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RESEARCH ARTICLE

The hydrosocial cycle in rapidly urbanizing watersheds

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Abstract Water is the essential resource of the 21st century where innovative water management strategies are needed to improve water security. This paper examines three case studies that exemplify the global water crisis, situated in rapidly urbanizing watersheds: Nairobi River Basin, Kenya; Citarum River Basin, Indonesia; and Addis Ababa River Basin, Ethiopia. Each of these watersheds are implementing large-scale water management strategies inclusive of local communities and regional governments to address water quality and waste management issues. The hydrosocial cycle (Linton, 2010) provides a framework to investigate the social, technical and physical aspects of water flows. Using the hydrosocial cycle as an organizing framework, these watersheds are examined to highlight how water security underpins water justice. The issues of gender and inequity are often overlooked in larger policy, development, and infrastructure discussions where technical requirements, restoration management, and engineering solutions obscure power inequities. Projects are compared to assess the implementation of the hydrosocial cycle through a discussion of social power and structure, technology and infrastructure, and the materiality of water in each location. This comparison reveals a dependence on large-scale technical projects with limited community engagement, and a need for science-based river restoration management. Recommendations are provided to improve and address holistic water management.

Keywords hydrosocial cycle, urban watersheds, water security, Citarum River Basin, Addis Ababa Basin, Nairobi River Basin

1 Introduction

Water has been characterized as the “oil of the 21st century” (Liveris, 2008) where water is the driver of local to regional economies and assured supply determine future well-being. We are in the midst of a global water crisis defined as the lack of adequate water to provide basic needs that include water supply of a quality to support life as well as strategies to ensure improved sanitation for human populations (World Economic Council, 2019). Similarly, environments around the world are water-stressed due to climate change resulting in loss of biodiversity, stresses on freshwater ecosystems, and impacted water quality (Srinivasan et al., 2012). This interlinked global water crisis is variably distributed reflecting unique geographies, governance strategies, and adaptive capacities of both place and people.

This paper examines three case studies that exhibit characteristics of the global water crisis in rapidly urbanizing areas: Nairobi River Basin, Kenya; Citarum River Basin, Indonesia; and Addis Ababa River Basin, Ethiopia. The case studies are located in high priority countries for implementing this strategy due to their status as developing countries, increasing population, and expanding urbanization (Table 1). These case studies are a result of activities of the US Water Partnership, a cooperative program with the US Department of State. Water experts are sent to high-priority countries to address critical water challenges through advice, consultation, and interaction with key host-country stakeholders (available at U.S. Water Partnership website). The US-GWS’s objectives are to promote access to safe drinking water and sanitation; encourage sound management and protection of freshwater resources; reduce conflict by promoting cooperation on shared waters; strengthen water sector governance, financing, and institutions (US-GWS, 2017). Each of these watersheds are implementing large-scale water management strategies inclusive of local communities and regional governments to address water quality and waste management issues.

Three critical characteristics of the global water cycle are evident in these watersheds. First, water security is a central aspect of these water management strategies. Water security refers to “the capacity of a population to safeguard sustainable access to adequate quantities of and acceptable

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Table 1 Population metrics in 2018—case studies

Country	Population	Urban population growth rate	Percentage (%) urban population	Population of capital city (in millions)
Ethiopia	109224559	4.79%	20.9%	Addis Ababa: 4.592
Indonesia	267663435	2.47%	55.8%	Jakarta: 10.639
Kenya	51393010	4.24%	27.4%	Nairobi: 4.556

Sources: World Bank Population Indicators: available at World Bank website; CIA World Factbook: available at CIA website

quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water related disasters, and for preserving ecosystems in a climate of peace and political stability" (Bigas, 2013). Second, these projects are closely aligned with the Sustainable Development Goals (SDG) 6 (clean water and sanitation) and 11 (sustainable cities and communities) (available at United Nations Foundation website). SDG #6 identifies the need for clean water and sanitation. By 2050, projections indicate that one in four people will experience chronic water shortages (available at United Nations Development Programme website). SDG #11 emphasizes the need to promote sustainable cities where the rate of urbanization requires increasing attention to services and utilities (e.g., water provisioning and treatment), particularly in dense peri-urban settlements, cities and towns (Table 2). Third, rapid urbanization is the hallmark of the early 21st century. By 2050, 70 percent of the world's population will live in urban areas needing access to water and sanitation infrastructure on a scale never before seen (Florida, 2018). The current rapidly urbanizing world is representative of uncharted human territory in water management, socio-political organization, and economies.

Using the hydrosocial cycle as the lens of analysis, these watersheds are examined to highlight how water security underpins water justice. Water justice integrates social and environmental justice to address issues related to distribution, allocation, equity for humans and between humans and the environment (Patrick, 2014; Sultana, 2018). These case studies are in areas with vulnerable populations where informal communities and specifically women and children bear a disproportionate impact of water need and are indicative of asymmetrical power relationships. The issues of gender and inequity tend to be overlooked in high-level policy, development, and infrastructure discussions where technical requirements, restoration management, and engineering solutions obscure power inequities (Taylor and Sonnenfeld, 2017; Sultana, 2018).

2 Adapting the hydrologic cycle

There are multiple conceptual models for understanding flows of water. Several examples of the evolution of an integrated water cycle reveal the complex interrelationships between humans and the environment. There is a rich history of the hydrologic cycle from Aristotle in the 4th century, Chinese scholars in the 9th century, and da Vinci in the 15th century that seeks to explain the flow of water (Nace, 1975; Lawford and Unninayar, 2017; Duffy, 2017). In the 16th century, Palissy defined the cyclical nature of water as "the role of processes such as precipitation, evaporation, condensation, infiltration, surface run-off and both groundwater storage and discharge (Karterakis et al., 2007). In early 1900s, water balance equations were constructed to measure water yield for water management with a specific emphasis on developing irrigation schedules (Shiklomanov, 1993). In the 1940s, Thornthwaite and others developed soil-water budgets using climate stations, precipitation, and temperature for an analysis of global and regional climatic classifications (Thornthwaite, 1948) to further inform water planning and agricultural production. These early examples of measuring the water cycle reflect an increasing understanding of the complexities of the hydrologic cycle, the need for locally derived climate and water data, and the importance of water measurements in management. Since the 1970s, computer-based models contribute in multiple ways for such analyses as: demand forecasting, water distribution, groundwater, watershed runoff, river and reservoir operations (Wurbs, 1994). These models are critical for providing the basis of

Table 2 Access to water—case studies

Indicator	Ethiopia (2015)/%	Indonesia (2015)/%	Kenya (2015)/%
Share of population with access to improved water	93.1	87.4	63.2
Share of population with access to unimproved water	57.3	94.2	81.6
Share of urban population with access to improved water	93.1	97.2	81.6
Share of urban population with access to unimproved water	9.6	5.8	18.4

Sources: Our World in Data: available at Our World in Data website; CIA World Factbook: available at CIA website information for sound water management. However, such models prioritize the geophysical parameters of water flows overlooking the intricacies of the social circumstances of water management for human purposes.

Efforts to address the close coupling of human, economic, and political aspects of water management yield other models. Integrated Water Resources Management (IWRM) laid the groundwork defined as: “a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems” (IWRM, 2009). In the early 2000s, several models explicitly measure the intersection of human, physical, and economic processes. Some examples include the water footprint, eFlows, and ecosystems services. In 2002, Hoekstra coined the term “water footprint” as a metric to measure the amount of water consumed and polluted to produce goods and services (Hoekstra, 2011). Environmental flows (eFlows) refers to the equitable distribution of and access to water and services provided by aquatic systems. EFlows are central to sustainable development by allocating investment not only for the built environment, but also for ensuring protection for downstream ecosystems and communities (Hirji and Davis, 2009). Ecosystem services are the benefits human derive from the natural environment and ecosystems (i.e., timber, fisheries, freshwater, natural pollination). The Millennium Ecosystem Assessment describe ecosystem service categories (i.e., supporting, provisioning, regulating, and cultural services) with assigned economic values to assist decision makers in managing and planning of water resources (Millennium Ecosystem Assessment, 2005). In 2014, Sivapalan et al. described socio-hydrology as an approach to integrate the human dimension into water science research through an examination of flows, stocks, and feedbacks between human and water systems. Clark et al. (2017) apply a model of hydrosocialities- water as transformed in place-based water histories with diverse water knowledge practices. These models recognize the recursive relationship between humans and water using new methods and integrative tools that use remotely sensed imagery, big data, and household surveys.

Linton’s volume on the history of the hydrosocial cycle (2010) has invigorated a healthy examination of the societal context of how we define, produce and interact with water. Embedded within the relationship between water and society are the power relations of governance and the politics of water (Linton and Budds, 2014). The hydrosocial cycle is an analytical tool to investigate the social aspects of water flows (Fig. 1(a)). For this analysis, the hydrosocial cycle is used to discuss “water” in its myriad forms across three cases studies applied to urban water (Fig. 1(b)). “Water” (in the center of the diagram) refers to the type of water, in this instance, urban water. H_2O is defined as the materiality of water for the type of water under discussion. Urban water has specific requirements to meet the needs of urban areas where source water, water flows in the city, and its metrics inform the hydrosocial cycle. Technology/infrastructure are the ways in which the landscape is redesigned to provide water to urban areas necessitating the particular social power/structure determined by policies, governance, regulation, and community engagement.

Urban areas are one aspect of the hydrosocial cycle that exert significant influence and impact on river systems and watersheds. The need to adapt water to the urban environment fundamentally changes and disrupts the hydrologic cycle. For example, construction of impervious surfaces increase runoff and add pollution to river systems (Frazer, 2005); urban heat islands form due to loss of vegetation and construction of roads and buildings increasing ambient temperatures (Imhoff et al., 2010); rivers are canalized and paved over to allow for urban expansion losing floodplains and riparian zones that provide valuable ecosystems services (Cox, 2017). Coupling the altered urban hydrologic cycle with trends in global climate change reveals the vagaries such places experience. Anthropogenic climate undermines the foundation of many water planning approaches — stationarity, the notion that natural systems change within a range of variability. Milly et al. (2008) stated “stationarity is dead” and identified the need for new models to optimize water

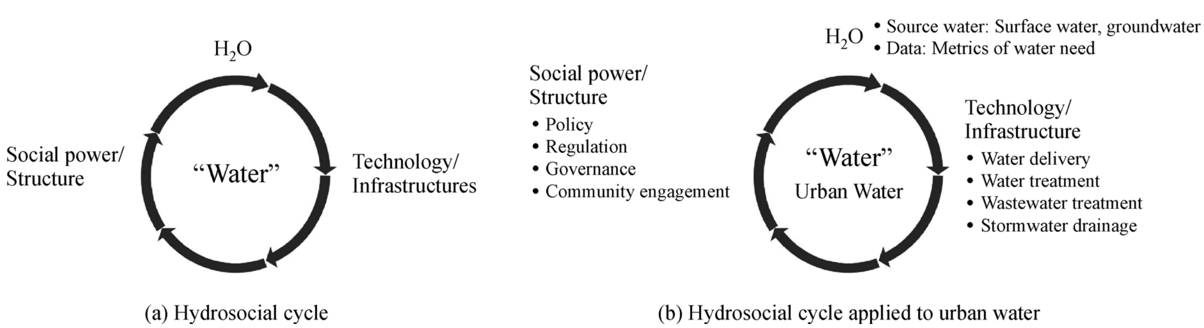

Fig. 1 (a) The hydrosocial cycle (Linton and Budds, 2014); (b) applied to urban waters.

use. The impacts from climate change further exacerbate the functioning of the hydrologic cycle through acceleration and the resulting weather whiplash and extreme storms many locations are experiencing (Loecke et al., 2017; Yeh and Wu, 2018).

The hydrosocial cycle provides a framework to examine the production of urban water through human redesign and reorganization highlighting hydrosocial relationship. For example, in these case studies, access to water in urban environments are measured as physical scarcity, population pressures, technical limitations or a combination of all. However, the social context reveals a complex landscape where low-income groups are deprived of water services due to issues related to land tenure, low political priorities, and government corruption (UNDP, 2006; Budds and Loftus, 2014). Examining urban water through the lens of the hydrosocial cycle allows us to consider how power relationships inform water planning and determine ways to improve water equity.

3 Methods: case studies in Kenya, Ethiopia and Indonesia

An assessment of these projects was undertaken through 1) field visits (Nairobi, Kenya, June 16–23, 2017; Jakarta, Indonesia, September 14–22, 2018; Addis Ababa, Ethiopia, May 2–12, 2019; 2) document review (i.e., water planning documents, city reports, plans and presentations, news articles); and 3) stakeholder discussions to determine needs, gaps and next steps for integrated watershed management. Field visits included visits to the headwaters, river reaches within city centers, and water facilities (i.e., water quality laboratories, wastewater and water treatment plants). Extensive and numerous planning documents describe these projects as multi-sectoral including both governmental representatives and local communities to implement the project and provide oversight: the Citarum River Basin Road Map Coordination and Management Unit (RCMU) Project (2007–present); the Nairobi River Basin Rehabilitation and Restoration Programme (1999–present), and the Addis Ababa Rivers and Riversides Development Project (2016–present). Stakeholder discussions with local community members were coordinated by US Embassy personnel and project leadership. Open-ended discussions took place during field trips with on-site community representatives; for each case study site, there were three to four community meetings. Representatives included local leaders, women's groups, youth organizers, and recycling center managers with roundtable discussions that included 15–20 people. Translation was provided by Embassy personnel. Meetings with city officials and technicians included presentations on the status of the project and discussions on next steps in planning and implementation.

3.1 Nairobi River Basin Rehabilitation and Restoration Program (NRBRRP)

The Nairobi River Basin Rehabilitation and Restoration Program aims to rehabilitate, restore and sustainably manage the Nairobi River Basin (NRB) to provide improved livelihoods, enhance environmental quality and values through well-regulated economic and recreational ventures. The NRB of Kenya is comprised of three rivers: Ngong-Motoine, Nairobi and Mathare that join River Athi. The basin covers an area of 700 km^2 and has an altitude ranging between 1500 and 1800 m. The basin hosts a population of about 4 million with projections showing an increase to 5 million by the year 2025 (Krhoda, 2002; Nyika, 2017; Kenya Water Resources Management Authority, 2017). The NRBRRP is a subset of the Athi River Restoration Program that is a regional and national effort to manage and restore rivers from the Ngong Hills to the Indian Ocean.

The NRB suffers from numerous issues that span the watershed: riparian encroachment by informal settlements, river pollution and contamination by farming and industry, direct dumping of waste and sewage all which adversely impact water quality and threaten adequate water supply. Rapid urbanization exerts immense pressure on the declining water resource, limited utility services, and the fragile environment. Approximately 56% of the city residents live in 46 highly congested informal settlements located along the Nairobi River banks (Kenya Water Resources Management Authority, 2017). Industrial, medical and commercial waste contribute to the spread of water-borne diseases, loss of livelihoods, loss of biodiversity, effects of toxic substances, and reduced potential to utilize the river as a resource (i.e., water supply, recreational site).

The objective of the NRRP program is to develop a multi-stakeholder initiative inclusive of the Kenyan Government, development partners, the private sector, and civil society to rehabilitate the watershed. This restoration program builds on previous initiatives beginning in 1999. The current program emphasizes stakeholder engagement for collaborative water management to include water user associations, youth and women's organizations, and residential associations. The combination of institutional changes (i.e., the Constitution of Kenya 2010, Water Act 2016, Nairobi Integrated Urban master plan) provide a context that facilitates and supports the NRBRR initiative. Additionally, project management is facilitated through a number of committees that represent the various stakeholders that include ministries, communities, non-governmental organizations and universities.

Using the hydrosocial cycle framework, "water" is defined as a healthy river in an urban setting (Fig. 2). Within the structure of the NRRP, H_2O is comprised of the river reaches across the city where point and non-point

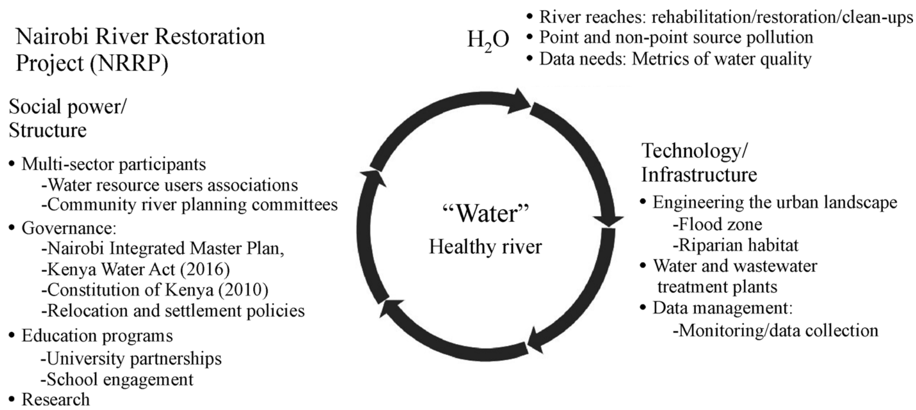

Fig. 2 The hydrosocial cycle of the Nairobi River Restoration Project. "Water" as a healthy river.

source pollution and contamination are identified. The importance of water data to inform and track the H_2O condition is essential for long-term water management. Technological solutions and state-of-the art infrastructure are needed to address both wastewater and water treatment facilities. Currently, approximately 50% of Nairobi's population has access to piped water (Reality Check Team, 2019). Engineering solutions are necessary to recreate flood zones and reintroduce riparian habitat to reconfigure the urban landscape to accommodate ways for the river to "do its job." In turn, these activities necessitate policies for relocation, settlement and improvement of services to informal communities. In the past decade, governance structures have been reconfigured in Kenya. For example, the Constitution of Kenya makes access to water a basic right. Government decentralization and reorganization established priorities for community-level participation in resource management planning through Water Resource Users Associations (Kenya Water Resources Management Authority, 2017). Efforts to empower the local community are embedded in educational efforts to teach young people about the benefits of healthy rivers, engage them in clean-up activities, and initiate behavioral changes about waste management.

3.2 Stakeholder engagement and rehabilitation of the Citarum River Basin (RCRB)

The Citarum River in western Java is one of the most polluted waterways in the world yet is of critical strategic importance to Indonesia (Bukit, 1995; Tarahita and Rakhmat, 2018). It is the third largest river in the country and provides Jakarta with 80% of its raw water supply (Coordinating Ministry for Maritime Affairs, 2018). The watershed population is approximately 27 million. The Citarum River is organized into three segments: the headwaters in Mount Wayang in Bandung District; the middle section with three hydroelectric producing reservoirs (Saguling, Cirata and Jatiluhur), and the lower river that flows to the Java Sea. The headwaters and upper watershed experiences pressure from increasing agriculture, deforestation, and population increases. The three dams located in the middle stretch of the Citarum River Basin (CRB) capture sediment from upstream deforestation. Aquaculture in the reservoirs have contributed to poor water quality impacting local fisheries. Throughout the basin, populations are experiencing rapid urban growth with increased waste from domestic and industrial sources and inadequate wastewater treatment facilities. The lower watershed experiences sedimentation, mangrove removal, and subsidence.

The Citarum River Basin represents a challenging situation where successful solutions are measured in incremental steps. The Presidential decree — "to clean the river in seven years" focuses attention on solutions with immediate results (Presidential Regulation Number 15/2018). A key method to address problems in the CRB is through the use of military units to work on large scale, heavy machinery projects in close coordination with local communities. Such projects include waste removal, channelization of the streambed and revegetation, sediment removal, landfill reclamation, reforestation, and relocation of village households to provide a buffer to springs and upper headwaters. Water quality is compromised in many areas and local communities are concerned with human health issues (i.e., stunting in young children). These projects are coordinated through the formation of 220 EcoVillages across 22 river sections. The Eco-Village approach empowers local communities through establishing neighborhood recycling centers, village beautification efforts, and participation with military unit clean-up efforts.

"Water", within the hydrosocial cycle analysis, is defined as river rehabilitation (Fig. 3). The Citarum project is longitudinal in scope from the headwaters to the mouth and targets specific issues of each sector. River rehabilitation starts at the headwaters. The headwaters support villages and agriculture for West Java as well as provide

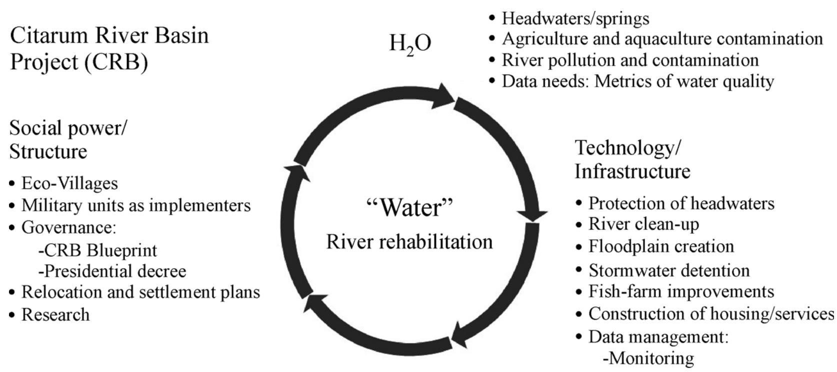

Fig. 3 The hydrosocial cycle of the Citarum River Basin Restoration Project. "Water" as river rehabilitation.

water for downstream communities including the mega-city of Jakarta. Efforts in the headwaters include a protected area to safeguard water quality and cultural values as well as promoting ecosystem services. Springs are identified and mapped with plans to relocate households and commercial enterprises by creating a buffer for spring protection. Reforestation efforts are being undertaken with partnerships established with non-governmental organizations and educational units to monitor and map these activities. The dams on the central Citarum had a robust fishery but has since succumbed to pollution and contamination. Many fish cages causing severe pollution and water contamination have been removed leading to improvement in water quality.

The large-scale projects of relocation, reforestation, and infrastructure construction are overseen by the Indonesian military. Many Citarum river reaches are choked with trash (e.g., garden waste), hazardous materials from industry, garbage (e.g., organic waste) and raw sewage. Large scale waste clean-up is being conducted by military units; but it is uncertain where waste is off-loaded due to the limited number of landfills. Military commanders oversee projects in partnership with local experts. For example, foresters work closely with military units in the upper watershed. Women's groups and local leadership coordinate closely with the military units embedded in the community with the goal of promoting healthy environments.

3.3 Addis Ababa River Restoration Project (AARRP)

The Addis Ababa River Basin is of critical strategic importance to Ethiopia. As the capital city, Addis Ababa is the gateway to the country and aims to improve the cityscape in innovative ways. Issues in the basin cross multiple sectors (agriculture, commercial interests, industry, and development) impacting water resources. Addis Ababa sources 98% of its water from the surrounding regional state of Oromia (AAU, 2016). This water supply is insufficient to meet rising demand from the rapidly growing population of approximately 4.9 million (Table 1; CIA World Factbook, 2018). Throughout the basin, communities contend with waste and polluted river systems due to domestic and industrial sources as well as increasing urban populations where wastewater treatment is limited or non-existent. Only 12% of the city's wastewater is treated before returning as effluent to rivers (AAU, 2016).

The AARRP aims to restore the river system across Addis Ababa to a fully functional river that will provide connectivity across the city for open space, ecosystems services, and improved community well-being. The project is envisioned in a series of five phases across an elevational gradient reaching from the headwaters to the lower reaches of the city's main reservoir. This is a high priority project for the current national government and city agencies. Three river systems (Big Akaki, Kebana, and Little Akaki) draining the city have a total of 119 km in length. The Kebena sub-basin (a 12 km reach of the Kechenee River) is selected as the pilot phase of the AARRP. The Chinese government and its corporations are completing this initial phase. The project connects a series of parks and open space to serve as stormwater detention areas and provide open space for river rehabilitation and recreation. The initial phase focuses on the city center and identifies key areas for river restoration in areas with numerous informal settlements and commercial areas. The second phase concentrates on waste and watershed management facilitated by a series of studies to characterize the water planning needs. The final phase builds on the Addis Ababa Master Plan to create a green city and global diplomatic hub (Ministry of Water, Irrigation and Energy, 2019).

The AARRP focuses on a three-year initiative "Beautifying the Sheger," and "greening" the city center (Fig. 4). In 2017, academic work from the University of Addis Ababa provided baseline information about the river and describes the environmental and social conditions of the watersheds in preparation for the restoration project (Addis Ababa Rivers Buffer Determination; Rivers Catchments and Riversides Vegetation Management, Addis Ababa Rivers Pollution and Sanitation Study). A combination of river clean-ups, restoration efforts, and monitoring sites are necessary to coordinate a comprehensive river manage-

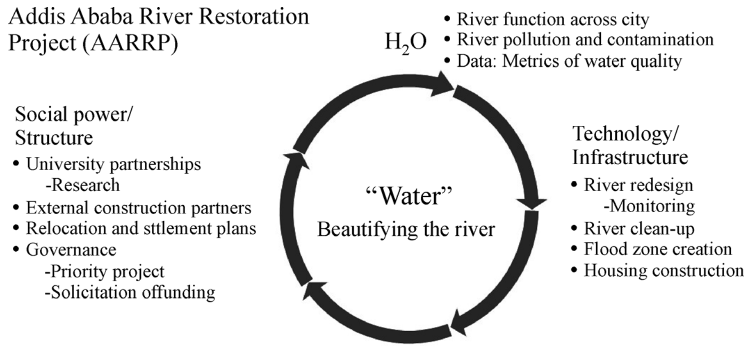

Fig. 4 The hydrosocial cycle of the Addis Ababa River Side Restoration Project. "Water" as beautifying the river.

ment strategy. The project includes the need to relocate informal settlements building on Ethiopia's resettlement plans and construction of housing units in the city periphery. Preliminary research includes a Resettlement Action Plan for the residents of the Kebena River (2017). However, concerns with extending the city beyond its current limits have sparked conflict with local communities and increased ethnic tensions (Gardner, 2017).

4 Discussion: hydro-social cycle analysis of large-scale urban water projects

These three case studies are indicative of numerous large-scale projects undertaken around the world. Often developed in conjunction with international partners and contributions from development banks, these projects are envisioned to restore degraded river systems in urban environments. These projects reflect a common set of issues (e.g., inadequate waste management and river pollution), a common set of methods to resolve the problem (e.g., large-scale river restoration plans that include community engagement, baseline data collection for monitoring, and identified demonstration projects), and common problems that inhibit change (e.g., societal behavioral patterns with respect to waste management, shifting political landscape, rapid informal urban growth, inadequate water treatment infrastructure). The cyclical nature of the hydro-social landscape makes explicit linkages between social power, policy instruments, science, and technology and reveals how water management is often disjunct between different societal sectors.

4.1 H_2O

H_2O refers to the materiality of water — functional rivers, streams, and sub-surface water flows foundational as a water resource for city water systems. However, the Nairobi, Citarum, and Addis rivers exemplify extremely degraded and dysfunctional river systems. Rapid urbanization, environmental degradation, and climate change have exerted pressure on declining water resources, limited utility services (i.e., water supply and wastewater treatment), and increasingly fragile environments. The compromised nature of the water resource is a driver for the rest of the hydrosocial cycle where the technological, political, and social responses must address an overwhelmingly broken river system. Efforts to restore and rehabilitate river functionality are increasingly linked to granting a river rights — the right to restoration, the right to legal standing. Such river rights have been granted in India, New Zealand, and Ecuador (Tanasuscu, 2017). For example, Ecuador's Constitution states that nature "has the right to integral respect for its existence and for the maintenance and regeneration of its life cycles, structure, functions and evolutionary processes" (Ecuador Constitution, 2008).

Recognizing the fundamental rights of a river are inextricably linked to increasing awareness of environmental rights, the benefits from a functioning river system and the advantages of a sustainable environment. Each of the case study countries have environmental and water law that explicitly address the right to clean and safe water for human communities (i.e., Kenya Water Act, 2016; Constitution of the Federal Republic of Ethiopia Proclamation No. 1/1995; Indonesia 2019 Water Resource Law). However, these countries do not have policies that directly focus on the rights of a healthy, functioning river.

4.2 Technology/Infrastructure

These river restoration projects are largely dependent upon a technological approach: re-engineering river channels across the city landscape, re-sculpting riparian areas, and removing waste (i.e., domestic and industrial solid waste). These structural improvements provide high-visibility outcomes and short-term improvements. For example, efforts to clean up the Citarum River have focused on removing solid waste dumped into the watershed. The second phase of the AARRP focuses on rehabilitating sewerage systems, stormwater drainage infrastructure, and technical measures to augment flows and stabilize channels. The Nairobi River Restoration Project identifies developing an integrated solid waste management system and rehabilitating the Nairobi dam.

All three case studies are constructing demonstration projects to provide a “proof of concept” for the larger river restoration projects. A reliance on technical solutions and engineering projects yield tangible results where change is overlaid on a landscape where underlying social issues are not adequately addressed (i.e., resettlement plans). These demonstration projects are: rehabilitation of a 2.5 km stretch in central Nairobi; upper watershed restoration for land, springs, and forests and community resettlement in Bandung, West Java — the headwaters of the Citarum River; and improvements of 12 km of riverfront traversing the city center of Addis Ababa.

In the hydrosocial cycle framework, Technology/Infrastructure includes projects and activities reactive to degraded river systems. The need for improved wastewater treatment and sanitation is recognized by city and community leaders, but these improvements are not an explicit project component due to being capital intensive and requiring multiple facilities to serve rapidly growing urban areas. The demonstration projects are an incremental step in improving specific river reaches. but are not integrated into overall urban planning to address upstream/ downstream relationships. Engineering projects give decision makers broad discretionary power for river redesign projects based on limited science-based foundations. The CRB project depends on military leadership to implement channelization projects and housing resettlement plans on abandoned landfills with no scientific studies to assess river health or soil conditions. The AARRP demonstration project is carried out by Chinese contractors with no integration with the numerous scientific studies developed by the Addis Ababa University Center for the Environment. Large-scale engineering projects create an unequal relationship with local communities where technical complexity obscures power relations embedded in engineering and technical solutions that often eclipse local knowledge and needs (Transparency International, 2008).

4.3 Water data

Water data are foundational to water planning. Water data are comprised of water measures, ecosystem services, and human population needs. In the hydrosocial cycle a holistic view of water data creates the basis for comprehensive water planning. Some water data are collected in these river basins but are inadequate for long-term planning (i.e., inadequate gauging stations, limited data collection, broken systems for data collection). All projects need improved baseline water data for long-term water management, development, and planning. The existing data are hard to find, often limited, disbursed among different governmental agencies, and not easily integrated for water assessments. There are few water laboratories to meet the requirements for adequate water quality testing. Data are not organized to provide for easy access to results by other agencies or stakeholder groups.

Additionally, there is inadequate data on city demographics, particularly informal settlements and water need and use. Understanding growth patterns, access to services, and the location of informal settlements are critical to urban planning and specifically water access (Shores et al., 2019). Ethiopia, Indonesia and Kenya are signatories to the UN Human Right to Water and Sanitation (Resolution 645/ 292, 2010). Implementing policies and programs to assure access to water need explicit data on human populations and city water resources. However, data development and management infrastructure are not identified as an explicit need and lack targeted funding.

4.4 Social power/Structure

Community participation and engagement is an explicit goal of these river basin projects. The primary reason for US-GWP to invite the author was to conduct an assessment of participatory and engagement activities of stakeholders. An initial observation of these projects is that community engagement is largely limited to working with youth groups and schools on river clean ups and tree planting. Other community activities differ across the three project sites. In Nairobi, community engagement is facilitated through the Water Resource User Associations. These are community organizations that manage different river reaches within the watershed, facilitating river clean up and vegetation planting in riparian zones. The WRUAs are variably active — some are better organized than others and many have women in leadership positions. In the Citarum watershed, Ecovillages are responsible for specific river reaches and have multiple obligations for trash clean up, establishment and management of community trash banks, recycling, and tree planting. In Addis Ababa, preliminary outreach and research has been undertaken by the University of Addis Ababa. A community survey was undertaken to assess implementation of resettlement strategies and discuss concerns with inhabitants of informal communities.

Community engagement remains a challenge due to fundamental issues raised by community partners that include distrust of government, lack of transparency in decision making, and high levels of corruption across government sectors and industry. Efforts to manage river systems reveal governmental failure due to inadequate community engagement and limited consultation and communication to improve transparency and address concerns over corruption in the water sector (Jenkins, 2017). The failure for early engagement and communication with local partners is in part due to political expediency and election schedules. Specifically, both the

AARRP and RCRB identify a short timeline for meeting deadlines linked to the next election cycle.

Women and water in urban environments are an under-examined area of study (Thompson et al., 2017; Javorsky, 2019). With respect to these case studies, gender issues remain largely overlooked despite national policies that promote women's empowerment. Launched in 2008, Kenya's Plan of Action to implement the National Policy on Gender and Development has suffered from weak implementation and a lack of funding. Gender equality is enshrined in the Indonesian constitution requiring a quota system where political party representation must include 30% women, but gender mainstreaming lacks sufficient funding (Bhardwaj and Dunstan, 2019). Updated in 2006, Ethiopia's National Action Plan on Gender Equality provides guidance for improving women's livelihoods and representation in decision making across all sectors in Ethiopia (MOWA, 2006). Similarly, to the Indonesia and Kenya case studies, Ethiopian implementation for gender equity has lagged due to funding limitations. Women's representation is largely perfunctory and lacks funding to implement efforts to support women in critical roles as defined by these national policies (Sever, 2005; Thompson, 2017).

Women have limited leadership representation across the three case studies; they are members of Kenya's WRUA, and Indonesia's Ecovillages. In Ethiopia, women are part of technical teams in the various government offices. This representation is largely circumscribed by how the projects are implemented — demonstration projects are composed of technical personnel, engineers, and foreign contractors where there are few women participants. Women remain largely absent in most upper level decision-making roles. However, women's organizations and youth groups plan activities such as river clean-ups to engage the local community groups and schools.

The hydro-social cycle provides a framework to examine the relationships between policy, river redesign, and relocation of people. The greening of the urban landscape means that people will have to move. The Indonesian government built new housing for people living too near to headwater springs in the Citarum headwaters. The government of Addis Ababa has undertaken construction of condominiums to accommodate people forced to move from the city center to make way for high-rise buildings and river restoration (Gardner, 2017). Engagement with communities in Nairobi include discussions on plans for resettlement and construction of commercial kiosks and housing. Removing informal settlements in city centers create gentrified, globalized landscapes (i.e., high rise apartments, hotels). People are moved to peripheral areas making it difficult to get to commercial centers, work sites, and breaking up community networks. Resettlement is a difficult task that needs to engage local people and assure their participation in the planning process and access to resources and services.

Recognition of the social forces that operate in informal settlements also need to be examined. In particular, the ability of the local community to create informal (and illegal) arrangements for their own water services through water connections and informal water services providers (Jenkins, 2017). Water delivery services may provide water of questionable quality as they operate outside of regulatory controls. Costs can be high for low quality services to poor city residents living in areas with non-existent land title. Entangled within this water provisioning structure are private/public partnerships where water and sanitation are linked to profit maximization and to locations adjacent to existing infrastructure which are easily accessible.

This hydrosocial analysis demonstrates the need for innovative water management strategies that are interdisciplinary, innovative, and comprehensive across multiple sectors and sensitive to the power relationships that drive water planning. Identifying and addressing feedback loops are needed to improve the urban waterscape. These case studies have elements of successful planning, but there is something wrong in the implementation — they need adequate funding, equitable partnerships in oversight, community engagement, and long-term commitment.

5 Conclusions and recommendations

Urban water systems create their own ecology where rivers are redesigned rather than rehabilitated or restored. River systems are adapted to the urban landscape creating a hybridized river system. This hybridized river system includes natural river reaches, diverted and channelized streams for flood management, stormwater drainage networks, subsurface flows of groundwater and piped water, water treatment systems, and effluent returned to rivers (Fig. 5). These rivers include reaches constructed to mimic

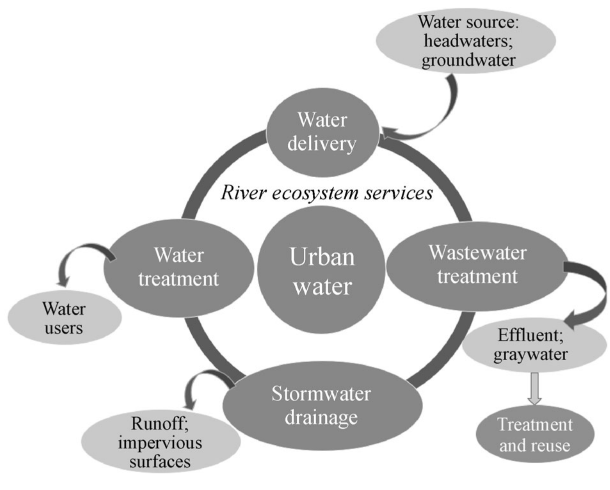

Fig. 5 Urban waterscape.

natural river services: floodplains and water recharge, re-establishing riparian habitat and enhancing green spaces. However, these are systems interrupted, where connectivity and feedback loops expose the complex urban waterscape that is increasingly difficult to manage as cities continue to grow at a rapid pace outstripping infrastructure and local resources.

These three case studies expose the need for broad consensus in water planning. Key recommendations to address the US Global Water Strategy are identified in Table 3. These recommendations encourage shared governance with local communities. Identification of common problems and goals through participatory approaches initiated early in the project planning ensure avenues for community engagement. Inclusion of communities in project implementation, data collection, and resource monitoring safeguard long-term, local investment. Coordination between communities and government offices to determine benchmarks, timelines, and deliverables demonstrate both accountability and responsibility. Coordination within communities is needed to ensure that women leaders are included in the decision-making process concerning water resources. Evidence shows that women's involvement in all stages of water planning, management, implementation, and monitoring is correlated with effective water systems (Sever, 2005; Javorsky, 2019).

Investments in partnerships that educate and employ youth are critical to water projects. Young people need to learn what is a functioning river and how the river can "do its job" in the cities in which they live. The youth are the sustainability drivers of the future. They are growing up in cities where rivers are paved over, choked with waste, and constrained by concrete channels. Field trips to healthy river, river clean-up activities, and demonstration projects to improve river health are ways to educate youth. Establishing student internships within laboratories and governmental agencies create opportunities for the next generation of water managers.

Sound scientific practices and research are foundational for these projects. Using technical expertise, building partnerships with experts within countries and across sectors are useful for developing and coordinating research efforts. River restoration projects need to be grounded in sound scientific approaches. Baseline data are needed to understand how hybridized rivers are managed, monitored and maintained. Conducting data assessments are necessary to identify existing data, determine data needs, and reveal data gaps.

The AARRP is the project that is closest to meeting its first phase in beautifying the Sheger. The central city redeveloped to accommodate a new series of river parks. This comes at significant cost to the informal communities of central Addis Ababa who have been relocated to peripheral locations on the outskirts of the city. New high-rise hotels and apartments are constructed in the city center

Table 3 Recommendations for the US Global Water Strategy

Recommendation	US Water Strategy	Characteristics
Assess institutional capacity	Engagement through diplomacy	-Communication and coordination between government sectors -Ensure local government engagement and support -Support local and in-country topical experts -Bottom-up contributions based on local knowledge
Conduct research to build a sound scientific base for solutions	Promote science, technology, innovation, and information	-Linkages to universities -Student internships in government offices -Integrated research activity -Recognize local experts
Data investment and development	Promote science, technology, innovation, and information	-Develop open data policy -Open access for sharing and transparency -Use of mobile tools, open source platforms, remotely sensed data
Establish technical partnerships	Promote science, technology, innovation, and information	-Develop urban water infrastructure: water supply, water quality monitoring, wastewater treatment, stormwater run-off -Establish data tracking for all aspects of water management
Identify how the river can "do its job" to enhance city	Invest in sustainable infrastructure and services	-Identify ecosystems services -Determine locations for flood management -Reintroduce riparian zones -Create river parks and green spaces
Facilitate community engagement and participatory activities	Strengthen partnerships, intergovernmental organizations, and the international community	-Identify and prioritize community issues -Community demonstration projects -Engage community in monitoring activities and data collection
Develop partnerships and create networks	Strengthen partnerships, intergovernmental organizations, and the international community	-School and university partnerships -Industry, business and school partnerships -Industry, university partnerships -Government, university, industry partnerships

and property values are increasing (Woldemanuel, 2020). The river is a hybridized channel of simulated river function (i.e., meandering streams with riparian grassy zones) and canals to capture and manage high flows. There are multiple benefits to be gleaned from this project, however, continuing to redesign the urban water system extends across the city. The University of Addis Ababa has written several reports that provide a baseline context for the larger scale project, but this information does not appear to be well-integrated into the current project planning. Concomitant with strengthening river function is improving community well-being. To complete the larger AARRP requires political commitment, large-scale funding, increased community engagement and collaboration across all sectors. River clean-up and rehabilitation is required at a massive scale occurring in sync with urban development planning. The 2017 Master Plan provides some guidance, but more importantly, is determining how to include communities in decision making, teach youth about healthy rivers, and letting the "do its job" is needed.

Solutions are cyclical not linear. These projects provide a blueprint for addressing critical water issues and understanding water justice. These projects exemplify the complex urban water system where the river provides connectivity with all communities and critical feedback loops between upstream and downstream water users. Successful solutions will be measured in incremental steps. While long-term investment is essential (20–30 years), short-term projects (2–5 years) are needed to demonstrate success through community engagement, education, and meeting benchmarks. Such solutions must be holistic; inclusive of policy objectives, gender mainstreaming, interagency collaboration, community participation, industry support, and technical applications based on sound science.

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