wattling (provisioning)	Market value of the refined product
Animals	Use of individual species as food (fish, shrimp, subsistence, or commercial)	Market value of the refined product

7. Technical Responses: Which Practical Engineering Approaches Can Be Applied

For rural river restoration in tropical and emerging countries, the general roadmap is relatively clear. Several concepts have already been developed [10,99], and many of them are ready for application, provided that an adaptation to the regional bio-geological, hydrological, and climatological settings was made. Very often, enforcement of existing laws (e.g., the Brazilian Forest Code, [54]), protection of riparian forests and headwater swamps [177], maintenance of environmental flows [87], and the public decision to keep parts of the river continuum entirely free of dams (e.g., [10]), and the principle of "espace de liberté" (space for river dynamics), can solve a large parts of the rural problem.

Projects to restore urban hydrosystems of the Global South are yet quite rare, probably due to the specific biophysical and socio-economic situation in fast-growing cities in extreme climatic zones (see above). Of course, all projects need to be tailored to the individual set of environmental problems, and social and political constraints. However, from the overview of impact studies and projects that we could analyze so far (see Table 4 with case studies), several generalizations can be developed.

Table 4. Case studies from Brazil and Argentina.

Name and Type (Stream/Wetland) City	Country	Short Description of the Measures that have Taken Place	Dimensions and Cost Estimation (Total Size, Total Costs, and Costs per Meter River/Wetland Bank)	Major Drivers for the Project	Major Success/Elements of Sustainability for the Project
Manuelzão Project, Belo Horizonte (MG) [166]	Brazil	Implementation and expansion of Sewage Treatment Plants (STP)	political mobilization US$ 100.000	Basin committee *University, Minas Gerais State Government, Belo Horizonte Municipal Government, civil society	Environmental education, human health, ecosystem health
Restoration of the das Velhas River basin, Ouro Preto (MInas Gerais, Brazil)	Brazil	Engineering; Sewage; Recovery of springs; Preparation of sanitation plan	US$ 50 millions	State Government and Sanitation Company Resources raised by the cost of water use	environmental education, human health, water quality improvement, public leisure
Revitalization of the Rio São Francisco [209]	Brazil	Basic and environmental sanitation sewage treatment engineering improving the navigability and recovery of riparian forest	US$ 3.3 millions	Federal Government	human health, water quality improvement, public leisure
DRENURBS, Belo Horizonte (MG) [172]	Brazil	Engineering sewage collection margin stabilization riparian restoration riverside population relocation	US$ 77.5 million (first phase)140 km	Municipal government and Banco Interamericano de Desenvolvimento	water quality improvement, public leisure, public health, some biological diversity improvement
Project Iguaçu at Rio de Janeiro (RJ) [210,211]	Brazil	Dredging of rivers and channels, establishment of 6 River Parks, sewage and solid waste collection, margin stabilization, replant riparian vegetation, relocation of 1700 (planned: 2500) families	US$ 5 millions	Federal Government through PAC (Growth Acceleration Program)	First part human health water quality improvement, public leisure Seconded part is in process yet
Paranaíba river restoration	Brazil	Engineering sewage treatment destruction of buildings in inappropriate places (APP) riparian restoration		State Government	water quality improvement, public leisure, human health, some biological diversity improvement, vegetation restored
Chubut river restoration [212,213]	Argentina	Green engineeringreforestation irrigation optimization herd rotation		private initiative (Coca Cola)	water quality improvement, public leisure, human health, some biological diversity improvement, vegetation restored
ReNaturalizeProject of Mangaraí river (ES)	Brazil	Restoration using wood trunks and structures in the riverbed		private initiative	water quality improvement human health, some biological diversity improvement
Linear Park Uberabinha River (MG)	Brazil	Planting of native seedlings for reconstitution of riparian forest, construction of artificial lakes, recreation area	US$ 610,000	State Government	water quality improvement, public leisure, human health

Table 4. *Cont.*

Name and Type (Stream/Wetland) City	Country	Short Description of the Measures that have Taken Place	Dimensions and Cost Estimation (Total Size, Total Costs, and Costs per Meter River/Wetland Bank)	Major Drivers for the Project	Major Success/Elements of Sustainability for the Project
Beira-Rio Project (SP)	Brazil	Replacement and improvement of sewage systems, drainage and street lighting, design and implementation of extensive landscaping project of green areas and margin recovery with native vegetation (formerly dominated by invasive species) and construction of a pedestrian walkway		Prefecture of Piracicaba	water quality improvement, public leisure, human health
Pró-Tijuco Project (SP) [214]	Brazil	Completion of the drainage system, solid waste removal, use of geotextiles for stream bank stabilization, construction of Linear Park Tijuco Preto with urban equipment (sidewalk for walking and a bike path, lighting and landscaping of the site)		Prefecture of São Carlos	water quality improvement, public leisure, human health
The Tietê Ecological Park (SP) [215]	Brazil	Maintenance of damping capacity of floods in floodplains of the River, and, as a by-product, use of the neighboring areas for leisure activities, sport, and culture for the preservation of fauna and flora		State Government	water quality improvement human health, some biological diversity improvement
OWL Park (SP)	Brazil	Improvement of drainage, use for recreation and motorized circulation in the stretch		Private Initiative	water quality improvement, public leisure, human health
Mangal das Garças Park (PA)	Brazil	Riverside animal recovery with the re-creation of lowland forests, implementation of the recreation area			water quality improvement, public leisure, human health
The Park Set Manoel Julião (APP) (AC) [216]	Brazil	Improving the degradation of a preservation area with clearance of igarapé, implementation, and awareness of local people about the importance of conservation of natural resources and recycling as a whole		Prefecture of Rio Branco	water quality improvement, public leisure, human health
Recovery of riparian forests of the Bayou Fund (AC)	Brazil	Cleaning and clearing of the bed, replacing invasive species by indigenous environmental education project		Federal Government	water quality improvement human health, some biological diversity improvement
100 Parks Program for São Paulo [217]	Brazil	Removal of buildings, construction of affordable housing, sewer collector system deployment throughout the stream, resetting the riparian forest deployment of recreational areas and public equipment		Private initiative and State Government	water quality improvement human health, some biological diversity improvement

Table 4. *Cont.*

Name and Type (Stream/Wetland) City	Country	Short Description of the Measures that have Taken Place	Dimensions and Cost Estimation (Total Size, Total Costs, and Costs per Meter River/Wetland Bank)	Major Drivers for the Project	Major Success/Elements of Sustainability for the Project
River Basin plan Cabuçu (SP) [171]	Brazil	Improvement in the drainage system, implementation of collection and treatment of sewage, rainwater filtering, environmental education, urban works		Private initiative and State Government	water quality improvement human health, some biological diversity improvement
Stone Creek Linear Park (SP)	Brazil	Recovery of riparian forests, environmental education, care of the wildlife, flood control, sanitation and the implementation of basin bicycle trail/hiking trail and green areas of enjoyment of the population, formation of an ecological corridor	US$ 82.2 million	Prefecture of Campinas, State Government and private initiative	water quality improvement human health, some biological diversity improvement
Programa de revitalização do Rio Sorocaba (SP) [218]	Brazil	Urbanization works Green engineering Recovery of the riparian Woods and springs Environmental education		Prefecture of Sorocaba	water quality improvement human health
Parque Linear do Rio Ressaca (PR) [219]	Brazil	Water cleaning Engineering sewage collection, margin stabilization riparian restoration riverside population relocation	US$ 113 million	Prefecture of São José dos Pinhais	water quality improvement human health
Viva Barigui Project (PR)	Brazil	Water cleaning, Environmental education, Urbanization works	US$ 22.5 million	French Development Agency	water quality improvement human health
Parque Linear do Córrego Grande (SC) [220]	Brazil	Recovery of water quality, creating a green recreational corridor along the entire length of the River, connecting two ecosystems that comprise the areas of preservation, source and mouth		Prefecture of Florianópolis	water quality improvement human health, some biological diversity improvement
Programa Várzeas do Tietê (SP) [221]	Brazil	Restoring floodplain areas, engineering sewage collection margin stabilization riparian restoration riverside population relocation	US$ 199.780.000	State Government and BDI	water quality improvement human health, some biological diversity improvement
Capibaribe Park (PE) [222]	Brazil	Revitalization and urban development of the edge of the river		Prefecture of Recife and INCITI-research and innovation for the cities	water quality improvement human health

In all the studied cases, water quality was the major problem. Connection to the sewage system and functioning water treatment plants and a decent separation of wastewater and storm water are obvious solutions. Artificial wetlands are an additional option for urban wastewater treatment [223,224] however, just with other open stagnant water bodies the risk of harboring disease vectors must be mitigated. Innovative, cost-efficient solutions applying the concepts of hydro-ecology [225], and "ecosystem-level bionics" principles (Wantzen et al. 2016, [13]) need to be further developed for the urban context.

The problem of excess storm water and extended periods of drought arises from surface sealing and can be addressed by reopening impervious (asphalt- or concrete-covered) areas; however, water quality issues need to be addressed. Purely technological solutions such as the gigantic storm water tanks as they were planned to compensate urban floods during the Rio de Janeiro Olympic Games [226] have a limited efficiency and do not refill the aquifer. Increased percolation of rainwater in unsealed areas (green-blue corridors, parks) can lower the risks of floods and droughts at the same time. In China, the concept of sponge city [227] is widely discussed. Launched at the end of 2014, the general objectives of the concept entail restoring the city's capacity to absorb, infiltrate, store, purify, drain, and manage rainwater and regulating the water cycle as much as possible to mimic the natural hydrological cycle [228]. Analyzing the local application of the concept, Chan, et al. [229] state that the finance and cost of sustaining sponge city program in larger areas in cities, the co-ordinations across bureaus, the public perceptions and support, the evaluation of effectiveness of sponge city program, etc., still remain big challenges.

Depending on the landscape morphology, a considerable part of the flood problem is caused by badly managed headwater areas far above the cities [230]. This part of the problem needs to be settled by reducing the crest of the flood wave upstream of the cities. In addition, climate change will require new areas to buffer floods and droughts, within the urban perimeter. Many buildings already built in high-risk flood areas will need to be dismantled to create floodways and multiple-use floodplains, on a similar scale to the restructuring of Paris by Haussmann in the 19th century (Wantzen et al. unpublished manuscript), as this is already claimed for green infrastructure [231].

Due to an intensive (and still increasing) agricultural and mining activity, and inefficient erosion control in the Global South, siltation problems are ubiquitous in urban streams and lakes. Here, too, a large part of the solutions must be found rather in the headwater regions than in the cities themselves (e.g., Wantzen et al. [177]). However, the dredging of streams and lakes is often unavoidable, and calls for careful deposition of the dredged material [175].

Morphological problems are ubiquitous, too, but have so far rarely been tackled in restoration projects in the Global South. In the city of Conception, Chile, natural geomorphological dynamics could be integrated into the urban stream restoration project, rather than fighting against them [230]. In the context of the Manuelzão Project (Brazil), banks were stabilized using geotextiles and green engineering with riparian bush species [166], similar to approaches now popular in the Global North. Considering the specific (and often extreme) hydroclimatological conditions in the Global South, further research on green engineering is needed, especially to develop plantation schemes and to establish hydrological thresholds between hard (concrete) and soft (plant) engineering options. Prolonged drought periods, siltation, and unauthorized harvest of bioengineering trees as firewood set further limits to this application. Mixed modelling of habitat requirements of target species and impacts of the human use of riverbanks may provide innovative planning tools for the choice of adequate morphological engineering (Zingraff et al. under review).

The use of the riparian zone has a specific dimension in cities of the Global South, as these river and lake margins are often used by marginalized people (see above). Whenever possible, riparian settlers should be brought into the project as this may strongly increase acceptance of the project.

All practical solutions need to be tailored to the specific local settings at the reach scale; however, considering the entire catchment. As an example, we describe here activities taken to restore the Baleares creek in Belo Horizonte, Brazil [142,166]. The major problems to be tackled in this stream were water pollution, sedimentation, lack of flow diversity, degradation of the riparian vegetation, flood risk to badly sited residents, but the creek itself had not been canalized. As a global measure, the entire catchment became connected to the sewage network (Figure 9). In the lowermost reach (1), the streambed was deflected because of the construction of a lateral street. The new streambed was built and covered by a rock structure, which gave stability to channel and banks. Furthermore, it provided roughness (flow diversity) and permeability. The banks were recomposed with grass, bushes, and young trees. Further above (Reach 2), the channel was maintained in its original position; however, it was covered by a rock structure too. The left bank became stabilized with geotextile and bush species. Reach 3 was fenced and belongs to newly created Baleares park area where the streambed and floodplain were maintained in natural state, and riparian vegetation was restored. In the both sides of the bank, full width streambank contentions were constructed with rocks or concrete structure and a small bridge for walkers was installed. Reach 4 is a small tributary of Baleares creek, which was strongly polluted, causing severe health problems. During the restoration project, it became partly canalized (i.e., not restored), but the wastewater outflows were connected to the sewage system (improvement of water quality). Reaches 5 e 6 are the headwater area outside the Baleares park and it is closed to public visitation. These reaches were maintained with streambed and banks in natural state, and riparian vegetation was restored too. Reaches 3, 5, and 6 had people removed. The riparian vegetation was restored, to increase its absorption capacity for rainwater, to reduce flood and drought effects.

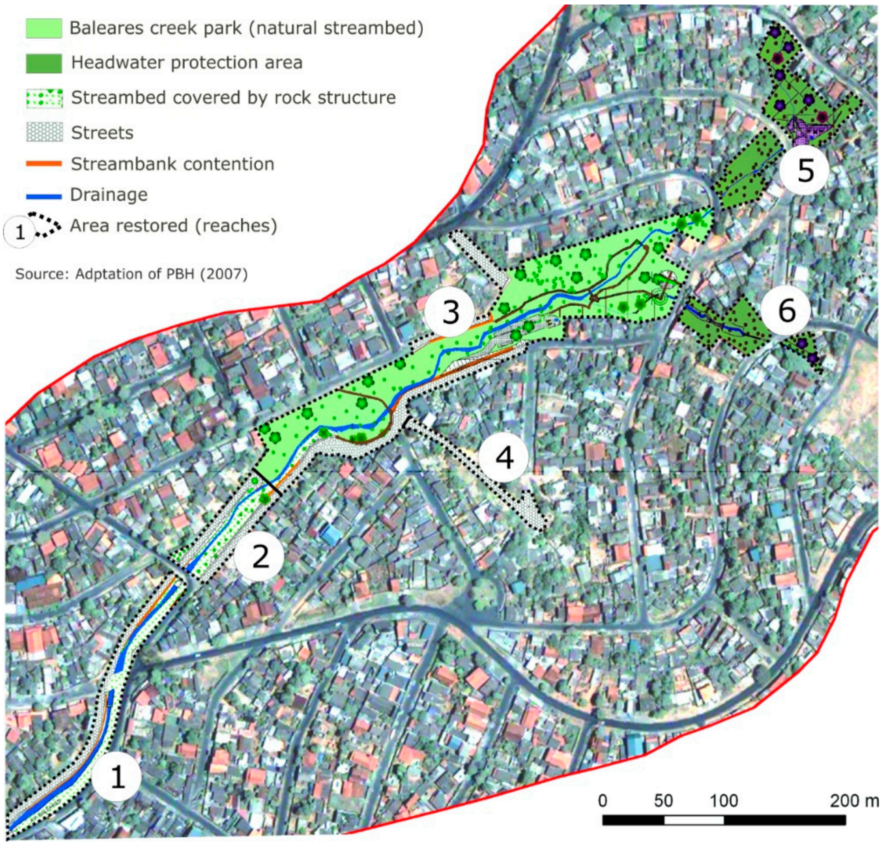

Figure 9. Map of the Baleares creek restoration in Belo Horizonte, Brazil, an example for a reach-wise urban stream restoration. Graph by Diego Rodrigues Macedo.

8. Conclusions and Outlook

Clearly, the best option for urban hydrosystem management is to preserve the existing water bodies and their riparian zone in the rapidly changing areas of the cities and their periurban zones. This requires the acknowledgement of their values, and a development of a “River Culture” to live respectfully and in harmony with those water features. As the rapidly occurring urban sprawl often overruns natural objects, and the low appreciation of the (already polluted) hydrosystems by the population prevails, this is not a simple task. Solutions are needed to define transition zones between intensive urban use and natural reserves, and to avoid that these are considered just as "yet uncovered" open space without any legal status. One option is to underline their ecosystem services such as flood protection and blue-green infrastructure [201]. In some cities, e.g., Kinshasa, the capital of the Democratic Republic of Kongo, it is still "not too late" to protect the extensive riparian zones from urban sprawl, as they have remained uncovered by concrete buildings due to natural flooding [232].

Most urban streams and rivers of emerging/tropical countries; however, are envisaging a pandemonium of environmental stressors combined with insufficient legal reinforcement and lacking collaboration among the responsible authorities. We have highlighted several positive examples to show that solutions are feasible—despite the dramatic situation. We hope that the synopsis of very different projects will help to transfer solutions from one site to another, and we strongly encourage the build-up of a global database for urban hydrosystem restoration. In the current situation, problems that have accumulated over decades need to be solved in a few years. As urban hydrosystems of the Global South have different characteristics from those of the Global North, novel, interdisciplinary solutions, integrating science and design, are needed. The creative potential of the riparian dwellers should be used to develop an urban hydrosystem identity, which may later spread over the entire city, integrating green and blue spaces [199].

Two elements appear to be specifically important for the success of restoration projects in the Global South: a broad acceptance and motivation of the local population that go beyond the purely "ecological" arguments, e.g., public healthcare or cultural linkages with a healthy ecosystem ("River Culture"), and the offer of feasible solutions of (often poor) people that have settled on river banks and wetlands.

Urban hydrosystem management must deal with this diversity of and interactions between problems, without losing from sight future trends [233]. Thus, the question we must deal with is "How to solve these environmental problems and at the same time integrate considerations on how to avoid them in the future?" Some of the concepts we show case in our proposal may support this aspect of sustainability. The River Culture Concept (Wantzen et al. 2016, [13]) provides some general suggestions on how to harmonize humans and rivers, to preserve biological and cultural diversities in riverscapes and to tackle the mentioned problems on a geopolitical and catchment perspective, rather than from urban/regional planning alone. If urban hydrosystems become a central element of the urban identity, the urbanites will be more sensitive about the environmental health of these ecosystems, and act earlier as before. Moreover, cities can then become the driving force for environmental restoration outside the urban perimeter, e.g. for headwater protection, or dam removal projects.

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