Making cities sustainable through rehabilitating polluted urban rivers:

Lessons from China and other developing countries

UN-HABITAT
FOR A BETTER URBAN FUTURE

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Foreword

The pollution of urban rivers is increasingly becoming a global challenge. It is estimated that more than half of the world's five hundred biggest rivers are seriously polluted. The United Nations World Water Development Report for 2017 reports figures to show that, on average, high-income countries treat about 70 per cent of the municipal and industrial wastewater they generate. That ratio drops to 38 per cent in upper middle-income countries and to 28 per cent in lower middle-income countries. In low-income countries, only 8 per cent undergoes treatment of any kind. The remainder finds its way into water bodies, threatening public health, food security, the environment and the availability of fresh water for consumption, which is significant in water-scarce regions in the developing world.[1]

The 2030 Agenda for Sustainable Development, adopted by world leaders at the United Nations General Assembly in September 2015 includes Sustainable Development Goal (SDG) 11 to "Make cities and human settlements inclusive, safe, resilient and sustainable". Goal 11 specifically commits countries to "*...reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management*" (target 11.6), and SDG 6 to "Ensure availability and sustainable management of water and sanitation for all". In this Goal, countries commit to "*...improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally*" (target 6.3).

In the New Urban Agenda, adopted at the third United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador in 2016, Member States committed to promote the conservation and sustainable use of water by rehabilitating water resources within the urban, peri-urban, and rural areas and reducing and treating wastewater. The Agenda 2030 for Sustainable Development and the New Urban Agenda reaffirm the commitment of world leaders to find sustainable solutions to restore the health of rivers and other water bodies. Increasing wastewater collection and treatment to restore the health of heavily polluted urban rivers is, therefore, an urgent global priority.

Delivering on these international commitments on wastewater management and the rehabilitation of water resources requires international cooperation and partnership. This publication is the product of an ongoing partnership between the United Nations Human Settlements Programme (UN-Habitat) and Tongji University. It presents lessons in technology and practices in urban river rehabilitation in China and offers measures and pathways to pursue the rehabilitation of heavily polluted urban rivers in developing countries. The rehabilitation project of the Suzhou Creek has proved that better management of drainage systems is key to controlling pollution discharged into rivers, both in dry and wet weather. Managerial and financial measures are also important in order to sustain a healthy environment for the whole river basin.

Developing countries may learn from China's experience in the rehabilitation of the Suzhou Creek, including the technical measures in sewage interception and pollution control combined with systematic planning and effective governance through a "river chief" system. Selected international case studies from the Mekong River Basin in the Greater Mekong Region in China, the Lake Victoria Basin in East Africa, the Densu River Basin in Ghana and Bethlehem City in Palestine are included in this publication to showcase the global nature of the challenge as well as efforts in wastewater management and rehabilitation of urban rivers. These examples also illustrate how UN-Habitat is actively engaged in supporting governments and diverse stakeholders to improve wastewater management and public open spaces in the urban environment.

> "By not addressing pollution at all levels of governance, countries risk not achieving the targets laid out in the SDGs."

1 WWAP (United Nations World Water Assessment Programme). 2017. The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris, UNESCO.

It is our hope that this publication will be a useful reference for those involved in the rehabilitation of heavily polluted urban rivers in developing countries. We further hope that this publication will encourage countries and cities to prioritize investments in wastewater management – which is often treated as an afterthought – in the urbanization trajectory. By not addressing pollution at all levels of governance, countries risk not achieving key SDG targets.

UN-Habitat and Tongji University are pleased to issue this joint publication and remain available to work with countries towards addressing diverse challenges associated with wastewater management and urban river pollution for the welfare of all urban residents.

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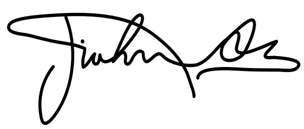

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Executive summary

Rehabilitation of polluted urban rivers is critical for the implementation of the New Urban Agenda and achieving the 2030 Agenda for Sustainable Development (Chapter 1).

The Chinese Government has prioritized environmental protection in the national strategy under ecological civilization and in recent decades, has achieved great success in restoring the urban water environment (Chapter 2). Their responses to pollution of urban rivers in China provide many lessons to developing countries. This is particularly the case with respect to the development of sewer systems that often have not kept up with the speed of urbanization, resulting in a significant negative impact to the water quality of urban rivers.

Through the support of Major Science and Technology Program on Water Pollution Control and Treatment of China, National High-technology Research and Development Program ("863"Program) of China, and science and technology projects of Shanghai Science and Technology Commission, Professor Zuxin Xu of Tongji University was able to lead the team that systematically studied the challenges of and related technologies to urban drainage pipe system. The team participated in many projects on the rehabilitation of heavily polluted urban rivers, including that of Suzhou Creek in Shanghai, which is a successful model of urban river rehabilitation with global significance. Meanwhile, UN-Habitat has put in considerable effort to support countries to overcome challenges associated with rapid urbanization, such as urban water resource management and the development and management of wastewater for the protection of urban rivers.

The publication highlights the challenges of rapidly growing cities around the world, their struggles with urban water pollution, and provides proven approaches, solutions and technologies to tackle these challenges.

Based on the above experiences, UN-Habitat and Tongji University have co-authored this publication. The publication highlights the challenges of rapidly growing cities around the world, their struggles with urban water pollution, and provides proven approaches, solutions and technologies to tackle these challenges.

This publication identifies some of the main challenges for improving water quality in urban rivers as incomplete systems, damaged pipelines, and illegal connection of sewer systems to stormwater drains (Chapter 3).

Incomplete sewer systems. Developing countries often prioritize the construction of sewage network frameworks composed of main pipelines and not collecting and intercepting pipelines. In addition, municipalities tend to focus on collecting sewage from central urban areas or downtown districts, while ignoring suburban areas.

Damaged sewer pipelines. The construction and management practices of drainage pipeline systems in developing countries result in damaged sewer pipelines and misconnection of stormwater pipelines to sewer systems. A large amount of groundwater ends up at the wastewater treatment plants (WWTPs) in areas where groundwater levels are higher than the depth of sewerage pipes, stormwater enters sewer pipelines and is sent to the WWTPs during wet weathers, exceeding their capacity and resulting in overflow at the WWTPs.

Sewer pipelines illegally connected to stormwater drainage systems. It is common to illegally connect sewage pipes to stormwater pipes in developing countries as sewer systems were constructed much later than stormwater pipes. This illegal condition explains the severe pollution of the flow from stormwater pipes, and therefore the deterioration of river water quality during wet-weather.

River pollution during wet weather can also be caused by overflow of combined sewer systems. In developing countries, overflow pollution of combined sewer systems (CSSs) is much heavier in wet weather. Due to inadequate operation and maintenance, sediments previously accumulated in stormwater pipes are resuspended and flushed into rivers, leading to considerable river pollution.

Systematic engineering approaches and technologies are required and have been developed for the rehabilitation of heavily polluted urban rivers to improve water quality. Proper planning, design, construction and maintenance of drainage networks, sewage collection and interception followed by proper treatment, and pollution load reduction in wet weather are indispensable aspects to reduce pollutants discharged from drainage systems in developing countries. Advanced technology for inspecting, repairing and maintaining sewers in densely populated cities is urgently needed to effectively reduce urban river pollution.

Planning and construction of urban drainage systems is important. Improving the comprehensive planning, construction and management of drainage systems contribute to effective pollution control and protection of the urban water environment.

Complete collection pipe networks extended properly to connect to sources of pollution based on investigations. The identification of pollution sources and their magnitude of pollution generation, the establishment of an appropriate database and the development of context specific sewage system models are indispensable first steps before the construction of sewage networks. Geographic information systems (GIS) can improve the efficiency and accuracy of construction of collection sewer systems.

Trenchless Pipeline Repair (TPR) technology is recommended for pipeline restoration in densely built urban areas. Damaged pipes can result in considerable discharge of pollutants into the environment, and they should be detected swiftly and repaired properly. Trenchless technology, which works without digging up the ground in city neighborhoods that experience heavy traffic, is helpful in replacing or repairing broken pipelines.

Simple and low-cost tracing technology is useful to detect and solve sewage cross-connections. Such technology supports on-going programmes of correcting sewage cross-connections and includes rebuilding the drainage system in old residential communities as a separate system with parallel sewer and stormwater pipes.

The application of low impact development (LID), initial rainwater storage tank, in-site sediment flush gate and Hydrodynamic Vortex Separators (HVSs) can contribute significantly to reducing pollution loads including runoff volume and pollutant loads of discharges from drainage network in wet weathers.

River rehabilitation is a long-term systematic process, and proper finance and governance is essential (Chapters 4 and 5).

Innovative finance models are needed to address the huge funding requirements for repairing, upgrading and maintaining of urban pipeline network. The Public-Private-Partnership (PPP) model can provide a viable option for addressing the investment gap in order to rehabilitate heavily polluted rivers, and also transform the management model from "construction-oriented" to "supervision and management".

Leadership and governance are the foundation for avoiding unnecessary pollution of rivers. The principal-responsible mechanism should foster better coordination and cooperation among water-related departments. In China, the adoption of "River Chief" has turned out to be an effective management model for the prevention of pollution and taking ownership of the condition of water in urban rivers.

The rehabilitation of Suzhou Creek in China, which was once a heavily polluted urban river, is a successful project (Chapter 6). This publication introduces the key technologies and practices adopted in the rehabilitation of Suzhou Creek. The technical approaches applied alongside the adopted management framework were fundamental in the improvement of the water quality, as well as the environment, of the whole river basin. The rehabilitation of the Suzhou Creek has proven that there are considerable economic, social and environmental benefits from pollution control and rehabilitating urban rivers that should encourage other developing countries to embark on similar interventions.

Selected international case studies in the publication - Bethlehem City in Palestine, Densu river basin in Accra Ghana, Lake Victoria Basin, Mekong River Basin – due to rapid urbanization, the shared nature of the challenges of developing wastewater management systems resulting in polluted urban rivers (Chapter 7).

Urban pollution from an agglomeration of secondary towns can have significant impacts on large water bodies affecting sustainable urban development. Comprehensive approaches based on appropriate studies and data, good planning, adoption of appropriate technology, proper institutional arrangements and public participation are important.

We believe that, tackling the challenges of developing wastewater management systems and rehabilitating urban rivers has economic, social and environmental benefits and are therefore fundamental to achieving the SDGs (Chapter 8). The experiences and practices in China and other developing countries presented in this publication can be useful and could be replicated in other countries in similar situation.

The rehabilitation of the Suzhou Creek has proven that there are considerable economic, social and environmental benefits from pollution prevention and control and rehabilitating the urban river that should encourage other developing countries to embark on similar interventions.

Suzhou Creek, Shanghai China.

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Abbreviations and Acronyms

ACP	African, Caribbean and Pacific
AfDB	African Development Bank
AFD	Agence Francaise de Development
BMP	Best management practices
CCTV	Closed circuit television
COD	Chemical oxygen demand
CSO	Combined sewer overflow
CSS	Combined sewer system
DOEE	Department of Energy & Environment
EAC	East African Community
EMC	Event mean concentration
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GIS	Geographic information system
HVS	Hydrodynamic Vortex Separator
ILO	International Labour Organization
IWRM	Integrated Water Resources Management
LID	Low Impact Development
LVBC	Lake Victoria Basin Commission
NGO	Non-governmental Organizations
NH_3-N	Ammonia nitrogen
PE	Polyethylene
PPP	Public-Private Partnership
PVC	Polyvinyl chloride
SC	Sponge City
SDGs	Sustainable Development Goals
SS	Suspended solid
SSS	Separate sewer system
SWMM	Storm Water Management Model
TN	Total Nitrogen
TP	Total Phosphate
TPR	Trenchless Pipeline Repair
UNESCO	United Nations Educational, Scientific and Cultural Organization
WASP	Water Quality Analysis Simulation Program
WATSAN	Water and Sanitation
WEC	Water environmental capacity
WQI	Water Quality Index
WWTP	Wastewater Treatment Plant

Figures and Tables

Figures

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Key messages

1. **Improving the water quality of urban rivers** around the world greatly enhances the quality of life and health of citizens, water availability as well as protecting the ecosystems. Water pollution must be tackled at the source.

2. **Managing wastewater by increasing the collection and treatment infrastructure (on site and off site) supports the achievement of the New Urban Agenda and the SDGs, particularly the targets that focus** on cities, water, ecological protection and climate change.

3. **The successful projects that rehabilitated heavily polluted urban rivers,** such as Suzhou Creek in China and other developing countries greatly improved the urban environment, the quality of life and the health of citizens which is critical for sustainable development.

4. **Rapid urbanization can lead to increased challenges** in terms of the development of sewage infrastructure, it requires high investments, repairs, renewal and maintenance.

5. **Good urban planning is key to prevent and address the pollution of urban rivers.** Incremental development without robust urban plans can result in major challenges, retrofitting in unplanned settlements adjacent to rivers is highly complex and investment intensive. It is therefore imperative to plan for drainage systems upfront, taking into consideration peculiarities of local settings.

6. Water and sanitation require **a new financing paradigm**. It calls for increasing the efficient use of existing financial resources and innovative ways of mobilizing additional domestic and international finance. Employing a Public-Private-Partnership (PPP) model can be an effective solution in some contexts.

7. **Local governments are increasingly held accountable for their actions** in protecting their ecosystems and environment, which includes rivers, lakes, wetlands and nearby greeneries, and the species that are dependent on them. Urban policy-makers are therefore called upon to actively contribute to protecting and conserving water ecosystems.

8. **Good governance is critical to the rehabilitation of polluted rivers and their maintenance.** The example of China has shown that developing and implementing a "river chief" system might help to ensure coordinated management of urban rivers and improve of the water quality. Public participation and instilling the sense of ownership are key to improve water management and maintain healthy rivers as demonstrated by international examples. Community participation in decision-making can yield many benefits.

9. **Building capacity in wastewater collection, treatment, recycling and reuse technologies for developing countries is essential**. A serious lack of institutional and human capacity across the water sector is constraining progress. Investing in capacity development requires short and long-term measures. Sharing best practices and experiences from China and other developing countries contributes to this goal.

Chapter 1

Background

Sustaining water-related ecosystems in urban rivers is crucial to improving living conditions in cities and economic growth. Sustaining and recovering water-related ecosystems, of which the world has lost 70%, of is vital for sustainable development.

Managing wastewater and rehabilitation of polluted urban rivers is critical for the implementation of the New Urban Agenda and achieving the Sustainable Development Goals in developing countries.

1.1 Global situation of urban river pollution

Rivers provide a myriad of in-stream and consumptive uses. They are sources of potable water for cities and towns, used for transportation, nature-based tourism and water sports, support agriculture and industry, improve aesthetic and landscape quality, provide ecosystem services, moderate climate, and generate hydroelectric power, among others. However, many urban rivers are not able to provide some of these services because of pollution. High population growth, unplanned rapid urbanization and uncontrolled industrialization cause pollution and degradation of river water ecosystems, especially in developing countries.

The main source of urban river pollution is increased discharge of untreated sewage. It is estimated that well over 80% of wastewater worldwide (over 95% in some developing countries) is released into the environment without treatment. According to the United Nations World Water Development Report 2017 on wastewater, on average, high-income countries treat about 70% of the municipal and industrial wastewater they generate. That ratio drops to 38% in upper middle-income countries and to 28% in lower middle-income countries. In low-income countries, only 8% undergoes treatment of any kind. [2]

Over

80%

of wastewater worldwide is released into the environment without treatment.

An assessment of water quality worldwide concluded that pollution in Latin America, Africa and Asia increased between 1990 and 2010 because of growth in wastewater loading to rivers and lakes. As an example, organic pollution (measured as biochemical oxygen demand) worsened in more than half of river stretches. Pollution increased to a severe level or was already severe and had worsened by 2010 in a subset of these river stretches.[3]

Lack of sewerage infrastructure, technical and institutional capacity to enforce water quality and wastewater emission standards, and financing constraints in lower middle-income and low-income countries in Africa, Asia and Latin America result in a large portion of the sewage from cities and towns being released untreated into urban rivers. In Europe, 71% of the municipal and industrial wastewater generated undergoes treatment, while only 20% is treated in the Latin American countries, an estimated 51% in the Middle East and Northern Africa (MENA), and minimal in sub Saharan Africa. In low-income countries, rivers are often used as dumping grounds for sewage and industrial effluent, except in a few larger municipalities where only a portion of the wastewater is treated. Due to lack of sewerage services, people are forced to rely on private solutions such as open drains or poorly constructed

2 WWAP (United Nations World Water Assessment Programme). 2017. The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. Paris, UNESCO, pg. 2.

3 Center for Environmental Systems Research (CESR), University of Kassel. April 2016, WaterGAP3.1. United Nations Environment Programme (2016).

septic tanks to dispose of human and liquid wastes thereby polluting and degrading the surrounding urban areas and water bodies, including urban rivers. Rapid water quality deterioration such as in Addis Ababa Rivers, or the Shenzhen River catchment in China, amongst many others, was caused by urbanization and rapid increases in domestic discharge.[4]

The report warns that if current trends persist, water quality will continue to degrade over the coming decades, particularly in resource-poor countries in dry areas, further endangering human health and ecosystems, contributing to water scarcity and constraining sustainable economic development.[5]

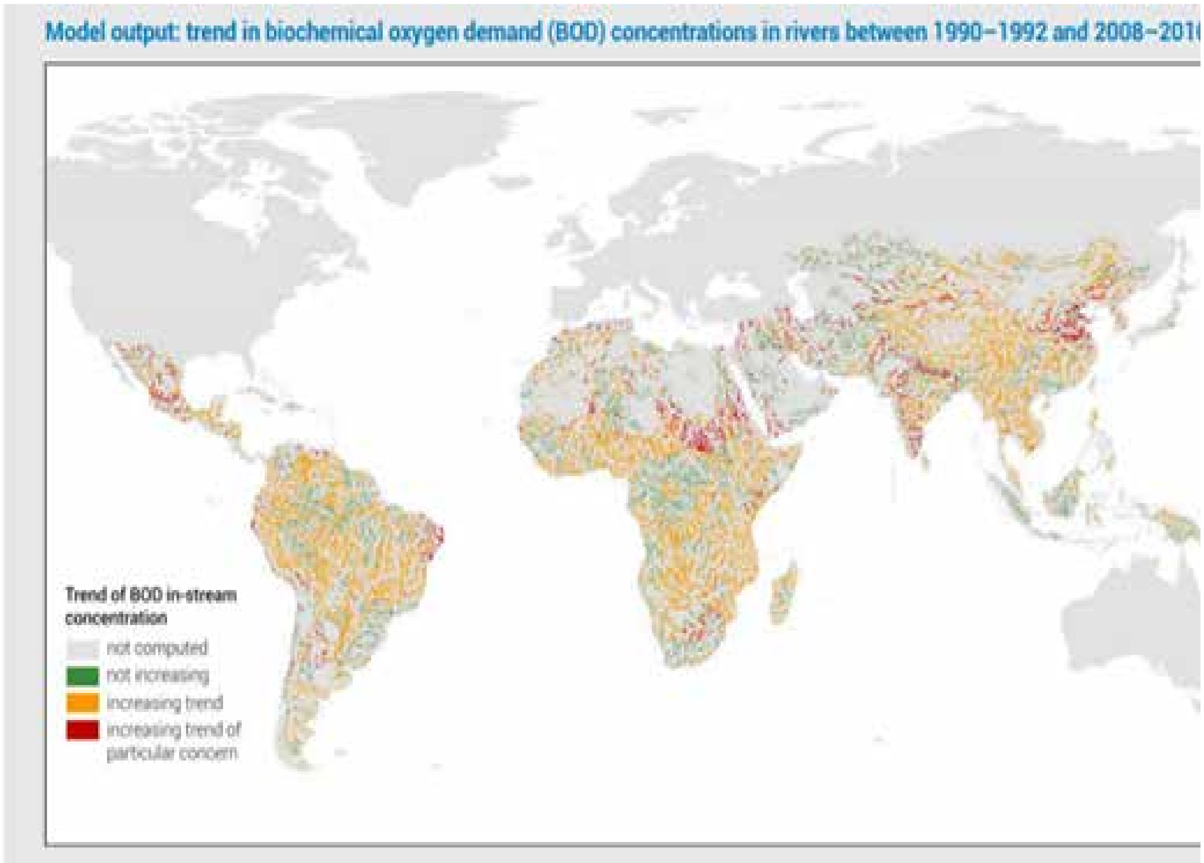


Figure 1-1 Model output: trend in biochemical oxygen demand (BOD) concentrations in rivers between 1990-1992 and 2008-2010

1.2 2030 Agenda for Sustainable Development and the New Urban Agenda

The 2030 Agenda for Sustainable Development and its 17 Sustainable Development Goals (SDGs) were adopted by world leaders at the General Assembly in September 2015. SDGs are the blueprint to achieve a better and more sustainable future. Within the SDGs framework, a specific goal (6) focuses on ensuring clean water and sanitation for all. Within this goal, Target 6.3 states: “By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally”. The Wastewater Target is complemented by SDG 11 on Sustainable Cities and Communities. Target 11.6 states “By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management”. These global goals and targets reaffirm the commitment of world leaders to finding sustainable solutions for restoring the health of rivers and other water bodies.

4 UNEP (2010). Sick Water? The central role of waste-water management in sustainable development: A Rapid Response Assessment. United Nations Environment Programme, UNHABITAT, GRID-Arendal Worku Y, Giweta M (2018) Can We Imagine Pollution Free Rivers around Addis Ababa city, Ethiopia? What were the Wrong-Doings? What Action Should be Taken to Correct Them? J Pollut Eff Cont 6: 228. doi: 10.4172/2375-4397.1000228

5 Ibid, pg. 2

The New Urban Agenda adopted at the United Nations Conference on Housing and Sustainable Urban Development (Habitat III) in Quito, Ecuador, on 20 October 2016 reaffirms the urgent need for technological and governance options for water and wastewater management. In paragraph 73, countries commit to "Promote conservation and sustainable use of water by rehabilitating water resources within the urban, peri-urban, and rural areas, reducing and treating wastewater, minimizing water losses, promoting water reuse, and increasing water storage, retention, and recharge, taking into consideration the water cycle."

Delivering on these international commitments on wastewater management and rehabilitation of water resources require international cooperation and partnerships. In SDG Target 6a - world leaders pledge that "[B]y 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies".

In paragraph 81 of the New Urban Agenda, world leaders also recognize that the realization of the transformative commitments set out in the Agenda will require international cooperation as well as efforts in capacity development, including the sharing of best practices, policies and programmes among Governments at all levels.

5 UNEP (2010). Sick Water? The central role of waste-water management in sustainable development: A Rapid Response Assessment. United Nations Environment Programme, UNHABITAT, GRID-Arendal Worku Y, Giweta M (2018) Can We Imagine Pollution Free Rivers around Addis Ababa city, Ethiopia? What were the Wrong-Doings? What Action Should be Taken to Correct Them? J Pollut Eff Cont 6: 228. doi: 10.4172/2375-4397.1000228

6 Ibid, pg. 2

Chapter 2

Actions taken in China

China has made significant progress with notable achievements in controlling pollution to improve water quality. However, some of the cities in China are still facing the challenge of heavily polluted rivers.t

2.1 Status of water pollution

China is the largest developing country in the world. China has experienced fast-paced economic growth and has also been urbanizing rapidly since the reform and opening of the country in 1978. Its urbanization rate has increased dramatically to 56.10% in 2015 from 17.92% in 1978.[1] It is widely acknowledged that urbanization plays a pivotal role in China's meteoric economic growth **(Figure 2-1).**

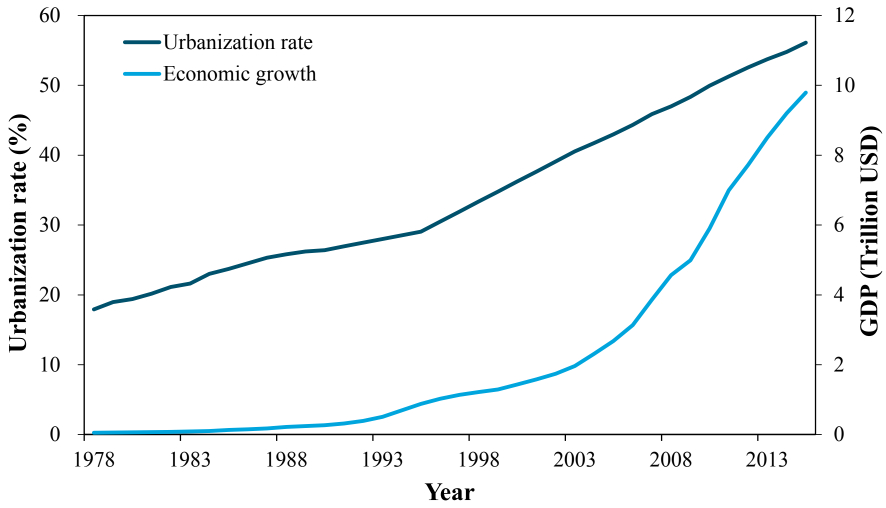


Figure 2-1 Urbanization and economic growth in China (1978-2015)

Rapid urbanization has brought significant social and economic changes in China but is also associated with serious environmental and socioeconomic problems. Figure 2-2 shows changes in surface water quality of various grades (Table 2-1). With the advancement in the construction of water and environment related infrastructure, the amount of inferior classed water has rapidly decreased given China's water and environmental pollution control, and water quality has gradually improved.

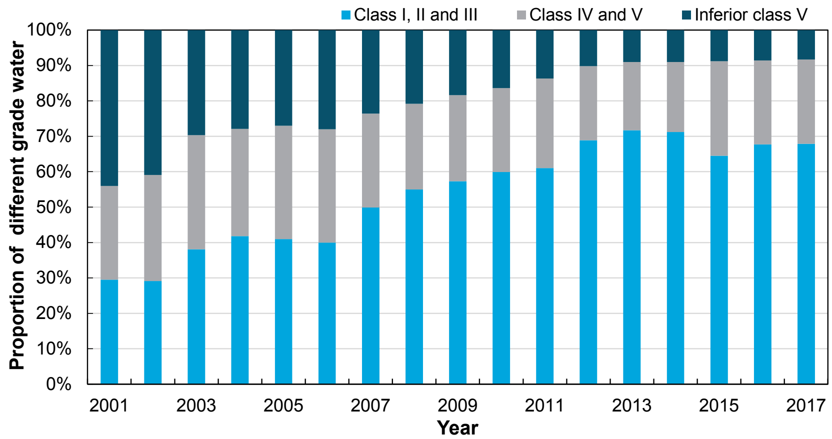


Figure 2-2 Changes of surface water quality in China (2001-2017)

Environmental quality standards for surface water of China (GB3838) defines the items and limits to be controlled for water environmental protection in accordance with the classification and protection objectives of surface water environmental functions, as well as the implementation and supervision of water quality evaluation, analysis methods and standards for water quality projects. This standard is applicable to surface water areas with operational functions such as rivers, lakes, canals, channels and reservoirs in the territory of the People's Republic of China. For waters with specific functions, the corresponding professional water quality standards shall be implemented.

There are five categories of surface water, organized according to environmental functions and protection objectives:

Class I: Mainly applicable to source water and national nature reserves.

Class II: Mainly suitable for the first-class protection area of surface water source areas of centralized drinking water, habitat of rare aquatic organisms, spawning grounds of fish and shrimp, and feeding grounds of larvae and juveniles.

Class III: Mainly suitable for the secondary protection area of the surface water sources of centralized drinking water, wintering grounds of fish and shrimp, migration passages, aquaculture areas and other fishery waters, and swimming areas.

Class IV: Mainly suitable for general industrial water use and recreational water areas where human bodies are not in direct contact.

Class V: Mainly suitable for agricultural water use and waters with general landscape requirements.

Table 2-1 Standard values of basic items of environmental quality standards for surface water of China

Item No.	Item	Class I	Class II	Class III	Class IV	Class V
1	water temperature(^{0}C)	Ambient water temperature change caused by man-made reasons shall be limited at: Maximum weekly average temperature rise≤1; Maximum weekly average temperature drop≤2				
2	pH	6~9				
3	Dissolved oxygen≥	Saturation rate 90%(or 7.5)	6	5	3	2
4	Potassium permanganate index≤	2	4	6	10	15
5	Chemical oxygen demand (COD)≥	15	15	20	30	40
6	Five-day biochemical oxygen demand (BOD5) ≤	3	3	34	6	10
7	Ammonia & nitrogen (NH3-N) ≤	0.15	0.5	1	1.5	2
8	Total phosphorus (as P) ≤	0.02	0.1	0.2	0.3	0.4
9	Total nitrogen(Lake, reservoir, as N)≤	0.2	0.5	1	1.5	2
10	Cu≤	0.1	1	1	1	1
11	Zn≤	0.05	1	1	2	2
12	Fluoride (as F) ≤	1	1	1	1.5	1.5

13	Selenium≤	0.01	0.01	0.01	0.02	0.02
14	Arsenic ≤	0.05	0.05	0.05	0.1	0.1
15	Hg≤	0.00005	0.00005	0.0001	0.001	0.001
16	Cadmium ≤	0.001	0.005	0.005	0.005	0.01
17	Chromium (hexad) ≤	0.01	0.05	0.05	0.05	0.1
18	Lead ≤	0.01	0.01	0.05	0.05	0.1
19	Cyanide≤	0.005	0.05	0.2	0.2	0.2
20	Volatile phenol ≤	0.002	0.002	0.005	0.01	0.1
21	Petro≤	0.05	0.05	0.05	0.5	1
22	Anionic surfactant≤	0.2	0.2	0.2	0.3	0.3
23	Sulfide≤	0.05	0.1	0.2	0.5	1
24	Dung large intestine bacterium(number/L)≤	200	2000	10000	20000	40000

National Environmental Protection Administration, Environmental quality standards for surface water, in GB3838. 2002.

Black and odourous water bodies in urban areas refers to the bodies of water that present unpleasant color and/or emit unpleasant odour in the built-up areas of a city. They are divided into "light black and odourous" and "severe black and odourous", which provides an important reference for the formulation of the black and odourous water body treatment plan and the evaluation of the treatment effect. The evaluation indexes include transparency, dissolved oxygen (DO), redox potential (ORP) and ammonia nitrogen (NH3-N). The classification standard is in Table 2-2. Compared with ammonia nitrogen index, the water quality of urban black and odourous water bodies is inferior to the V water quality standard of environmental quality standards for surface water of China (GB3838).

Table 2-2 Standards for grading the pollution degree of heavily polluted (black and odourous) water body in urban areas

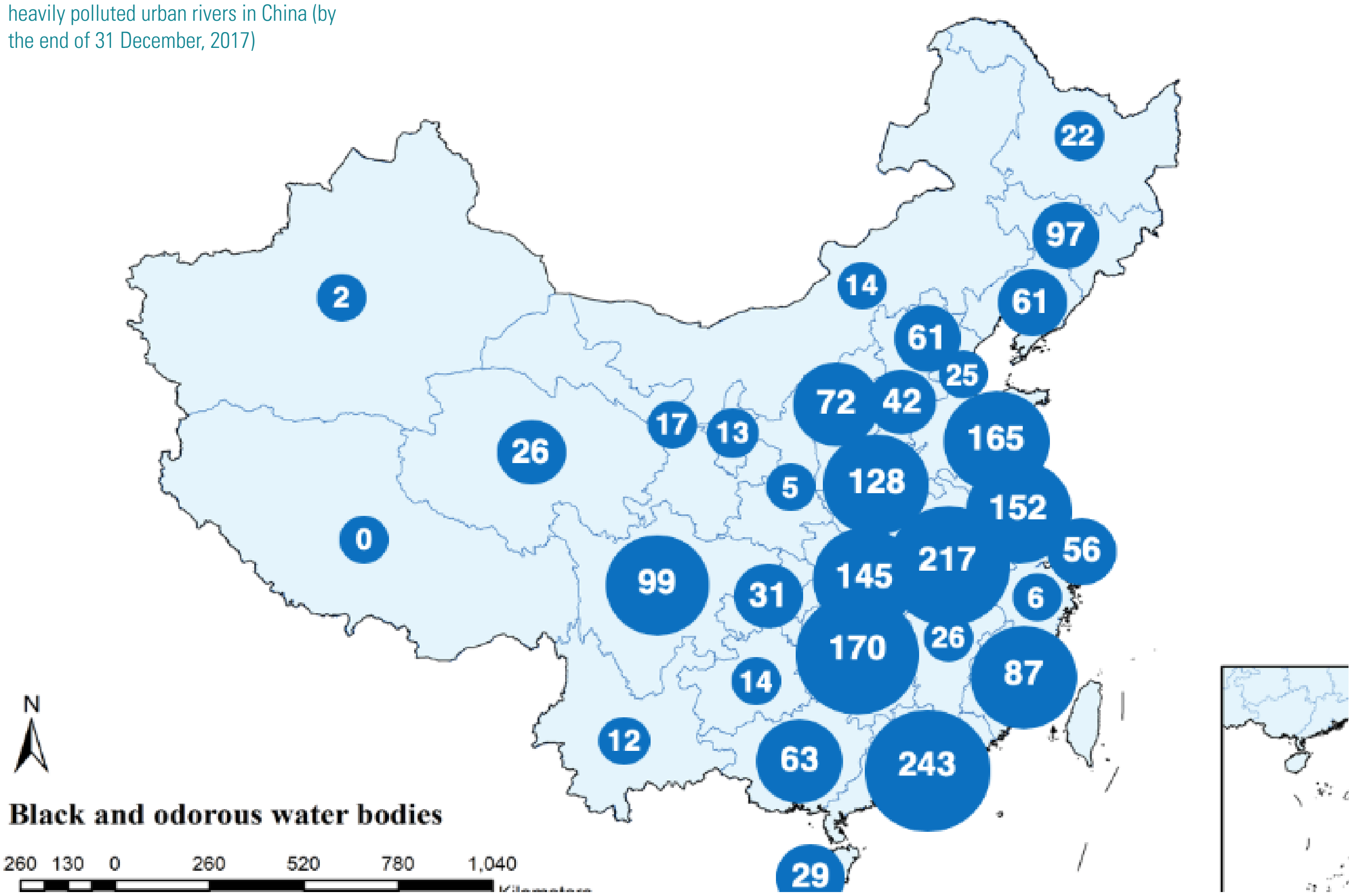
Characteristic index (unit)	Mild	severe
Transparency (cm)	25~10*	< 10*
Dissolved Oxygen(mg/L)	0.2~2.0	< 0.2
Oxidation-reduction potential(mV)	-200~50	< -200
Ammonia nitrogen(mg/L)	8.0~15	> 15

Note: * when the water depth is less than 25cm, the index is calculated according to 40% of the water depth

Ministry of Housing and Urban-Rural Development, Guide for the renovation of urban Black and Odourous Water Bodies. 2015. [000013338/2015-00231]

In February 2016, the Ministry of Housing and Urban-Rural Development and the Ministry of Environmental Protection of the Chinese government officially released a list of heavily polluted water bodies. There were 2,100 heavily polluted water bodies as classified in Table 2.2 in more than 220 cities above the prefecture level in China, and 64% were concentrated in the southeast coastal regions **(Figure 2-3).[2]**

Figure 2-3 Location and distribution of heavily polluted urban rivers in China (by the end of 31 December, 2017)



In summary, after substantial investments in huge sewage treatment infrastructure construction, and the construction of large-scale water pollution control projects, great success has been made in pollution control for restoration of the environmental quality of water, such as wastewater treatment plants (WWTPs) and drainage systems construction and improvement in urban areas, but there are still some pollution problems in urban water bodies. The key lies in the drainage network problem, a common problem not only in China, but also in other developing countries. Its causes and remedial measures are worthy of in-depth analysis and discussion in order to provide important guidance and reference for the rehabilitation of the environmental status of water and sustainable urban development in China and similar countries in the world.

2.2 Policy framework guiding action for the rehabilitation of the water environment in China

The Chinese Government has prioritized environmental protection in the national strategy under 'Ecological Civilization', aiming to promote sustainable development to the height of green development. Particularly since 2012, 'Ecological Civilization' has been included in the plan to promote coordinated economic, political, cultural, social and ecological advancement. In this respect, the Chinese Government actively promotes rehabilitation of heavily polluted water bodies in urban areas.

A series of successive policy actions are worth noting. In April 2015, an "*Action Plan for Prevention and Control of Water Pollution*" issued by the Chinese Government initiated China's largest and most comprehensive restoration action of the water environment.[3] It is required that by 2020, the black and odourous water bodies in the built-up areas of prefecture-level cities and above will be controlled within 10%, and that by 2030 the black and odourous water bodies in urban built-up areas will be eliminated.

In December 2016, the Chinese Government issued the *"Opinions on the Full Implementation of the River Chief"* , to promote progress in water environment rehabilitation. [4]

In April 2018, the first meeting of the Central Committee of Finance and Economics preauthorized the rectification of black and odourous water bodies as one of the key issues to be addressed to improve ecological environment quality.

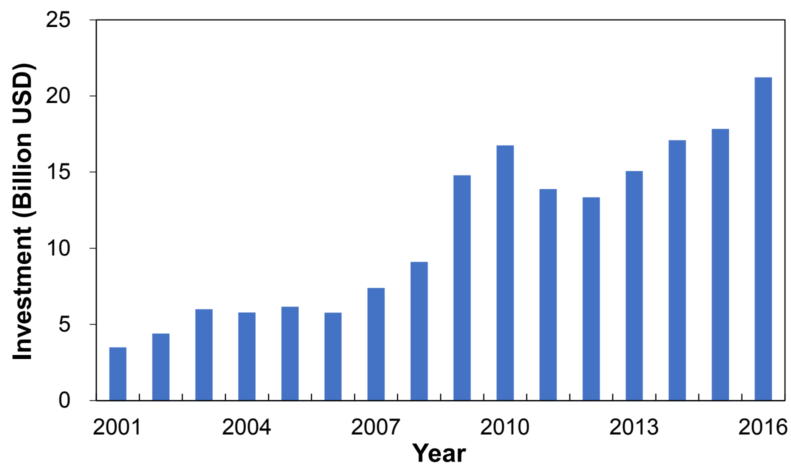
In June 2018, the Chinese government promulgated the *"Opinions on Comprehensively Strengthening Ecological Environment Protection and Resolutely Fighting Pollution Prevention and Control"*, which reported detailed programmes for the "Five Water-related Campaigns" such as urban black and odourous water treatment.[5]

In October 2018, the Ministry of Housing and Urban-Rural Development and the Ministry of Ecology and Environment jointly issued the Action Plan on Rehabilitating Urban Heavily Polluted Rivers, which clearly defined the specific goals in order to significantly improve river environment in 3 years.[3] The powerful leadership of the central committee was necessary to improve the multisectoral efforts for the rehabilitation of heavily polluted urban rivers and the restoration of water environments.

2.3 Efforts of restoration

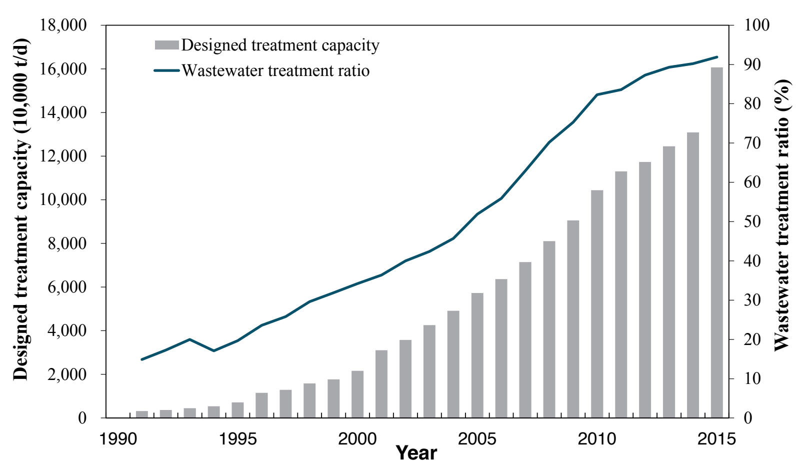
The investment in the construction of infrastructure to control water environmental pollution by Chinese government has increased year by year since 1990s. From 2001 to 2016, the proportion of total investment in China's urban sewage treatment projects in GDP increased continuously, reaching 148.55 billion RMB (US$ 22.15 billion) in 2016 **(Figure 2-4)[6].**

Figure 2-4 Annual investment of China in sewerage treatment projects (2001-2016)



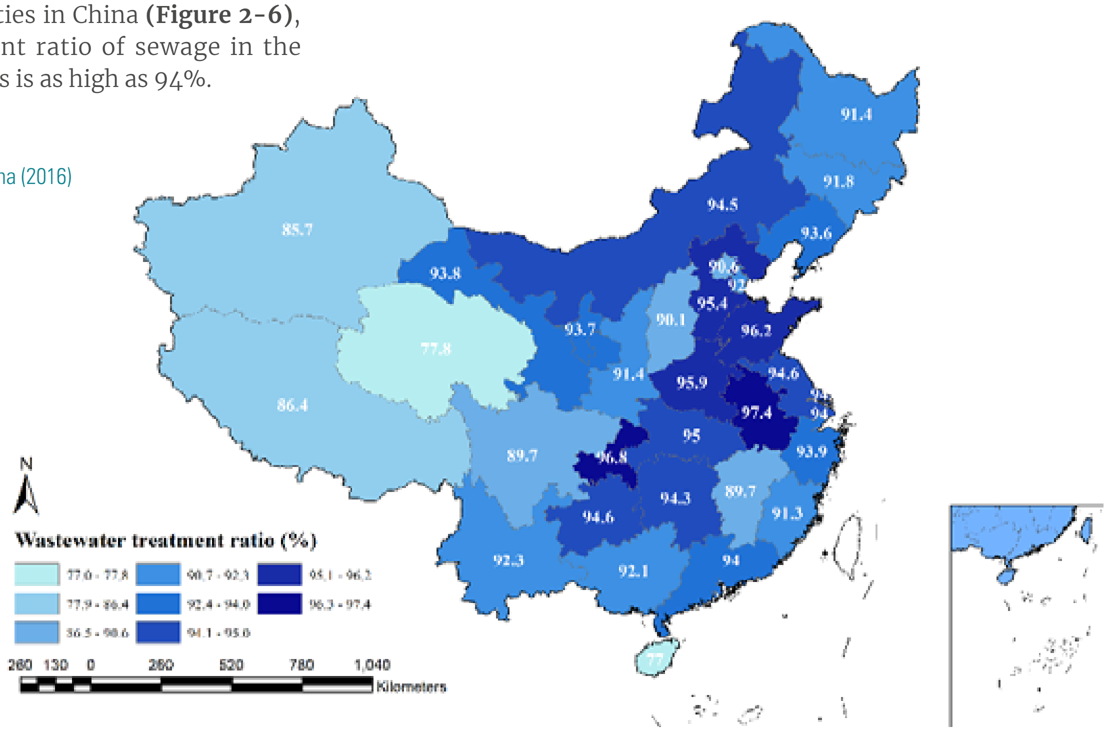
From 1990 to 2016, the total capacity of urban sewage treatment in China has also been increasing year by year **(Figure 2-5).** In 2016, on average 90% of sewage generated by Chinese cities was treated.[1]

Figure 2-5 Annual increase in municipal wastewater treatment capacity in China (1990-2015)



Looking at the sewage treatment ratios (wastewater generated as opposed to wastewater treated) of various provinces and cities in China **(Figure 2-6)**, the centralized treatment ratio of sewage in the southeastern coastal cities is as high as 94%.

Figure 2-6 Statistics of municipal wastewater treatment ratio in China (2016)



China's urban sewerage pipe network is also expanding. The density of the pipe network has increased from 3.17 km/km2 in 1981 to 10.61 km/km2 in 2016 **(Figure 2-7, Figure 2-8).[1]**

Figure 2-7 Sewerage pipe network density across China (2016)

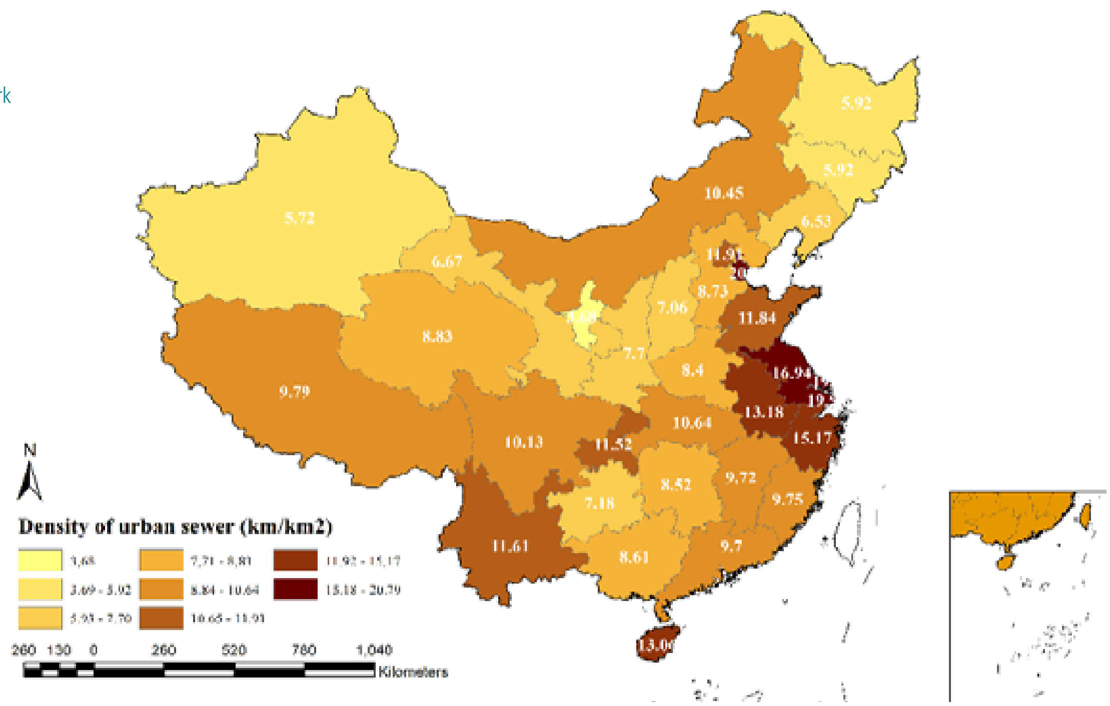
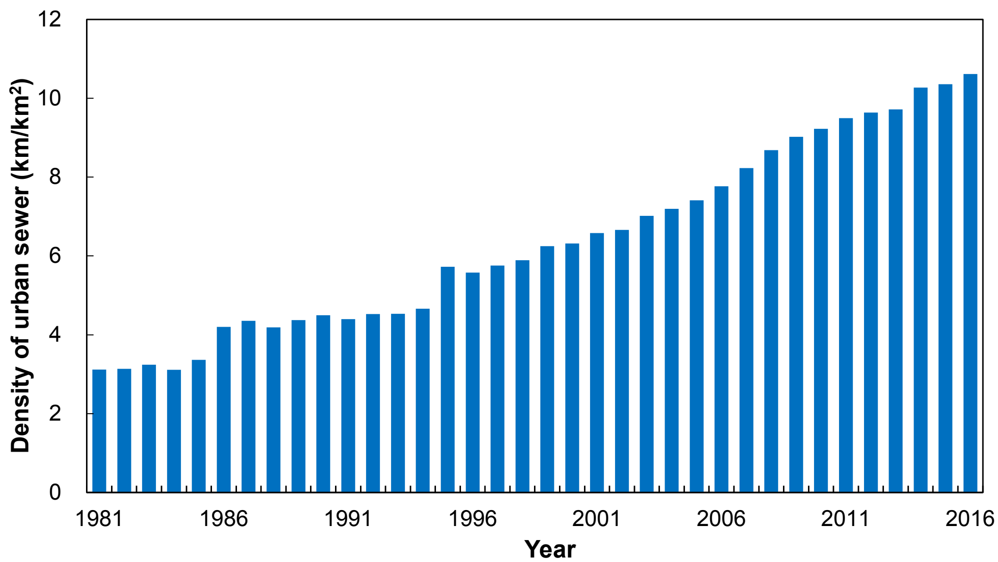


Figure 2-8 Annual increase in drainage pipe density in China (1981-2016)



Chapter 3

The main challenges for water quality improvement of urban rivers

Inappropriate planning, incomplete drainage systems, as well as poor construction quality result in a large amount of pollutant load discharging directly into rivers from drainage system not only in both dry and wet weather. If the deficiencies in the urban drainage system are not identified and corrected, urban river restoration efforts will be undermined, even resulting in serious river pollution, such as the occurrence of black water and foul smells in urban rivers.

The urbanization process generally leads to increasing loads of pollutants discharged into rivers by human activities, causing serious deterioration of the quality of the water in the river (which could turn black and odourous), and harming the surrounding environment as well as human health. Sewer systems, consisting of sewer collecting networks and WWTPs, are essential components of urban environmental infrastructure, for collecting, transporting and treating wastewater. Thus, the construction of sewer systems, especially sewer collecting networks, is important to control river pollution and to protect the water environment.

Developing countries are at different stages of urbanization, leading to many challenges in the development of sewer systems and river pollution control. In most of the least developed countries, the main challenge is that sewer systems are often absent, resulting in direct discharge of wastewater into rivers. In countries with rapid economic growth and industrialization, the challenges associated with the development of sewer systems and river pollution control are more complicated. For example, since the reform and opening up of China policy, the past four decades have witnessed rapid urbanization and sewer systems have been constructed, but the rehabilitation of urban rivers still faces huge challenges. These factors are described in sections 3.1 to 3.3 below.

3.1 Sewer coverage

3.1.1 The problems associated with the construction of collecting sewer systems

There are two indicators for measuring urban sewer systems: the coverage and the density of the sewer systems. After more than 40 years of reform and opening up of China, the coverage of urban sewer systems in the country has reached more than 90%, which compares well with Europe, the United States and Japan.[7] However, the density of urban sewer systems is only 10.61 km/km2, much lower than those in Japan and the US. Japan had for instance by 2004, a sewer system with a length of 350,000 km and a density of 20-30 km/km2, even as high as 50 km/km2 in some urban areas. The length of the sewer system in the US was around 1.5 million km in 2002, and the average density in cities was above 15 km/km2. The problem in China is that it attaches importance to the construction of trunk sewers, while neglecting to develop collecting sewer systems. This problem is more common in the county-level cities of China, which results in some sewage not being collected by the pipe networks and therefore being directly or indirectly discharged into rivers.

3.1.2 Lack of river network interception and pollution control

Generally speaking, cities with more serious river pollution are usually located on plains with relatively small water level differences and poor water mobility, especially in coastal plains. River networks in these cities are dense, criss-crossing, interconnected, and interacting. Due to financial and construction problems, developing countries often give priority to the treatment of mainstream pollution when they rehabilitate polluted urban rivers, ignoring the interception and pollution from tributaries. The priority is given to pollution control in the central urban area, neglecting the interception and pollution control of the whole water system, resulting in ineffective pollution control of major rivers and central urban areas. The Suzhou Creek rehabilitation project in Shanghai has achieved remarkable results due to the construction of the sewerage networks which effectively and comprehensively intercepted pollutants out of the river networks and entire water system.

3.2 Sewage treatment

3.2.1 Pipeline damage leads to greater groundwater seepage

By the end of 2015, the total length of urban sewers in China had reached 540,000 km, of which 261,000 km were used for more than ten years. Damaged sewers were common due to pipe corrosion, erosion, deposition, ground loading etc. Groundwater could easily seep into the sewers constructed below groundwater level, which reduced the sewage transfer capacity as well as the influent concentration in sewers. In general, chemical oxygen demand (COD) concentration of domestic sewage is about 350 mg/L. However, among the 4,000 WWTPs in China, almost a quarter of them have an influent COD below 150 mg/L. The problem is more common in the cities of southern China, where the depth of sewers is generally about 3-5 m (up to 7 m), which is well below the groundwater level. The results of investigation on groundwater seepage in sewage pipelines in southern China are shown in **Table 3-1**. The proportion of groundwater in the sewer system was as high as 28-40%, and the seepage rate could reach 3800-6300 m3/(km2·d), which is about three to five times that of Germany (1296 m3/(km2·d)).

Table 3-1. Groundwater seepage into urban sewer in Southern China [8-13]

Region	The results of investigation on groundwater seepage
Eastern Cities	Groundwater seepage in most areas is between 20% and 30% of the original sewage volume.
Southern Cities	Groundwater seepage is between 10% and 25% of the original sewage volume.
Small Coastal Cities	The groundwater seepage rate is 0.25 m^3/(km·mm·d). The average daily seepage amount reaches 75,000 m^3, calculated according to the sewage pipeline with a length of 1000 km and a diameter of 300 mm. This amount is equivalent to increasing the treatment needs of a medium scale sewage treatment plant.
Southwestern Cities	Groundwater seepage is between 34% and 51% of the original sewage volume.

3.2.2 The large amount of unintended stormwater discharging[7] into WWTPs

To illustrate the unintended access of stormwater to WWTPs, the water quantity and water quality of dry weather and wet weather in China's separate sewer systems were investigated and analyzed. **Figure 3-1a** shows the average amount of water inflow of dry and wet weather in a large-scale WWTP from 2011 to 2018. The average annual water inflow in dry weather is generally stable and the inter-annual variation is not obvious. However, the amount of water inflow in wet weather tends to increase year by year and the increased flow will exceed the capacity of WWTPs, as the WWTP then has to treat large quantities of stormwater. The average inflow to WWTPs in wet weather is 14 - 23% higher than that in dry weather. It can even be 1.7 - 2.2 times higher. The analysis of the ammonia nitrogen concentration in WWTPs in dry and wet weather is shown in **Figure 3-1b.** The annual average concentration of NH3-N is about 18-25 mg/L in wet weather and 21-26 mg/L in dry weather. **Figure 3-2** shows a comparative analysis of inflow in dry and wet weather during May to August (i.e., the rainfall season) in the same WWTP. The difference is more obvious, and the inflow in wet weather is 16 - 35% greater than that of dry weather. Stormwater discharge into WWTPs increases the amount of sewage, reducing the pollutants concentration, and overloading the transportation capacity of the sewer system.

7 Stormwater pipelines connected illegally to the WWTP discharging stormwater into the WWTP

8 In this report, we defined the rainy day and following three days as wet weather, and the other days as dry weather.

Figure 3-1 Influent wastewater quantity (a) and NH3-N (b) of WWTPs during wet weather and dry weather conditions (2011-2018)[8]

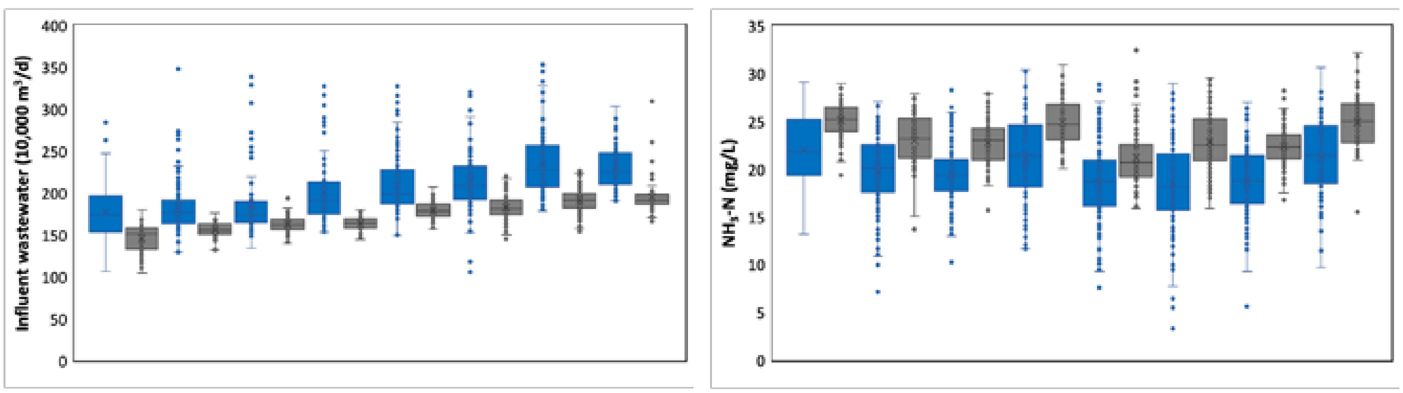
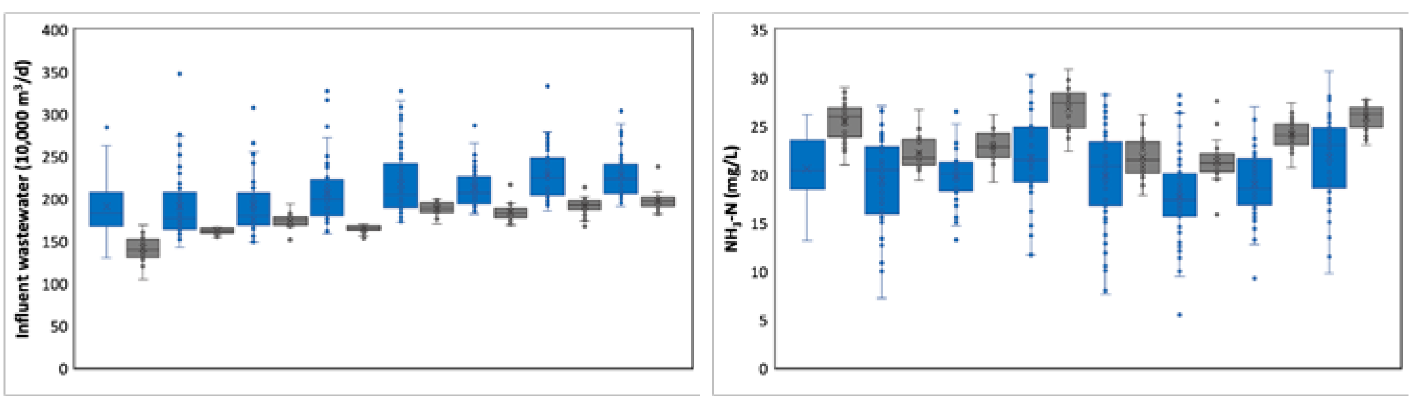


Figure 3-2 Influent wastewater quantity (a) and NH3-N (b) of WWTPs during wet weather and dry weather (May, June, July, and August of 2011-2018)



This problem is more often in small and medium-sized cities [14, 15]. Figure 3-3 shows the results of the survey in dry and wet weather for a WWTP in China. The inflow of wet weather is twice of that in dry weather. The main reason for the unintended access of stormwater to sewer system is due to the lack of supervision of pipe network construction.

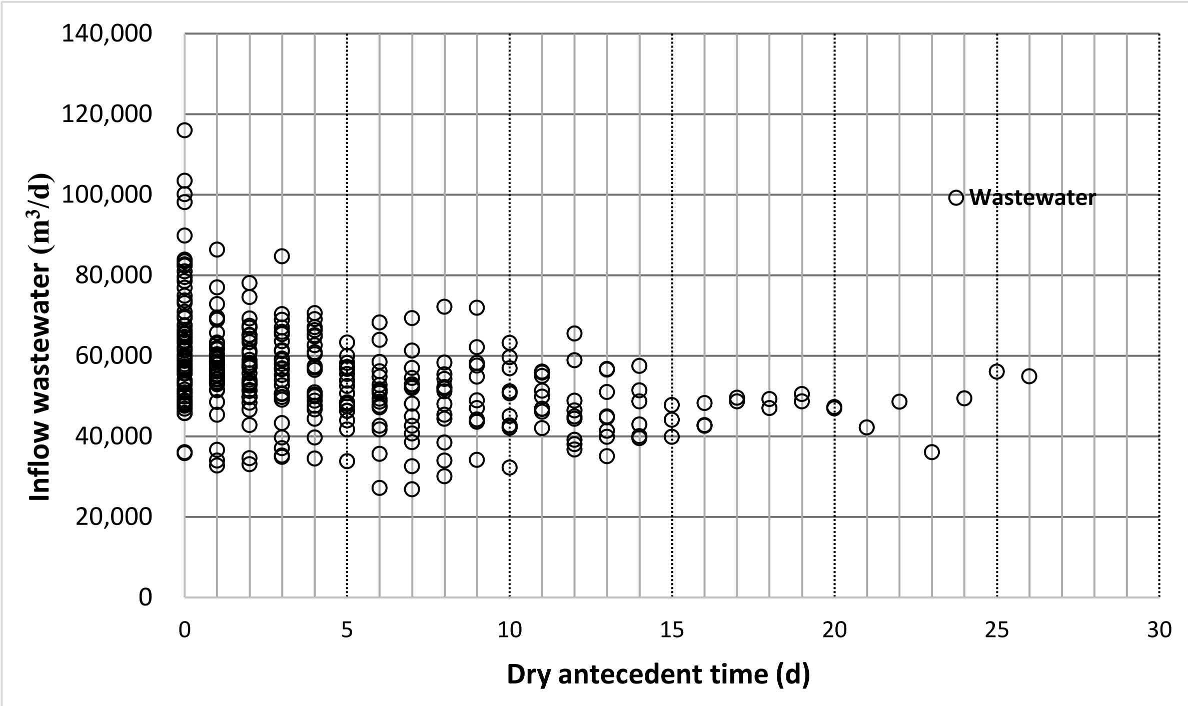


Figure 3-3 Relationship between wastewater inflow of a WWTP and dry antecedent times

3.3 Water quality in different weather conditions

Pollution discharging into rivers in wet weather is common throughout the world, but is a larger problem in developing countries. **Figure 3-4** is a comparison of the dry and wet weather of the same river in Shanghai. It can be seen that the water quality on the rainy day is significantly deteriorated. The combined sewer overflows (CSOs) and the initial stormwater discharge of separate sewer systems are large sources of pollution in wet weather. This phenomenon is more serious in developing countries due to the cross-connection of stormwater pipelines and corresponding control is the most difficult task in urban river rehabilitation.

Figure 3-4 Yangshupugang river in dry and wet weather conditions in Shanghai

3.3.1 Serious sedimentation pollution in combined sewer system of rapid urbanization

Developing countries tend to have large populations, and the cities are growing due to rapid urbanization. In China, sewerage networks in old cities, especially in downtown areas, were usually combined systems, characterized by long and indirect distances to WWTPs, a direct result of urban expansion. The total length of combined sewer systems in China is approximately 109,000 km.[1] As a result, pollutant deposition occurs in the sewers through the long distance conveying, especially when the flow is slow in dry weather. In other words, sewer systems can become storage tanks of pollutants, lowering the pollution concentration of the inflow entering WWTPs.[16] **Table 3-2** and **Table 3-3** show the influent water quality of some typical WWTPs in China and the comparison between China and developed countries. The influent concentration of SS in WWTPs is 100 mg/L lower than that of developed countries. The average concentration of BOD5 and SS are 74.3% and 62.6% of that in developed countries, respectively. These results indicate that nearly a third of the particulate pollutants are deposited along the conveying process in combined sewer systems.

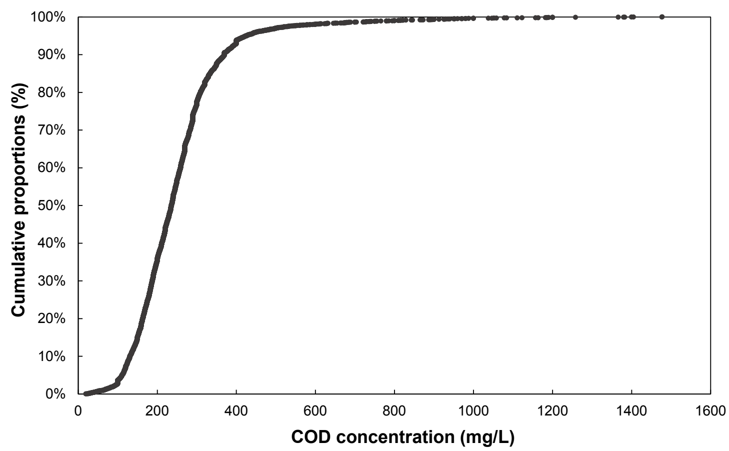


Figure 3-5 COD concentration of influent wastewater in WWTPs in China

Table 3-2 Influent water quality of some typical WWTPs in China[17-21]

Region	Number of WWTPs	Number of Samples	COD (mg/L)	BOD_5 (mg/L)	SS (mg/L)	NH_3-N (mg/L)	TN (mg/L)	TP (mg/L)
Southern Jiangsu	63	744	226	87.9	131	22.3	30.6	2.91
Shanghai	50	571 - 595	286	125	159	23.5	33.6	4.1
Tianjin	24	240 - 280	331	115	142	24.0	30.0	3.8
Beijing	36	363 - 430	347	160	169	36.7	49.2	5.0
Chongqing	57	656	318	150	197	28.6	40.3	4.1

Table 3-3 Comparison of influent water quality of some typical WWTPs in China and developed countries (unit: mg/L)[22, 23]

Region	Parameter	COD	BOD_5	SS	NH_3-N	TN	TP
China	Range	226 - 347	87.9 - 160	131 - 197	22.3 - 36.7	30.0 - 49.2	2.9 - 5.0
	Average	314	136	181	28.1	37.9	4.4
Europe	Range	441			22.0		
Southern California	Range		154 - 217	272 - 311	28.0 - 31.0		
	Average		183	289	30.0		

Note: The concentration of BOD5 in the influent water from the Southern California WWTP is converted to 70% of BODT.

3.3.2 Sewer system construction lagging behind resulting in cross-connections in separate sewer systems

Faced with rapid urbanization, developing countries often give priority to building stormwater drainage networks. When the social economy develops to a certain extent, construction of sewage collection systems begins. By this time, the problem of illegal connections will have generally taken root. Sewer construction generally lags behind the development of cities by more than 20 years. In the case of the central urban areas where the cities' main trunk pipes have not been fully developed, in order to address sewage discharge, measures to integrate sewage into the stormwater drainage network were adopted to meet the sewage discharge demand. As follow-up measures have not been implemented to address this, a large amount of wastewater is still directly discharged into the stormwater drainage networks.

Major Science and Technology Project of Water Pollution Control and Management in China has carried out a study on identifying and correcting the misconnection of combined sewer systems in such cities **(Figure 3-6)**. Evidence shows that heavily polluted rivers in southern cities of China have a high COD level of 800-1100 mg/L, as a result of overflow pollution.[24] The average proportion of sewage discharged into stormwater pipes in the service area ranges from about 26.2% to 70%.[25]

3.3.3 Impact of cross-connections in separate sewer systems and sedimentation in the combined sewer systems.

Initial stormwater in combined sewer systems (CSSs) and CSOs are the main reasons for river pollution in wet weather. **Table 3-4** shows the concentration of overflow pollution in selected cities in southern China, France, Germany and the United States in wet weather. The concentration of COD in combined sewer systems is as high as 1200 mg/L in southern China, and the mean value is about 540 mg/L. In terms of separate sewer systems, the maximum and median concentration of overflow pollution are larger or even more than twice higher than other listed countries.

Figure 3-6 Survey results of illegal sewer system

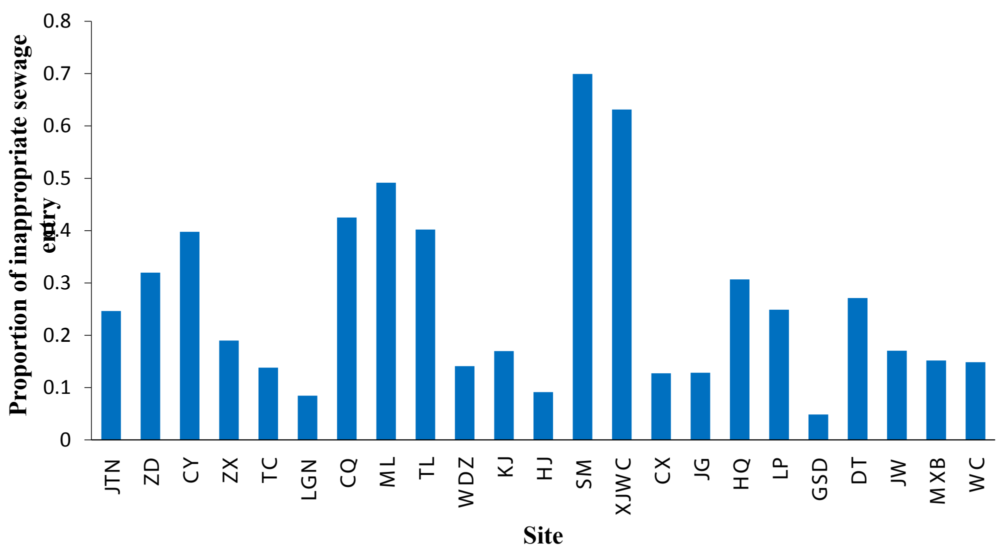


Table 3-4 Comparison of pollutant concentrations in combined sewer overflows during wet weather in southern China and some developed countries (unit: mg/L)[26]

Type	Region	SS			COD		
		minimum value	maximum value	median value	minimum value	maximum value	median value
Overflow in combined sewer system	French	240	670		350	570	
	USA NURP	270	550		260	480	
	Germany			174			141
	Shanghai	30	1322	362	113	1206	353
	Hefei	252	1764	538	139	632	250
	Zhenjiang	24	800	425	78	989	543
Overflow in separate sewer system	France	160	460		80	320	
	USA NURP	141	224		73	92	
	Germany			141			81
	Shanghai	48	1611	225	47	1090	190
	Hefei	73	1438	313~335	56	843	171~215

In conclusion, incomplete, misconnected and damaged pipe networks are the main challenges towards the rehabilitation of highly polluted rivers in developing countries. The success of the rehabilitation of highly polluted rivers depends on whether the problems related to the pipe networks are resolved.

Chapter 4

Practices and lessons from construction of urban drainage pipe networks

Proper design, construction and maintenance of drainage networks, sewage collection and interception, followed by proper treatment, and pollution load reduction in wet weather, are indispensable to reducing pollutants discharged from drainage systems in developing countries.

- Good planning and construction of urban drainage systems is important.
- Complete collection pipe networks should be extended properly to connect to sources of pollution based on investigations.
- Trenchless Pipeline Repair technology is recommended for pipeline restoration in densely built urban areas.
- Scientifically simple and low-cost tracing technology is a useful approach to solve sewage cross-connections.
- Application of patched Low Impact Development (LID), storage tanks, in-site sediment flush gates and hydrodynamic separators can achieve significant results in reducing pollution loads of overflow discharge in wet weather.

4.1 Urban planning and wastewater management

Well-constructed and functional drainage systems are the key to ensure urban river water quality. Urban planning needs to include specific drainage system planning. Countries, towns and urban areas, although at different stages of development, need to explore different strategies and approaches as they prepare context specific planning of the drainage systems. The application of planning tools, such as cost-benefit analysis (CBA) and ecological performance analysis, to determine the types of systems that best serve their respective cities, are inevitably necessary.

Most cities and towns in China have completed the planning of their drainage systems and have already built drainage systems and corresponding WWTPs in the last twenty years. For example, 140 years ago, Shanghai was China's first city to build modern drainage facilities with drainage pipes, and in 1921, they built the first sewage treatment plant.[27] However, a number of water bodies are still polluted to different degrees, some of them heavily. It is necessary to comprehensively assess and re-examine the aspects that need improvement in planning and construction of China's drainage systems, including improvements in the collection systems of pollution sources and strengthening supervision of the construction of quality of drainage systems. Without proper guidance and control, wastewater will still be discharged into rivers, harming the basin environment and human health.

It is necessary to continuously improve techniques of construction and management of drainage systems. In highly urbanized areas, especially in the central urban districts with heavy traffic and high population densities, apart from emphasizing proper design and construction of drainage systems, it is equally important to assess, evaluate and repair the existing drainage systems in order to address the cross-connection challenges, including groundwater leakage into the networks and sewage cross-connections.

Municipal stormwater drainage systems overflow during wet weather should be addressed thoroughly because the impact of wet weather outflows on water quality is significant. The wet weather outflows from stormwater pipeline networks of separate drainage systems carry pollutants from the ground and flush the sediments into water bodies. In some cities with separate drainage systems, the exit has different degrees of sewage cross-connections leading to the release of significant pollution loads into water bodies. In other cities with combined drainage systems, it is necessary to reduce the volume of overflows of stormwater and the concentration of overflow pollutants in wet weather. Improving the planning, construction and management of drainage systems in a comprehensive manner contributes effectively to the pollution control of the urban water environment.

4.2 Wastewater collection and interception

Lack of systematic urban planning under rapid urbanization in developing countries results in fragmented and incomplete construction of environmental infrastructure. The common phenomenon in urban drainage networks is that when the government department plans the urban sewage systems, the construction of household pipelines is often neglected. The main reasons for this in China include: a) the responsible officials lack professional knowledge and scientific evaluation methods, thus overlook or underestimate the need for sewage collection pipes; b) designers have biases and focus or prefer working on large design tasks, and easy and quick designs process; and c) the drainage pipeline builders do not have sufficient motivation to construct sewage collection pipes. China has profound lessons to learn in this regard and has taken many detours.

During urbanization, developing countries need to do their best to avoid the occurrence of such phenomena and consider the location, quantity and nature of pollution sources in the construction of sewage systems. Fortunately, with the continuous and rapid development of information technology, a large number of geographic information software, software data models and database systems have emerged that provide decision-makers a clear demonstration of the scope of the sewage networks required, and their transport capacity and mode, before constructing the sewage networks. Therefore, the identification of pollution sources and magnitude, the establishment of their database and the development of suitable sewage system models, have become an indispensable first step before the construction begins.

Drainage information systems include spatial and physical attributes of pipelines, nodes, outlets and pollution sources. Based on the information above, through field investigation or modern technology (drainage pipeline robots, periscopes, etc.), the type and nature, flow direction, structures and ancillary facilities on drainage pipelines, as well as locations and quantities of sewage outlets along rivers can be identified. By supplementing this part of the attribute data, the drainage information systems can be further improved to meet the requirements for efficient operation and management of drainage systems, and ultimately formulate the improvement plan for final sewage collection pipes.

Due to China's large size and number of urbanizing areas, the task of checking and repairing the sewage network is extremely difficult. On 12 October, 2006, the Chinese government issued the *Circular of the State Council on the First National Pollution Source Census.* The objectives of this census included the establishment of discharge amounts and places of industrial, agricultural and domestic pollution sources. With the support of the central government, the relevant functional departments cooperated actively with various scientific and research institutions to establish the geographic information systems (GIS) for a large number of urban pollution sources. Because of these databases, construction departments can clearly identify the tasks still needed to complete the laying of collection sewer systems and improve the efficiency and accuracy of construction.

Investigation and classification of urban pollution sources resulted in the establishment of a GIS database of pollution sources. Urban pollution sources included: pollution sources of enterprises and institutions, domestic pollution sources, industrial pollution sources and pollution sources of livestock and poultry.

In order to improve the accuracy of the investigation, it was necessary to follow the proper procedure: a) to conduct building-by-building investigation of industrial enterprises that produce wastewater; b) to conduct building-by-building investigation of industrial enterprises and general administrative enterprises together with institutions that do not produce wastewater; c) investigation and statistics of residential districts by residential committees or administrative villages; d) household-by-household investigation of livestock and poultry.

Case study 1:

Urban pollution source investigation

An investigation into pollution sources in Shanghai was conducted in 2000, and an information database of findings was established based on GIS **(Figure 4-1)**. Information from this investigation indicated that:

There were a total number of 55,979 pollution sources found in the city, and the total amount of sewage generated was 5.04 million tons per day. Among them, the total amount of untreated sewage discharged into the water body was 2.8204 million tons per day which accounted for approximately 56% **(Figure 4-3).**

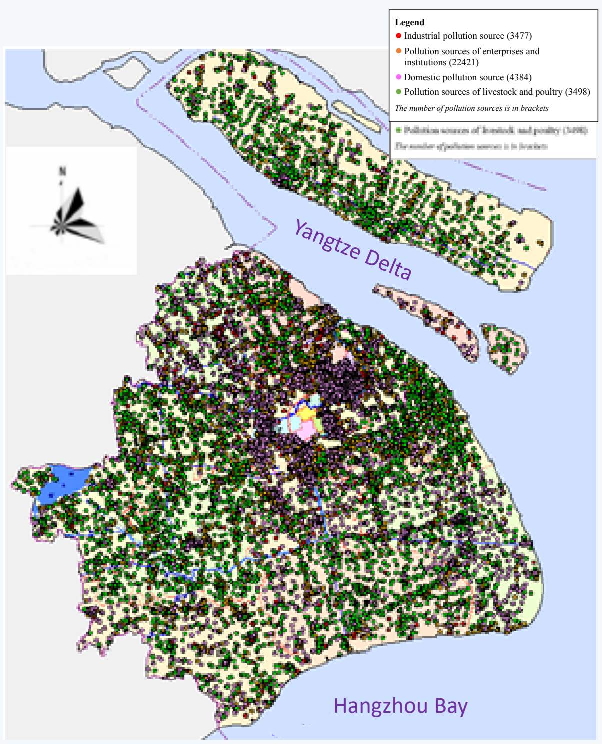


Figure 4-1 Distribution map of pollution sources found in Shanghai

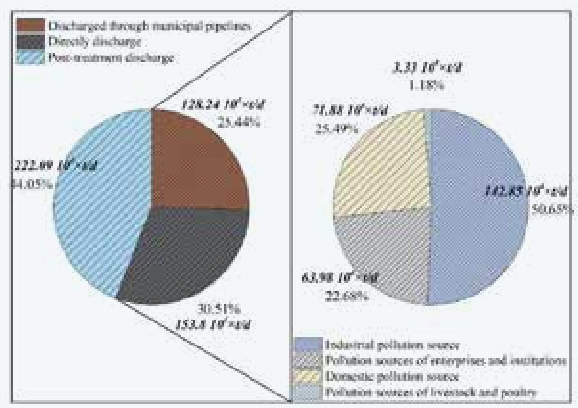


Figure 4-2 Pollution water distribution contributed by river discharge sources in Shanghai of 2000

According to the different source of discharging into the water body, the total amount of sewage discharged directly into the natural water body is 1.2824 million tons per day, accounting for 25.44%, and the total amount of sewage discharged into the natural water body through the municipal pipeline network was 1.538 million tons per day, accounting for 30.51%.

The total amount of pollution sources discharged into natural water bodies without effective treatment were as follows: 22,421 pollution sources were enterprises and institutions (639,800 tons of sewage water per day), 4,384 pollution sources were domestic pollution (18,800 tons of sewage per day), 1,868 pollution sources were livestock and poultry (33,300 tons of sewage per day), 3,477 sources were industrial pollution sources (1.4285 million tons of wastewater per day).

Based on the survey information of pollution sources, relevant government administrative departments can put forward corresponding countermeasures of source control, sewage collection, sewage transportation and sewage treatment.

Reference: *Survey of water pollution sources in Shanghai, 2000.*

4.3 Pipeline Repairs

Pipeline corrosion can not only cause water leakage out of the pipeline, but also can cause groundwater seepage into the pipeline; the former resulting in the direct pollution by wastewater of the environment, while the latter reduces the concentration of sewage discharged into urban wastewater treatment plant[16] thus decreasing the sewage treatment efficiency. In addition, pipeline corrosion also causes the sinking of the pavement above the pipelines, thus disrupting flow of traffic and pedestrians. Therefore, urban drainage pipes need to be comprehensively assessed and necessary repairs undertaken.

Pipeline repair technology includes traditional excavation technology and trenchless technology. Busy urban traffic, environmental requirements, cultural relics protection, crop and vegetation protection, as well as highways, railways, buildings, and rivers, etc. require pipeline owners and relevant government departments to minimize the excavation workload in pipeline construction. The use of traditional excavation methods inevitably affects social life and other human activities. Trenchless construction is advised.

Trenchless Pipeline Repair (TPR) technology is a type of subsurface construction work that requires few trenches or no continuous trenches. In the 1970s, Eric Wood, a British engineer, proposed this technology. The TPR technology has obvious advantages as far as engineering pipeline and structure (building) safety is concerned. Minimizing traffic disruption and disturbing soil/pavement structure have proven to be a much preferred approach. In 1990, seamless liner products came out, and this material can repair circular or egg-shaped pipelines. Its construction length can reach 135 m, while solidification time is only one hour.[28]

In China, the application of TPR technology and related equipment is still relatively limited. This lack leads to a higher cost of the application of trenchless technology, hence small and medium-sized cities are still dominated by excavation technology. Presently, the technologies being applied in China include spot in-situ curing method, stainless steel sleeve method, ultraviolet in-situ curing method, segment lining method, short tube lining method and expanding tube method.

The Chinese Government has realized the importance of pipeline repair, therefore, the Chinese government issued the *Guiding Opinions of the General Office of the State Council on Strengthening the Construction and Management of Urban Underground Pipelines* in June 2014, which set the following target: "By the end of 2015, the general survey of urban underground pipelines should be completed, a comprehensive management information system should be established, and the comprehensive planning of underground pipelines should be completed within five years to significantly reduce the accident rate of pipeline networks and avoid major accidents."

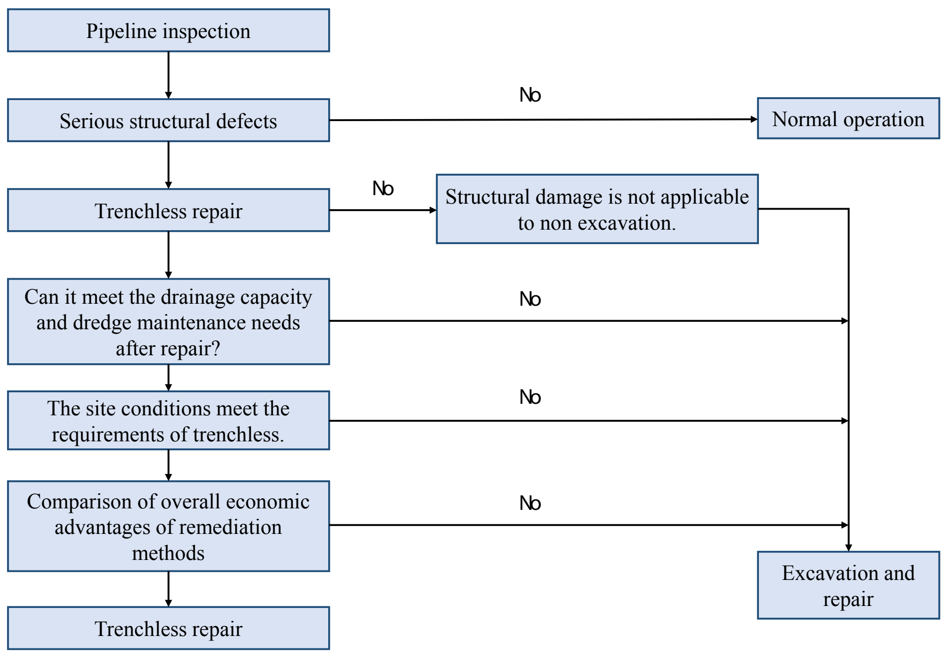


Figure 4-3 The diagram of assessment method for state and repair of pipelines

Case study 2:

The sewage pipeline repair project of Jiangyue Road (between Hengnan Road and Sanlu Road), Minhang District, Shanghai.

(1) Investigation and inspection of basic conditions of pipelines

In February 2014, a CCTV inspection was conducted regarding the sewage pipeline of Jiangyue Road (between Hengnan Road and Sanlu Road). It was found that the pipeline was seriously damaged with multiple corrosions and ruptures in the sewage pipeline. In addition, there were 28 leaks and one depression in the 15 sections of pipeline.

(2) Drainage pipeline evaluation

The sewage pipeline of Jiangyue Road had serious structural defects such as leakage and corrosion. Some sections had undergone uneven settlement, with a risk of pavement collapse.

(3) Design of a pipeline repair scheme

The design to repair the pipeline was aligned by the following basic principles: a) the load requirements of the pipeline must be met; b) the flow rate of the pipeline after repairing is similar with the original design flow rate; c) the technical standards of pipeline maintenance is not reduced. In-situ lining curing repair technology was applied to damaged and corroded pipelines. Since uneven settlement results in insufficient bearing capacity of pipelines, soil grouting is applied to increase the bearing capacity of soil around pipelines to avoid pavement collapse.

(4) Results of pipeline repair

The sewage pipeline repair project of Jiangyue Road was completed in 2016. After the completion of the project, according to CCTV inspection of the pipeline, structural defects such as leakage and corrosion were repaired completely.

Reference: *Junzhe, G., Discussion on the application of soil grouting and in situ curing and repairing technology. China municipal engineering, 2017(04): p. 34-36+39+107.*

4.4 Correction of sewage cross-connections

Proactive corrections of unauthorized or inappropriate entries to stormwater systems are being conducted in cities like Shanghai and Nanjing. Potential inappropriate dry-weather discharge may come from residential communities, commercial or administrative units, shops facing streets and industrial enterprises. There is also river water inflow or groundwater seepage into stormwater pipes.

Identified connection problems mainly arise from a range of circumstances. Firstly, there are separate pipes for sewers and stormwater drains under the municipal roads, but not in old urban communities. The old combined sewer pipes remain connected to the municipal stormwater drains to prevent flooding in case of rainfall. Secondly, there are cases where the laundry water is connected to downspouts due to the installation of washing machines on balconies. Thirdly, road wash or car wash wastewater is connected to stormwater pipes through inlets on the curb in some places. Investigation in China's southern cities show that the dry-weather flow with inappropriate entries of wastewater into stormwater pipelines could cover more than half of the total sewage output in the catchment area, and could be up to 70% in extreme case.

Current actions about correcting sewage cross-connections include rebuilding the drainage system in old residential communities as a separate system with parallel sewer and stormwater pipes. For improper use of separate stormwater pipes in newly built residential communities, a correction technique should be performed by designating balcony downspouts as sewer pipe and rebuilding additional downspouts. For the fully developed communities where developing a new separate sewer system in the near future is challenging, interception measures can be considered at the residential sewage outfall. By this method, dry-weather outflow from the residential community is intercepted into the sewer pipes under the traffic road, and the wet-weather flow in excess of interceptor capacity will be discharged into parallel municipal stormwater pipes. Such corrective action is easy because only a small part of road requires rehabilitation. However, the wet-weather pollution containing rainfall and domestic raw sewage remains a problem. While undertaking considerable investment and the commitment to rebuild the system as a truly separate system and to control the wet-weather flow should be encouraged in the long run, for the time being, the sewers in old residential areas are acting as combined systems.

Case study 3:

Identification of cross-connection sewage sources into stormwater drains using marker species

Correction of misconnected sources needs to proceed in a systematic way, through investigating areas causing problems from high to low potential and establishing priorities. Cost-effective methods of tracking or tracing cross-connection sewage sources are very important so that high-risk areas can be prioritized, and achieve a system-wide condition assessment. Most of the current urban drainage network inspections are predominantly conducted using physical methods such as CCTV (closed circuit television). However, these methods are labor-intensive when conducting a thorough assessment of the condition of the entire system. Additionally, the wastewater non-stormwater entry situation cannot be assessed from the quantitative perspective. Alternatively, novel low-cost methods based on water balance and chemical markers have been developed to trace and quantify non-stormwater sources with inappropriate entry into stormwater drains, while presenting a basic strategy for stormwater drain correction.

In the study site of the Caohejing urban drainage system of Shanghai, non-stormwater sources also found their way into stormwater drains and contributed significant pollutants to receiving waters, even resulting in serious black-odourous waters. Surveys showed sewage output arose from domestic activities (i.e., residential communities, commercial and administrative units) and industrial activities featuring semiconductor manufacturing. For this study site, source flow components of each cross-connection sewage source type were quantified based on measured marker profiles at catchment outfall in combination with chemical mass balance. The selected ideal markers for domestic sewage and semiconductor wastewater are total nitrogen or artificial sweetener acesulfame, and fluoride respectively. Additionally, there is potential groundwater seepage into stormwater drains, and the selected marker for groundwater is total hardness.

Table 4-1 Statistics of measured marker concentrations for non-storm source categories and catchment outfall

Chemical markers	Domestic sewage	Semiconductor wastewater	Groundwater	Catchment outflow
Total nitrogen (mg/L)	53.4±8.5	19.5±2.75	5.0±2.3	35.1±4.9
Acesulfame (μg/L)	15.1±8.8	1.56±0.032	0.02±0.002	9.09±2.2
Fluoride (mg/L)	0.36±0.09	10.6±1.41	0.37±0.16	1.27±0.05
Total hardness (mg/L)	162±24	92.8±10.8	416±50	204±14

Source apportionment results showed dominant illicit or inappropriate discharges came from domestic wastewater, covering approximate 64.5% of the total dry-weather outflow from the stormwater drains. Source flow component of groundwater seepage and semiconductor wastewater was 16.4% and 9.1% respectively. It was surprising that inappropriately connected domestic and industrial wastewater discharges covered almost half of the total raw sewage output in this catchment, indicating widespread wastewater entrance into stormwater pipes. Apportioned groundwater flow component did not indicate high groundwater flow and associated high risk for pipe defects. This showed that physical inspection for stormwater drainage system was not necessary.

Concentrations of possible sources | **Source flow components** | **Outfall water quality**

$$\begin{bmatrix} C_{TN,\,sanitary} & C_{TN,\,industrial} & C_{TN,\,groundwater} \\ C_{fluoride,\,sanitary} & C_{fluoride,\,industrial} & C_{fluoride,\,groundwater} \\ C_{hardness,\,sanitary} & C_{hardness,\,industrial} & C_{hardness,\,groundwater} \end{bmatrix} \cdot \begin{bmatrix} m_{sanitary} \\ m_{industrial} \\ m_{groundwater} \end{bmatrix} = \begin{bmatrix} C_{TN,\,outfall} \\ C_{fluoride,outfall} \\ C_{hardness,\,outfall} \end{bmatrix}$$

Figure 4-4 Calculation method of mixed pollutant concentration

Reference:

1 Xu Zuxin, Wang Lingling, Yin Hailong, Li Huaizheng, Benedict R. Schewegler. Source apportionment of non-storm water entries into storm drains using marker species: Modeling approach and verification. Ecological Indicators, 2016, 61:546-557.

2 Xu Zuxin, Wang Lingling, Yin Hailong. Quantification of Non-storm Water Flow Entries into Storm Drains using Monte Carlo Based Marker Species Approach. Journal of Tongji University (Natural Science), 2015, 43(11):1715-1721, 1727. (In Chinese)

4.5 Pollution control of wet-weather discharges

Unlike the pollution of first flush discharged from stormwater drains in the separate drainage system in developed countries, cross-connection is common in China, and the flow velocity of sewage in stormwater drains is lower. This allows pollutants to deposit and accumulate more easily, resulting in higher concentration of pollutants, more serious organic pollution, and greater contribution of sediment pollution load from the first flush discharge during wet weather. Therefore, it is necessary to take appropriate measures to control or reduce the deposit of pollutants in the drainage network and the deposition pollution load of overflow.

Case study 4:

Statistical results of wet weather discharges in some cities of China

Some researchers have collected samples 70 times from 12 separate drainage systems during wet weather in Shanghai. The concentration and load of pollutants discharged to rivers in wet weather from stormwater drains with the illicit connections were close to that of the overflows of the combined drainage system, which is significantly higher than that of the first flush discharged from the stormwater drains without the illicit connection.

In an analysis of pollution sources for combined sewer overflow (CSO) in Chaohu City, China, it was found that the pipeline sediments in overflow suspended particles contributed 46.3%. In the Overflow Pollution Load of a pumping station of a drainage system in Shanghai, it was found that the proportion of SS, COD, TN and TP in the total overflow load was 57%, 62%, 42% and 57%, respectively. Except TN, the contribution of sediments in other indicators was greater than that of stormwater runoff and sewage.

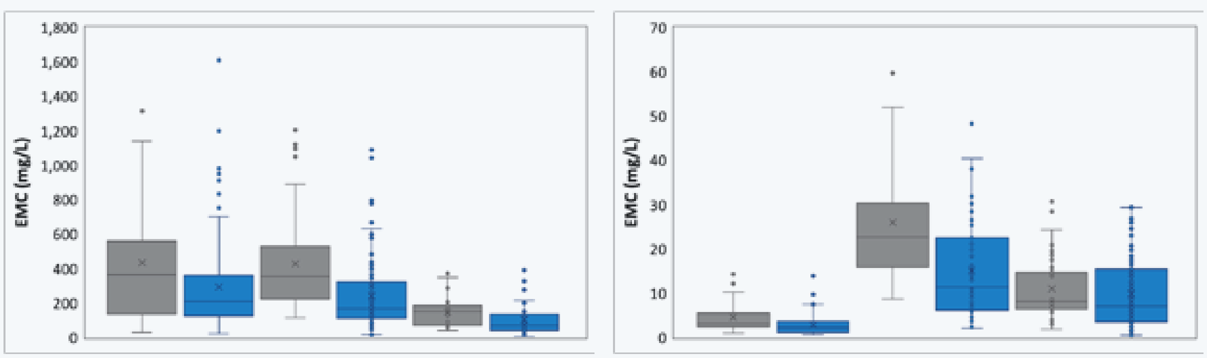


Figure 4-5 EMC concentration of pollutants discharged from combined sewer system and the separated sewer system with cross-connection

(The asterisk represents the outlier, the square represents the mean, the top edge represents the upper edge, the bottom edge represents the lower edge, the top edge of the rectangle represents the upper quartile, the bottom edge of the rectangle represents the lower quartile, and the middle line of the rectangle represents the median value.)

Reference: *Wu, Z., Statistical analysis of river drainage in Shanghai drainage system. 2015, Tongji University.*

4.5.1 Use of Low Impact Development (LID) to alleviate stormwater runoff and discharge pollution

Low Impact Development (LID) is an approach to land development that uses various land planning and design practices and technologies to simultaneously conserve and protect natural resource systems, reduce infrastructure costs, and control stormwater runoff volume, thereby reducing pollutant loading on receiving waters. In the 1990s, LID based on best management practices (BMPs) was implemented in the United States[29] and integrated the concept of stormwater management and resource utilization into sustainable drainage system planning.[30] The Washington, D.C. Department of Energy & Environment (DOEE) drafted an amendment on stormwater regulation, requiring new projects to capture 31 mm of rainwater. If the cost of the stormwater renovation project exceeds 50% of its own value, it shall meet the requirement of intercepting 20.3 mm stormwater.[31]

The adoption of LID for landscape design abounds. The gym of University of Minnesota uses LID facilities to infiltrate and purify stormwater, reducing the annual SS load by 70%.[32] High Point community in Seattle built a concrete pedestrian walkway to achieve zero outfall of stormwater runoff for a 24-hour storm with a return period of 0.5-year, with less peak stormwater runoff than before the development for a storm with a 24-hour duration.[33] Germany issued the Standard of Stormwater Utilization Facilities in 1989.[34, 35] The stormwater utilization project of Hannover Kongsberg City is a famous case. After completion, the regional runoff was 19mm/a, which almost reached 14mm/a---the same value as pre-development.[36] In order to solve the problem of waterlogging and overflow pollution caused by traditional drainage systems, sustainable urban drainage systems (SUDSs) mitigates environmental pressures from point and/or diffuse pollution from surface water runoff from polluted areas, degraded watercourses and erosion caused by increased runoff rates, combined sewer overflow spills, or minor and incremental flooding. It involves adoption of the policy; legislation; technical regulation and guidance; and training for both public and private sector. In Britain, SUDS was built into the Century Dome Demonstration project, the Barnes Wetland Park and the Olympic Park.[37-39]

LID, known as Sponge City (SC) in China, is being actively promoted and practiced by the Chinese Government. In April 2015, the Chinese government issued the Notice of the State Council on Printing and Distributing Action Plan for Water Pollution Prevention and Control (GUOFA [2015], no.17), and actively implemented the construction of LID models. From 2015 to 2016, China approved the construction of two batches of 30 sponge city pilot projects, focusing on addressing the water environment, water ecology and flooding problems in urban areas. Through the construction of sponge city pilot demonstrations, prevention and control of urban flooding and runoff pollution had been remarkable. A representative case is Beijing, the Future Technology City, where the collection and utilization of city road stormwater is located in Xiaotangshan town and Qija town, covering an area of 10km2, including 12 municipal roads, with a total length of 25km, to retain and store the runoff from rainfall with one year return period. More than 85% of the total annual runoff has been controlled, and SS load has been controlled more than 60% from the total.[40, 41] The sustainable drainage system project was constructed in the urban best practice area of the Shanghai World Expo, an area of 5.6ha, with the capacity to infiltrate 662m3 of stormwater in situ within three days.[42]

In some cities and areas from developing countries, with large urban populations and a high density of buildings, the available land resources are relatively limited, so the application of LID is difficult. The optimized layout method of the patch LID measure refers to a LID spatial entity with a certain scale, which is different in nature or appearance from the surrounding environment. The types and locations of LID patches are distributed according to different functions of land use and local conditions. It can make full use of dispersed and available urban land resources to deal with runoff, alleviate urban waterlogging and alleviate river stench, so as to avoid large-scale expansion of urban drainage systems and effectively reduce the design volume of rainwater storage tanks. The optimized layout method of LID provided an example for planning, development and design in highly urbanized regions of developing countries.

Case study 5:

The technology of controlling pollution in wet weather - LID patches

The area of a single drainage system in Shanghai is 3.74 km2 and the population density is 230 people/ha. The main underlying surface types are roof, road and green space, and the proportion of impervious area is 76%. The sewage cross-connections amount of this system is 17,305 tons/day, 46% of the total regional sewage, and the groundwater infiltration amount is approximately 3,624 m3/d. Two sewage interception pumps and six stormwater pumps are set on the end of the drainage system, and the mixtures of stormwater and sewage are discharged into the river by the pump during rainfall events.[8] In dry weather, pollutants in cross-connections sewages accumulated in the storm drains, and the overflow pollution included not only runoff pollution and cross-connections sewages, but also sediment erosion in pipe networks in wet weather, which had seriously polluted the river water environment quality, and was odourous.

Figure 4-6: Spatial layout of the LID patches in a drainage system

Based on spatial analysis in GIS, stormwater management model and pipeline sediment calculation method, the control effect of LID patches on wet weather discharge pollution in the pipe network was evaluated. The spatial layout information of available land in this area was extracted by GIS tools, and the arrangements of six kinds of LID patches included permeable pavement, sunken green belt, permeable pool, rain barrel, green roof, and grass ditch. This was carried out by combining the location of water accumulation points and runoff path (Figure 4-6). No overflow occurred for 6.5 mm of rainfall, therefore the overflow pollution was reduced by 100% (calculated by the concentration of suspended matter, SS). Under a heavy storm of 46.0 mm (peak rainfall is 27.7 mm/h), the overflow discharge can be reduced by 34% and overflow pollutants can be reduced by 19%. The above results indicate that the LID patches can effectively control stormwater pollution in pipe networks for highly urbanized region.

Reference: *Xu, Z., et al., Influences of rainfall variables and antecedent discharge on urban effluent*

4.5.2 Regulation and Storage Technical Methods of Drainage System Overflows and Initial Stormwater Discharges

Regulation and storage are an important method to control overflow pollution in drainage systems and initial stormwater pollution. In the 1960s and 1970s, the United States carried out a study on the control of overflow pollution from storage tanks. The city of Chicago built a large underground storage tunnel to reduce flood risk and stormwater pollution.[42]

In the second phase of the comprehensive environmental improvement project of Suzhou Creek in Shanghai, China, five underground storage tanks were built to control overflow pollution. As the first batch of China's storage tanks for combined sewer overflows, the operational results are remarkable; the reduction rate of the total overflow from these five storage tanks is 12.8% to 21.3%.[43] In Kunming, an important city in southwest China, 16 stormwater storage tanks have been constructed to address the challenge of initial stormwater pollution in the combined sewer system in the old city of Kunming. The total interception sewage volume of the above 16 storage tanks was 1868.73 m3 in 2008.[44] In addition, many cities, such as Beijing, Wuhan and Hefei, are also promoting the construction of storage tanks to control the pollution of urban drainage system overflows and the initial stormwater discharges.

The challenges faced by the construction of storage tanks in developing countries mainly lie in the universality of sewage cross-connections, substantial sedimentation and shortage of land resources. The impact of initial stormwater discharge and overflow pollution is increasingly attracting attention. When designing the capacity of the storage tanks, European and North American countries mainly consider intercepting the stormwater volume, while developing countries should also consider pollutant concentration from the drainage system and the water environmental capacity (WEC) of rivers. The variation of concentration in drainage systems in wet weather are related to the number of sunny days in the preceding period, pipe sediments, mixed sewage, rainfall characteristics and appropriate intercepting standards, etc. It is only when these factors are included in the design, that the storage tanks can truly control the overflow pollution and protect the receiving waters. Therefore, the design and operation of storage tanks should be based on those main characteristics of land conditions mentioned above for improved ability to control the pollution of urban drainage system overflows and the initial stormwater discharges.

Case study 6:

Design and analysis of storage tanks of separate sewer systems of high-density city in Shanghai

The covered acreage of drainage systems in Shanghai is 3.74 km2, 76% of which is impervious. 46% of sewage in this system comes from cross-connections.[7] Based on the calculation method of storage tanks from Germany, the total volume of storage tanks for the Shanghai drainage system is 17,054 m3.

However, considering the real conditions, in order to determine the influence of cross-connection and dry weather days before rain, the hydrograph of contaminants concentration and the hydrograph of flow are analyzed using a Storm water Management Model (SWMM). The input conditions were: cross-connection is 46%; sewer sediments are the main contribution causing overflowing pollution; 8 dry weather days before the rain; and rainfall duration is one hour and the rainfall depth is 8 mm. The Chicago rain pattern is used in the model. The result indicates that if the limiting concentration of COD is 100 mg/L for drainage during rainy days, the volume of storage tanks is 39,085 m3.

Thus, it can be concluded that the volume from the SWMM model is higher than that calculated by German formula. The difference is 22,031 m3. Furthermore, results indicate that the design considering various factors mentioned above can control the emission concentration to below 100 mg/L, but the design based on rainfall alone will lead to the fact that the COD concentration of stormwater discharge is higher than 300 mg/L, which causes serious overflow pollution.

Analyzing the contributing factors, it appears that it is cross-connection that leads to the difference. To be more specific, unprocessed sewage is connected to the separate stormwater pipe, and is discharged to the river directly. Moreover, the pollution from sewer sediment deserves more attention, which is considered an important contribution for overflow pollution. Otherwise, the pollution from discharge of initial stormwater in wet weather will be much more serious, which is difficult to control.

Reference: *Xiong L., et al., Influences of rainfall variables and antecedent discharge on design and analysis of storage tanks of separate sewer system of high-density city.*

4.5.3 In-line storage and optimal control of urban drainage system

In both developed and developing countries, minimization of the risk of wet weather sewer overflow is of great importance. In European and North American cities, the most evident solution is enlarging the infrastructure of the sewer system by adding in-line storage facilities. Construction of underground deep tunnels for temporary storage of stormwater and sewage are evidently key mitigation measures.[45, 46]

In old urbanized areas of developing countries, e.g. in China, historically the constructed sewers were designed to accommodate the stormwater runoff of one-year event or less, which have become insufficient to carry the load from the combined sewers during wet weather. Increasing the storage capacity of the sewer system by adding in-line channels, constructing new pipelines or expanding the existing ones, is not feasible in many cases, as they are particularly associated with crowded buildings and narrow roads. The method of choice in most developed countries, to build deep CSO storage tunnels 20 meters or more from the surface, involves high construction and post maintenance costs. In addition, implementation requirements and time to construct deep tunnels are also very high. If the same decisions were made in developing countries, we must be mindful that many cities may find themselves facing difficult financial constraints for both construction and follow-up maintenance. This has forced developing countries to look for improvement of the system operation performance, in combination of limited local conditions.[45, 47] Therefore, as an alternative, optimal control of urban drainage system is a reliable and cost-effective solution that improves the performance of urban sewers[47] and helps the system to achieve the CSO abatement objectives in a better way.

With the objective of maximizing the utilization of collection and storage capacity within the entire drainage system, optimal control of the urban drainage system is applied where all regulators such as sluice gates, weirs, valves or pumps are operated in a coordinated manner based on real-time information. In this way, discharges of sewer overflow into receiving waters should be minimized, and only occur if the available storage capacity has been used up. In Japan, optimal real-time control system was implemented in April 2000 at the Shinozaki pumping station, Tokyo. This system includes components such as prediction of rainfall and water level in trunk sewers, rational control and management of pumps and movable weirs, and efficient use of the storage or flow capacity of trunk sewers.[48] In Berlin, Germany, the demand for enhanced protection of the environment led to an increasing application of collection and storage capacities within the sewer system. After an overview of available storage capacities before and after realization of the rehabilitation program, the efforts to enforce real-time control at the Berlin system were addressed in the project "Integrated Sewage Management" (ISM) by the Berlin Centre of Competence for Water. The ISM project aimed to develop decision support tools for the planning and operation of the Berlin sewage system.[49] Evaluation of recorded data showed that coordination and global optimal control of sewer systems could help to reduce discharge volumes of sewer overflows by 70%.[50] Active studies and practical application are also being pursued in China. To implement the global optimal control of urban drainage systems on a large scale, smarter urban sewer modeling systems capable of on-line simulation, self-optimizing control and decision support, have been developed.[51, 52]

Case study 7:

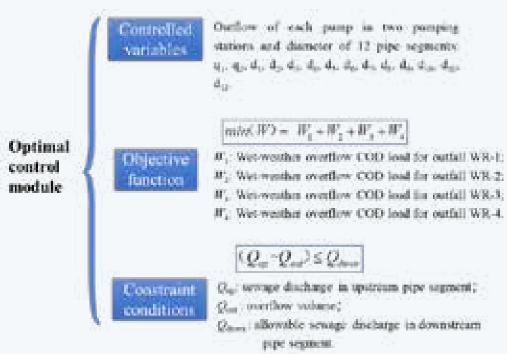
Optimal control and modification strategies for the urban sewers of China

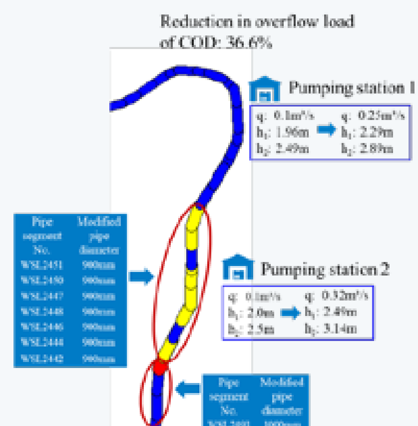
The demonstration site is in Eastern China, where the old urbanized area covered by the WWTP is 14.4 km^2, with a trunk sewer length of 58.3 km. The whole area can be divided into five sub-catchments, and two mid-way sewage pumping stations were installed. Due to the historical environmental impacts during the city's development, the area is characterized as incomplete and cross-connected urban drainage systems featuring constructed trunk sewers and associated local developed separate storm pipes or combined sewers. The sewage discharge intercepted into WWTP is 29,854 m^3•d^{-1}.

In the early stage of rainfall events especially under medium and high rainfall events, due to a "transportation bottleneck" in several key pipe segments, the combined waters are dammed up within the sewer network until a critical level is reached, and there is discharge from the combined sewer overflows. Activation of in-pipe storage and transportation capacity depends on the size of conduits and capacity of sewage pumps.

By developing sewer network modeling, the key components to exert influence on sewer overflow were determined for the whole sewer system, which were related to four sewage pumping stations and 23 pipe segments. Specifically, two sewage pumping stations and 12 pipe segments were located in the sub-catchment of east inner circle river, which was the top priority area for sewer system modification.

A global control of individual pump stations can lead to a uniform utilization of storage capacities. Furthermore, a global optimization scheme was presented by developing a self-optimizing SWMM modeling system that couples PySWMM platform and the Sobol algorithm. Specifically, for sub-catchment of east inner circle rivers, the reduction in total CSO load for COD will be 36.6% compared to 25.8% using a simple enumeration method, by upgrading the lifting capacities of two pumping stations and simultaneous modification of 12 pipe segments





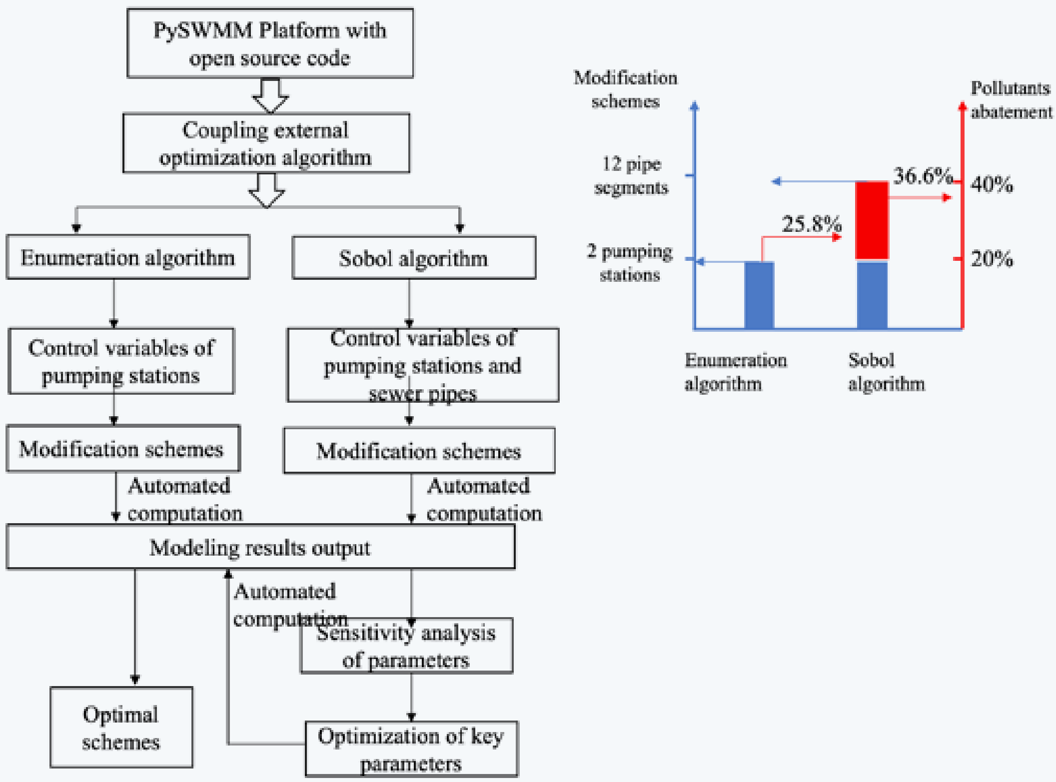


Figure 4-7 Representation of optimal control and modification schemes for the sub-catchment of east inner circle rivers

Reference: *Zhao, Z., The Development and Application of Optimization Regulation Model for Urban Drainage System Using Sobol Algorithm. 2018, Tongji University.*

4.5.4 Real time flushing gate for sediment deposits

A real-time flushing gate is very efficient for removing silt and sediments in drainage systems, and it has a low operating cost and requires no human manipulation. Due to these advantages, it has been widely used in Europe and the United States in recent years.

There are three typical forms of flushing gate for drainage pipelines, named Hydrass, Hydroself and Biogest. These techniques originated in Europe. These three flushing technologies are similar in principle and working process, which is to scour water waves formed by water storage and drainage, and has a strong scouring effect on the bottom sediment in the pipeline, thus removing silt. The difference between the scouring technologies above is mainly about methods for water storage. Hydrass' water storage is accomplished by hinged doors installed inside the pipeline at a closed state; Hydroself's water storage is accomplished by a reservoir built on the side of the pipeline wall; and Biogest's water storage is accomplished by a vacuum system.

In developing countries and regions with rapid urbanization, staggering of urban drainage systems is very common. The types of pollutants in drainage pipelines are complex, which brings difficulties to the application of a real-time scouring system, greatly increases its maintenance cost, and results in the pipeline management department facing some serious challenges. More importantly, the real-time flushing systems in Europe and the United States are taken into account while designing and constructing the drainage pipelines, so the flushing devices and drainage pipelines match each other, which make this combination much more effective. However, the application of real-time flushing systems has generally not been considered in developing countries during the design of the drainage system. Therefore, it is necessary for developing countries to research and develop approaches for the installation and operation of hydraulic scouring devices in the pipeline networks that have already been built and put to use in order to solve the problem of automatic clearance.

Case study 8:

China's expansion and innovation in sewer sediment control

In order to promote the application of automatic flushing devices, and according to the characteristics of pollutants in drainage pipelines in China, an automatic overturning weir plate interception flushing device for drainage pipelines based on spring compression was developed. This device is suitable for scouring sediment in stormwater pipes, sewage pipes and confluence pipes, at the same time. It is able to intercept mixed sewage and initial stormwater runoff in stormwater pipes. According to the characteristics of existing drainage pipelines in China, the automatic overturning weir interception and flushing device can be installed in inspection wells or interception wells. The overflowing pollution can be reduced by continuously scouring the pipeline through automatically opening and closing the overturning weir without power. The device has shown good results during its application in Chaohu City, China. It ensures that the average thickness of the pipeline sediment does not exceed 2 cm, requiring no manual dredging. The above features greatly improve the applicability of the real-time flushing device for drainage pipelines in China, and promote the general application of the device.

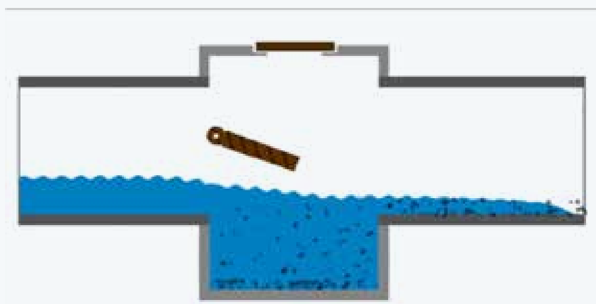


Figure 4-8 Schematic diagram of working principle of real time flushing system in drainage pipeline

4.5.5 Rapid separation or treatment of discharge in wet weather

The discharge from the drainage pipe networks in wet weather is a worldwide problem, which leads to the deterioration of the water quality of the receiving water body. Taking corresponding measures to quickly separate or remove the pollution load of the discharge in wet weather at the end of the drainage system can effectively control this problem.

In the pollution control of CSOs, some methods based on physicochemical principles, such as vortex separator, coagulation & precipitation, filtration and other measures, have been developed and applied in different developed countries for rapid separation or removal of discharged pollutants.[53-56] The centrifugal force formed inside the vortex separator by a high-speed tangential inlet result in effective separation of particulate pollutants. This also has characteristics of high load operation, low maintenance and no risk of blockage of particle impurities. Among them, Hydrodynamic Vortex Separators (HVS) can achieve efficient solid-liquid separation without power input and are more widely used. Since the 1960s, the swirl/vortex regulator- the separator (R, S), the US EPA swirl Concentrator[57, 58], Storm King® Overflow[57], FluidsepTM, Downstream Defender® and VortechTM Stormwater Treatment System[59] and other typical vortex separator were gradually developed, and widely used to control the pollution of combined sewer overflows in the combined drainage system and first flush of stormwater drains in the separated drainage system in Europe, the United States and other developed countries.

However, the inappropriate and unintended sewage entry into stormwater drains in the separated drainage system is substandard and common in the rapidly urbanized areas of developing countries, such as China. The traditional HVS is inefficient when dealing with particles of pollution discharged from those systems in wet weather, since they normally have a particles size much smaller than 75 μm.[60] Hence, it is necessary and important to improve the separation efficiency of fine particulate pollutants discharged from those systems in the developing countries. Moreover, it is hard for the traditional HVS to separate or remove the dissolved pollutants, such as dissolved organic matters, ammonia nitrogen, etc., discharged from those systems in wet weather. Some combination methods, such as flocculation enhanced vortex separation technology, achieve more effective separation of pollutants. Furthermore, land constraints in highly urbanized areas require a higher treatment capacity per unit area (m^3/m^2) of HVS. Therefore, it is necessary to improve the technology and method of the traditional vortex separation facility in order to more effectively control the pollution discharged in wet weather.

Case study 9:

Application of hydrodynamic vortex separation technology in a drainage system in Chaohu City, China

The fine and dissolved pollutants contributed more than 50% of the contaminants discharged from the drainage systems in wet weather. The combined process of flocculation and enhanced vortex separation can effectively improve the separation efficiency of fine particles and dissolved pollutants while maintaining the traditional vortex separation effect.

The combined flocculation-enhanced vortex separation process has nearly doubled the separation efficiency of 36μm inorganic fine sand particles. At the same time, it has a similar synergistic effect on organic particulate pollutants. With the aid of flocculants, the separation efficiency of HVS for SS and COD pollutants discharged in simulated wet weather reaches 57.5% and 34.8%, respectively. Compared to the vortex separator without flocculation-assistance, the separation efficiency increased by 50% and 60%, respectively, but the separation effect on TN and TP was not significant.

The city of Chaohu carried out a demonstrative application of the vortex to separate pollution loads discharged during wet weather. The separation efficiency of SS and COD pollutants discharged from a stormwater drain by HVS was 17.11-26.47% and 15.94-22.99% under two rainfall events, respectively, and the flocculation-assisted hydrodynamic vortex separation efficiency increased by about 50%. However, due to the influence of different rainfall conditions, the characteristics of pollutants discharged during wet weather were quite different, which can significantly affect the vortex separation efficiency. In conclusion, flocculation will be helpful for the separation of fine particles and dissolved pollutants, thus improving the vortex separation effect and the water environment.

Figure 4-9 First application of large-scale hydrodynamic vortex separator for wet-weather overflows in China

Reference: *Qianqian, M., Study on vortex separator and its strengthening technology to reduce overflow pollutants. 2016, Tongji University.*

Chapter 5

Finance and governance

Public-Private Partnership (PPP) models can provide an efficient way to address the investment gap for heavily polluted river rehabilitation, and also transform the management model from "construction-oriented" to "supervision and management".

A clearly designated principal-responsible mechanism can provide better coordination and cooperation among water-related departments for pollution control and environment protection of urban rivers to ensure sustainable development of water resources.

5.1 Finance

River rehabilitation is a systematic process. In recent years, markets and related enterprises for water basin rehabilitation in developing countries have developed. Due to increased prioritization of wastewater and sewer systems, and the good performance of enterprises managing sewerage systems in China, the sewerage systems that were previously not valued, have a promising future.

However, the demand for urban river pollution control is huge. For example, the market for comprehensive water environment management will exceed billions of US dollars in China, of which more than 50% will be for the rehabilitation of ecological landscapes and heavily polluted rivers. Unfortunately, for most developing countries, it is difficult to mobilize funding to support river rehabilitation.

Therefore, it is necessary to identify innovative financing sources for wastewater management and the rehabilitation of rivers. The participation of social capital, which means financing sources come from networks, groups of people and private enterprises, can complete the construction and maintenance of environmental public interests.

The Chinese Government has explored a variety of options. For example, in 2015, the Ministry of Finance and the Ministry of Environmental Protection issued *the Opinions on Promoting the Cooperation between the Government and Social Capital in the Field of Water Pollution Prevention and Control* that proposed the Public-Private Partnership (PPP) model. It improved the financing environment and the investment, guided the social capital to participate, and improve water pollution control capabilities. This was followed by the introduction of *Water Pollution Control Action Plan* that put emphasis on supervision and accountability, promoted diversified financing, and guided social capital investment.

The PPP model has proven to be very suitable for river rehabilitation projects. On one hand, it is easy to quantify performance, which is conducive to achieving the goal of river rehabilitation; on the other hand, technologies for river rehabilitation are relatively complex, and operation needs the participation of professional companies.

In the PPP model, the government pays for the bill according to rehabilitation results, and regularly assesses the investment governance of social capital and operation effectiveness in the project operation process. The assessment results serve as the basis for paying the operating expenses. The cooperation is based on the concept of "win-win" or "multi-win" on a project between the government, for-profit enterprises and non-profit enterprises. All the participants achieve results favourable to them.

PPP is a project-based financing activity, which is mainly based on the expected benefits, assets and the strength of government support. It is expected to broaden the financing for water basin rehabilitation and enable enterprises to participate in the preliminary work of project validation, design and feasibility studies, reducing investment risk, introducing the management methods and technologies into the project, and effectively implementing the control during construction and operations, which is conducive to reducing the risk of investment and protecting the interests of both the government and the enterprises. It shortens the construction cycle significantly, reduces the operation cost, and evens the assets-liability ratio.

The participation of social capital can solve the government shortage of short-term centralized investment, and also transform environmental management projects into cost-effective and manageable combined contracts. In this way, short-term rehabilitation and long-term maintenance will occur through multi-participation cooperation; the river rehabilitation process can be promoted; and stable operation of the rehabilitation scheme can be ensured. At present, the PPP project approach for river rehabilitation in China has been developed to a remarkable scale. By July 2018, the Ministry of Finance had recorded 131 PPP projects for river rehabilitation, with a total investment of 226 billion RMB (USD 33.6 billion).

However, there are still some problems encountered in the practice of PPP projects for river rehabilitation in China. For example, the implementation of the PPP projects for urban water environment governance does not include the repair and improvement of sewer systems. Because of the rapid development, the recorded information on urban sewer systems is not up to date and does not reflect the actual situation. Meanwhile, there are many problems in drainage networks, such as groundwater seepage, foreign matter penetration, pipe misconnection, pipe siltation, pipe network rupture, etc., making it more difficult to improve and repair sewer systems for incorporation into PPP projects of river rehabilitation. At present, most enterprises participating in PPP projects are comprehensive environmental protection service enterprises or cross-border ones with a strong capital basis. The enterprises specializing in comprehensive river rehabilitation are still few. Therefore, the professional expertise and technologies required to ensure innovative repairs of sewer systems are lacking, especially in high-density cities. If pipeline networ repair and improvement are included in river rehabilitation projects, the investment will be much higher, and the complexity and workload of later maintenance will be increased.

The next decade will be a critical period for the implementation of Sustainable Development Goals. Sustainable development of water resources is closely related to the effective rehabilitation of heavily polluted urban rivers in developing countries. Developing countries should allow the market to fully participate and allocate resources to investment opportunities offered. Governments should increase public funds and play the role that allows market forces to enlarge funding for this sector. Policies and markets should integrate organically to promote sustainable development of water resources and social economic development.

Case study 11

Public-Private-Partnerships (PPPs) in Fuzhou, China

There are 107 major rivers in the greater urban area of Fuzhou, the capital city of Fujian Province in China, with a total length of 244 kilometers and a water surface area of 5.31 square kilometers. Due to historical reasons and geographical conditions in Fuzhou, around 42 rivers forming the city's water system have been trapped and waterlogged (large amounts of stormwater exceed the capacity of sewer network) They have also been heavily polluted for many years.

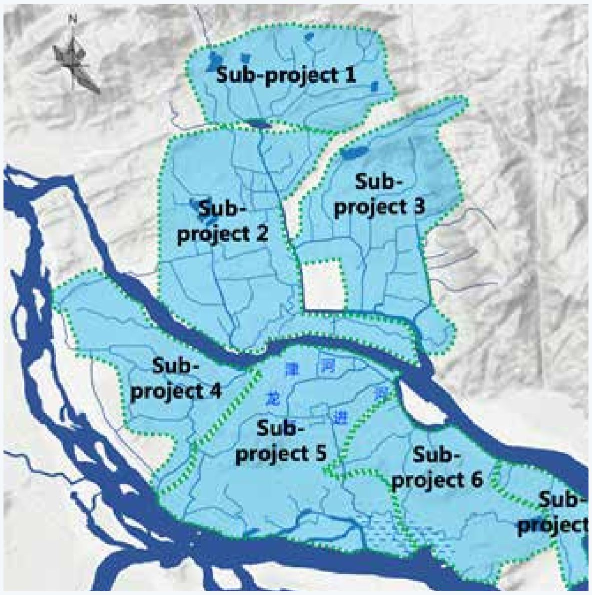


Figure 5-1 Map of the Fuzhou project area

In order to fundamentally solve the problem of these heavily polluted rivers, improve the water quality, and achieve cleanness of the urban water environment over the long term, the Government of Fuzhou launched the river rehabilitation project in September 2016. In December 2016, in accordance with the overall planning and regulation goals / objectives of the water system, the Fuzhou local government commissioned seven river rehabilitation project packages for 102 major rivers (including the 42 that were heavily polluted) and tendered the PPP projects. More than 1300 engineering projects are included in the seven PPP river rehabilitation projects packages, including sewage interception and storage, initial rainfall regulation and storage, pipeline silt removal, river dredging, interconnected river system network, ecological restoration and greening, intelligent stormwater management and other types of interventions, with a total investment of approximately 10.8 billion RMB (US$ 1.61 billion)

The PPP river rehabilitation in Fuzhou was envisaged as a cooperation between the government and social capital. Companies with different specialties first formed a joint venture company for bidding. The joint venture company that won the bid was responsible for completing the whole process of investment-construction-operation-transfer of the entire river rehabilitation project, and profited from the procurement of their collective services by government.

The project cooperation between the joint winning bidders (joint venture company) and the government was for 15 years (with construction periods between two to three years and; the operation period is 12-13 years). The joint company was responsible for the implementation and management of the whole process including project design, construction, and operation. The relevant government departments were responsible for the evaluation of river rehabilitation project construction and operation outcomes at different phases. During the operation period, a third party would evaluate the project of river rehabilitation, and the government would pay the operation fee year by year according to the improvements in water quality assessments. The PPP model could effectively solve the problems of funding, construction, operation and maintenance in river rehabilitation projects.

5.2 Governance

At present, developing countries often face a conflict between development and environment protection. If their focus is more on economic growth, the environment departments in the government are weaker.

Challenges are also linked to inadequacies in administration. Instead of establishing a systematic approach, construction and management of urban drainage systems are often fragmented. Moreover, many river basins do not match the administrative divisions of government, and tasks of many water-related government departments overlap, resulting in unclear allocation of responsibilities. The integration between river ecological environments and administrative divisions is not uniform, resulting in the inability to form a watershed concept in river management among regions. In addition, the many existing water-related departments have unclear mandates and responsibilities, a common phenomenon in developing countries.

To deal with river pollution control, it is necessary to establish comprehensive arrangements with clear responsibilities. Governments should promote efficiency in rehabilitation through strict supervision and regular evaluation with the objective of ensuring sustainable development of water resources.

In some local governments in China, the principal, that is either the mayor or the director-general, bears the full responsibility of ensuring that river water is of good quality, and therefore leads the management and protection of the river basin.

To address the challenges outlined above, the principal office bearer consolidates and coordinates the implementation of tasks between different units, which greatly improves their execution, and mobilizes the public to be involved. This is a problem-oriented approach that addresses the perennial problem of coordinating water management. The Principal in charge coordinates various aspects - legislative, economic and technical, and directs junior government officials, which significantly enhances the supervision capacity of the local environment. This strengthened mechanism can coordinate various departments effectively, protect the environment through various interventions - by means of law, economy and technology. Thus local leaders make better environmental decisions and directly and effectively oversee the ability of the local government to execute its environmental regulatory responsibilities.

In recent practice, the Chinese Government has realized the importance of sewer systems. Experience has demonstrated that, if this matter is not solved, river rehabilitation will face the predicament of "repeated problem and repeated rehabilitation". Placing urban drainage network restoration and renovation under the daily management of PPP projects can fundamentally address the current situation of urban sewer systems. The operation and maintenance of urban sewer systems is also required to explore new models, which can mobilize specialized operation and maintenance teams, and utilize professional experts, new technologies and management approaches that effectively cover four stages of "investigation, diagnosis, treatment and maintenance".

The new operational arrangements will be responsible for the management of the whole process: urban sewer system operations, and solving the existing problems. Governments carry out the assessment of the operation and management of urban sewer systems, and implements the transformative management model that includes "construction-oriented" and "supervision and management".

Case study 12

River Chief in China

While promoting the rehabilitation of heavily polluted urban rivers, the Chinese government is also committed to instituting innovative management arrangements. In December 2016, China's Government issued the *'opinions on the comprehensive implementation of the river chief system'*, which called for the full establishment of the river chief system by the end of 2018, in order to comprehensively address the perennial challenges of river management and protection. For the rehabilitation of heavily polluted water, the river chief system requires the principals in charge of Chinese Government at all levels to be the first responsible Officers for the management and protection of rivers and lakes within their jurisdictions and to mobilize investments required from government and the private sector. The system integrates the executive force of local governments to the greatest extent, effectively reduces regional and departmental conflicts, forming coordinated governance which provide a good example for the river rehabilitation to developing countries.

Chapter 6

Comprehensive rehabilitation of Suzhou Creek in China, a successful case of heavily polluted urban river basin

The experience from Suzhou Creek rehabilitation project has proven that there are significant gains to be achieved from prevention and control of pollution, systematic planning and effective governance.

The rehabilitation of Suzhou Creek greatly improved the urban environment, the quality of life and the health of citizens that is critical for sustainable development of Shanghai.

6.1 Background of Suzhou Creek

Located downstream of Yangtze River which discharges into the Pacific Ocean, Shanghai is one of the fastest growing regions in China, with the highest level of economic development and urbanization (Figure 6-1, Figure 6-2). In 2016, the population of Shanghai reached 24.2 million, with an area of 6340.5 km².

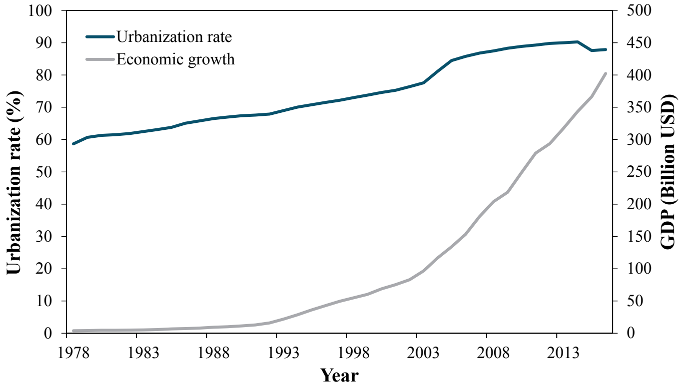


Figure 6-1 Urbanization rate of Shanghai (1978-2016)

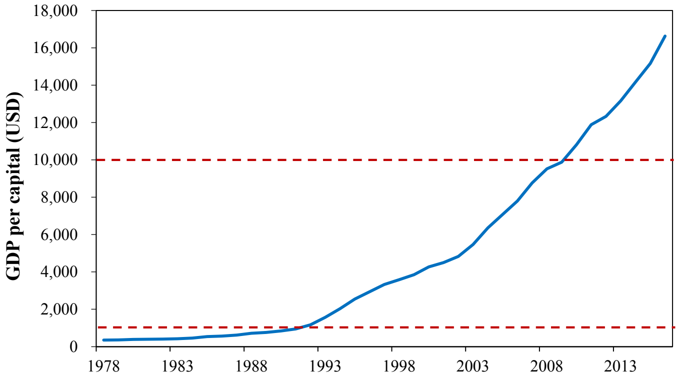


Figure 6-2 GDP per capital of Shanghai from 1978 to 2016

Suzhou Creek is a very important water body in the history and development of Shanghai. Both sides of the river nurtured modern China's industrial civilization, and together with the Huangpu River, it is known as the mother river of Shanghai.

Suzhou Creek is 125 km long. The segment of the river in Shanghai is about 53.1 km, and the length in the urban area is about 23.8 km (Figure 6-3). It traverses through nine administrative districts in Shanghai, including the most densely populated and most prosperous downtown area.

Originally, the water quality of Suzhou Creek was clear. During the period of 1914-1918, due to the increase in population and acceleration in industrialization in Shanghai, a large amount of domestic sewage and industrial wastewater were discharged directly into the river, gradually polluting the water quality. By 1920, some segments of the river had become black and odourous; and by 1978, the entire river was polluted.

Fish and shrimp were extinct in the 1980s and by 1999, Suzhou Creek was black and odourous for most of the year. Residents living along the river dared not open windows and pedestrians passed by with their noses covered. The extremely black and odourous Suzhou Creek had a negative impact on the urban landscape and human settlement, which was at variance with the image of Shanghai as an international metropolis.

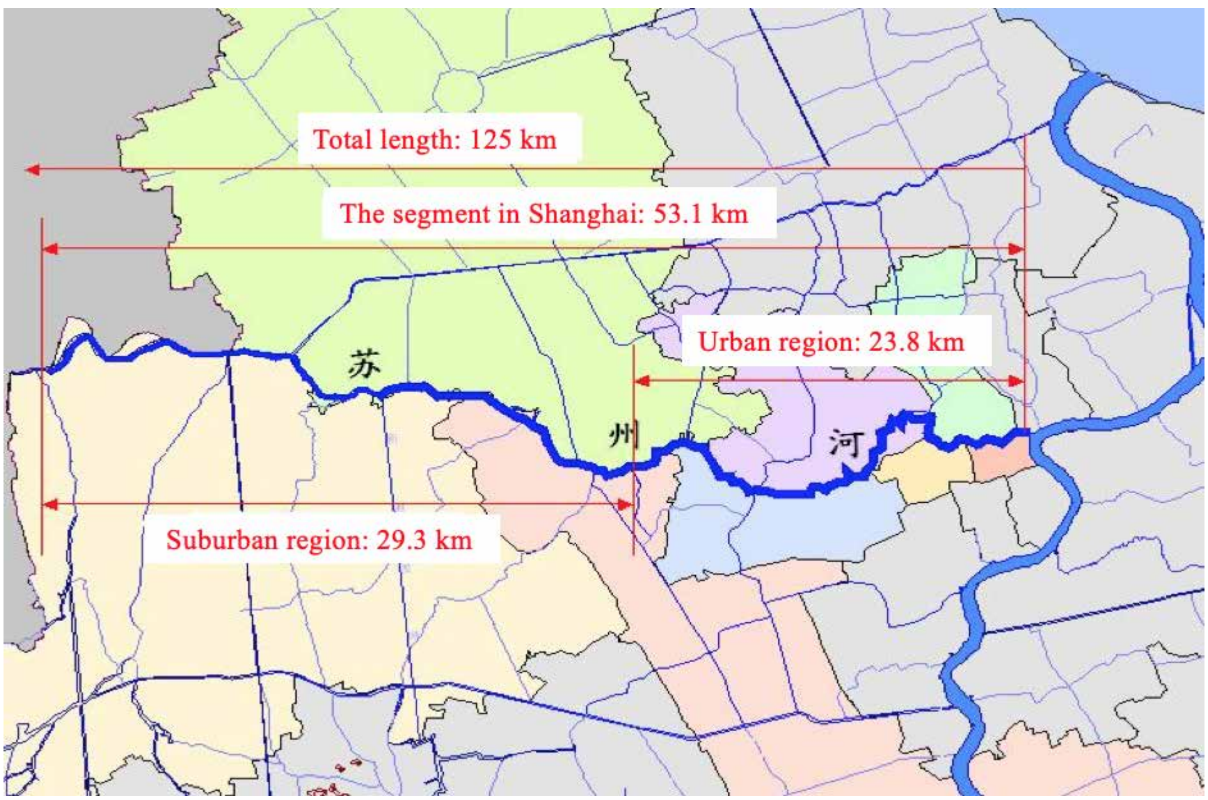


Figure 6-3 The map of watershed of Suzhou Creek

6.2 Major phases of rehabilitation

The rehabilitation of Suzhou Creek began in the 1980s.

In 1996, the government of Shanghai established a group to coordinate the rehabilitation of Suzhou Creek.

The main actions undertaken were:

- **Shanghai Combined Wastewater Treatment Project (1988-1993)**

  The implementation of the Shanghai Combined Wastewater Treatment Project began in 1988 and was put into operation in 1993 to collect domestic and industrial wastewater within the urban areas, to be transferred to WWTP for treatment. Approximately, 1.4 million m3 of sewage was collected by the system per day.

The COD of the main stream of Suzhou Creek was reduced from 150 mg/L to 80 mg/L. This laid a good foundation for eliminating the blackness and odours from the creek and improving the water quality down to the lower reaches of the Huangpu River.

In 1998, the Shanghai Suzhou Creek Rehabilitation and Construction Company was established (Figure 6-4).

- **The first phase of Shanghai Suzhou Creek Rehabilitation Project (1998-2002) Investment: 7 billion RMB (US$ 1.04 Billion)**

The objective of the project was to eliminate the black and odourous phenomenon occurring in dry weather.

Actions undertaken included: interception project of six tributaries; the Shidongkou WWTP project; comprehensive water diversion project; construction project of control gates; dredging project; re-aeration project; garbage collection stations and surface cleaning project; flood control wall renovation project; dry sewage interception project in Hongkou Port and Yangpu Port area; and Hongkou Port water system improvement project.

The Shanghai Committee and Government issued the Decision on the Enhancement of Environment Protection and Construction in 1999. The decision instructed the city management to prioritize implementing construction measures to improve the environment of Suzhou Creek from 2000 to 2002, and promote the rehabilitation of other rivers in Shanghai through the treatment project.

Inappropriate pollution identification technology, pollution traceability technology in sewer systems, river network discharge inventory analysis technology, tidal kinetic energy hydrodynamic control technology, and comprehensive water quality quantitative evaluation technology were developed to enhance the impacts of the sewage interception project. Tidal power was used to regulate water flow by building an estuarine lock in Suzhou Creek. By the time the project was completed in 2002, the black and odourous phenomenon in dry weather was eliminated.

- **The second phase of Shanghai Suzhou Creek Rehabilitation Project (2003-2005). Investment: 4 billion RMB**

The objective of the project was to eliminate the black and odourous phenomenon occurring in wet weather

Actions undertaken included: reducing overflows of municipal pumping stations along the Suzhou Creek during wet weather; the interception project in the middle and lower reaches; the sewage collection system project in the upper reaches of Huangdu area; construction project of sluices in Suzhou estuaries; greening project on both sides; Mengqing Garden Phase II project; environmental sanitation project of the city; and reconstruction of Tibet Bridges.

The project put water rehabilitation at the center, addressing the symptoms and focusing on the root causes. Sewage interception, pollution control and ecological restoration continued to be focused on in this phase so as to systematically and comprehensively advance the improvement of the water environment and the transformation of the environment in general across the straits.

- **The third phase of Shanghai Suzhou Creek Rehabilitation Project (2006-2008) Investment: 3.14 billion RMB (US$ 0.47 billion)**

The objective of the project was to continue to improve water quality

Actions undertaken included: sediment dredging project; flood control wall reconstruction project in urban sections; sewage interception and pollution control project; auxiliary sewer system project focusing on sewage treatment plant in Qingpu District; relocation project of sanitation or garbage wharf in Changning District; and comprehensive supervision and management project.

Whether it was the flood control wall, or the environmental protection docks, sewage docks, garbage docks, and even the buildings on both sides, all were the focus of this rehabilitation phase. In 2008, after the completion of the main works of the third phase project, the Suzhou Creek aquatic ecosystem had been restored.

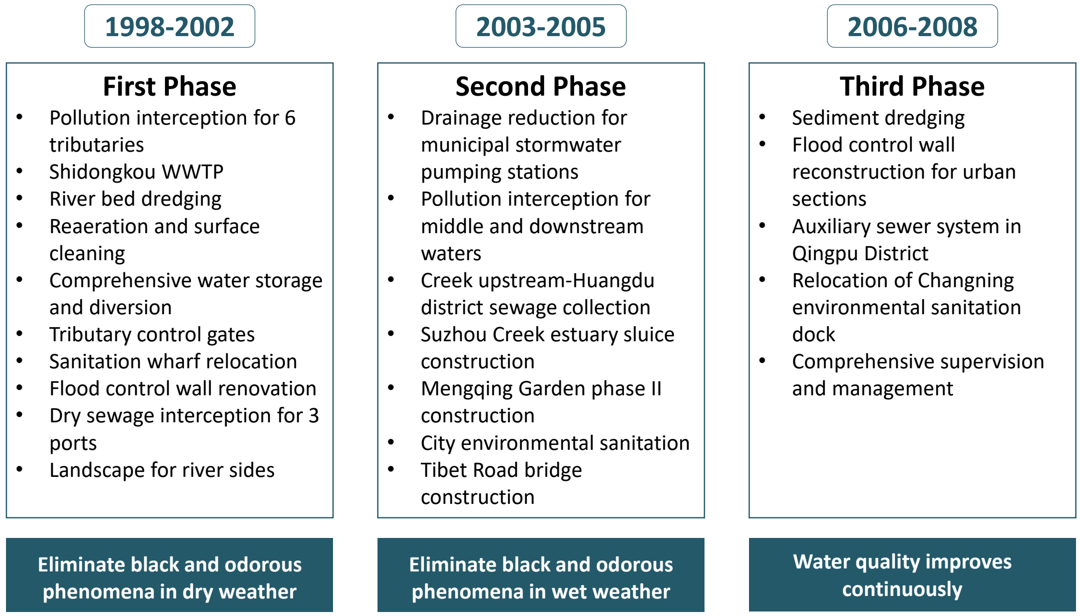


Figure 6-4 Summary of interventions and results from the Shanghai Suzhou Creek Rehabilitation Project - first phase to third phase

6.3 Technical measures

The main stream of Suzhou River is 53.1 km in Shanghai, covering an area of 855 km2, with more than 20,000 rivers, and thousands of pollutant sources. The complex system of pollution migration and transformation from the diverse river networks, huge pipeline network, numerous pollution sources and controlling gate groups all discharge into the outer rivers and seas. Among the international urban river management cases, the Suzhou Creek system counts as one of the most complex. The approach adopted included collecting pollution discharged directly to Suzhou creek in dry and wet weather, improving water fluidity to increase the self-purification capacity of the water body and advanced tools for supporting a water environment management decision system.

Most of the issues regarding where the pollution comes from and how to control the discharge are also faced by other countries or urban areas, and the rehabilitation of Suzhou Creek provides lessons to other developing countries.

(1) Sewage interception projects

According to the present pollution control facilities and sewage outlets, the Suzhou Creek is divided into three regions: the six tributaries of the Suzhou Creek located in the middle reaches, the upper reaches located in the west of middle, and the lower reaches located in the east of middle (Figure 6-5). Sewage interception and pollution control are designed in these areas for optimal performance.

Villages and towns surround the upper reaches of the Suzhou River system. Due to a lack of sewer systems, sewage basically drains into the rivers. Because upstream pollution sources are concentrated in the town areas, and the distances between towns are large, sewage collection and treatment in the upstream villages is combined with small sewage treatment plants and decentralized treatment methods. Corresponding collecting sewers, interception pipes and lifting pump stations are laid at pollution sources. Other decentralized treatment facilities are also built to intercept the sewage.

The middle reaches are urbanized areas where sewage is mainly discharged into the tributaries of the Suzhou Creek or small rivers with water dispatching pump stations. The main task of these areas is to improve the collecting sewers and increase the coverage of sewer system. Here, the biggest challenges are to collect sewage directly discharged into small rivers, regularize illegal buildings on the urban edges, intercept sewage to the six tributaries, and stop sewage from draining directly into tributaries.

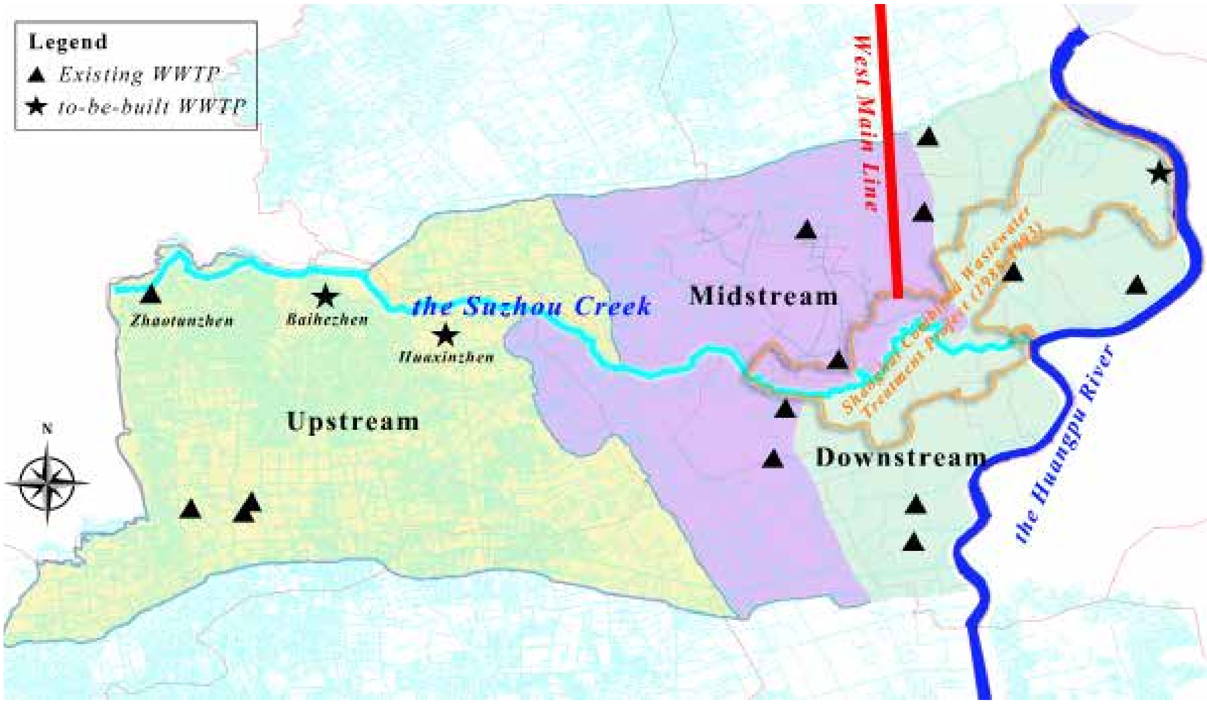


Figure 6-5 Planning area of Suzhou Creek rehabilitation

The downstream area was the city area with the highest population density, heavy traffic, and many skyscrapers, so it was difficult to build collecting sewers. Based on local conditions, rehabilitation planning was designed for the whole system while interception measures were different in various areas. Taking the main stream of the Suzhou Creek as the boundary, the downstream areas were divided into the northern part and the southern part. The northern area of the Suzhou Creek was divided into two regions. One was within the service scope of the combined sewage system and connected to the combined sewage system. The other one worked in a separated system and was serviced by the new wastewater treatment plants. The southern area of Suzhou Creek was connected to the separated system under construction at that time. Meanwhile, sewage interception facilities were built in dense residential areas with substantial misconnected sewers. Sewage in dry weather was transported to WWTPs.

The main outputs of the sewage interception projects were:

- Constructed 40 km of interceptor sewers, 165 km of collectors and branches, and 20 pumping stations for six tributaries of Suzhou Creek, intercepting an average of 230,000 m3 of sewage every day.
- Constructed 26 km of interceptor sewers, 26 km of collectors and branches, and eight pumping stations for wastewater interception for Hongkou Gang and Yangpu Gang, intercepting an average 320,000 m3 of sewage every day.
- Constructed a sewage treatment plant with a capacity to process 400,000 m3 of sewage per day.
- Interception of 400,000 m3/day of wastewater entering Suzhou Creek and tributaries, and transporting it to WWTPs for treatment and disposal.

Sources: Suzhou Creek Rehabilitation Project (Loan 1692-PRC) In the People's Republic of China

(2) Overflow control

After completing the Phase I of the Suzhou Creek rehabilitation project, the sources of pollution in dry weather periods in urban areas have been effectively controlled and managed. While the general water quality is improving, it still fluctuates.

There are 37 municipal pumping stations along the river, serving to transport sewage during dry weather and to prevent urban waterlogging during wet weather.

However, these pumping stations cause overflow when it rains. A large amount of sludge was discharged into the river by pipelines with stormwater and sewage, resulting in the re-pollution of the Suzhou Creek. Therefore, while ensuring the safety of the urban area from flooding, the capacity of the existing drainage and built storage facilities have to be fully utilized in order to reduce the initial stormwater overflow into the Suzhou Creek and to protect the water quality.

Between 1996 and 1999, the 37 municipal pumping stations discharged a total of 30.05 million m3 and 4,320 tons of COD into the river. The highest COD concentration of pollutants, detected by municipal pumping during the initial rainwater discharge, reached 1,500 mg/L.

The main measures taken to address this phenomenon were:

Municipal pumping station interception reform: Revamping or adding sewage interception pumps in pumping stations to improve the sewage interception rate and eliminate overflow in dry weather periods.

Optimizing the operation of municipal pumping stations: The operation mode of municipal pumping stations along the Suzhou Creek was optimized and adjusted. The municipal pumping stations that were mainly focusing on the function of flood control before now gave equal attention to both environmental protection and flood control. The operation strategy of municipal pumping station in dry weather now mainly operates at high water level, reducing sewage pump operating frequency, using the large amount of flow sewage interception pump operation to hydraulically dredge and scour the pipeline network, thereby reducing the pollution load of overflow sewage.

The pre-emption method before rainfall in municipal pumping stations reduces the water level of the drainage network in advance, fully using the storage capacity of the network to reduce the amount of overflow sewage in wet weather periods.

In 2001, after the operation optimization, the annual discharge capacity of the 37 pumping stations along the Suzhou Creek was 16.65 million m3, about 40% lower than that before the optimization.

Wet weather storage tank construction at municipal pumping stations: Five new storage tanks in Mengqing Park, Chengdu Road, Furongjiang Road, Changping Road and Jiangsu Road, are used to intercept initial stormwater along the Suzhou Creek. The total storage capacity is over 50,000 m3, thus solving the pollution problem of overflow and drainage into major municipal pumping stations during wet weather periods.

With the storage tanks constructed, annual COD load discharged into the Suzhou Creek has been reduced by 2,300 tons, or approximately 53%.

Major outputs of this project were:

- Constructed five wet weather storage tanks, the total wet weather storage capacity increased from 0 m3 to 50,000 m3.
- The interception ratio of the original combined drainage system was increased from 1.5 to 3.0.
- The discharging frequency of pumping stations was reduced by 70%.

Sources: Post doctor report by Hua Ming

(3) Water quality improvement

The flow direction of Suzhou Creek is bidirectional based on tidal action whose upstream receives the discharge from downstream of Taihu Lake basin, and the downstream receives the tide from the Yangtze Estuary and Huangpu River. Therefore, the average annual discharge of Suzhou Creek is small, leading to a small water environmental capacity (WEC) and insufficient self-purification capacity. Thus, it is difficult to improve the water quality even if point source pollutions are intercepted completely. Therefore, it is very important to improve the hydrodynamic force of the flow and to increase the net discharge of the main river and tributaries of Suzhou Creek.

If a pump station is built to improve hydrodynamic conditions, considerable operating costs are involved. At the same time, according to the tidal characteristics of the system, discharging through sluices can increase flow rates and flow velocities which will improve water quality. There are many sluices in the Suzhou Creek, some being used as diversion gates. They are opened to divert water during high tide and closed at low tide to prevent outflow of water. Some sluice gates are used as drainage gates, and the ebb tide is opened and drained. As a result, the main stream and tributary of Suzhou Creek changed from tidal reciprocating flow to unidirectional flow (Figure 6-6). In this way, the tidal backwater effect was eliminated, while the net discharge, dissolved oxygen concentration and self-purification ability were improved. Through the regulation of the water flow, the average discharge of the Huangdu section in the upper reaches of Suzhou Creek increased from 8.7 m3/s to 15.25 m3/s. The downstream average flow of Zhejiangluqiao increased from 12.2 m3/s before water diversion to 39.54 m3/s. The COD of Beixinjing, Wuningluqiao and Zhejiangluqiao improved (Figure 6-7). Wuningluqiao decreased by 20 mg/L, and that of Zhejiangluqiao decreased by nearly 30 mg/L compared with previous figures. The COD of Wuningluqiao was reduced by 50 mg/L, and that of Zhejiangluqiao was reduced by 30-50 mg/L compared to previous figures. This shows that under normal water and weather conditions, the Suzhou River was changed from a bi-directional to uni-directional flow through the estuary gates, and the water quality of the middle and lower reaches (especially the section from Beixinjing to Wuningluqiao) was very much improved.

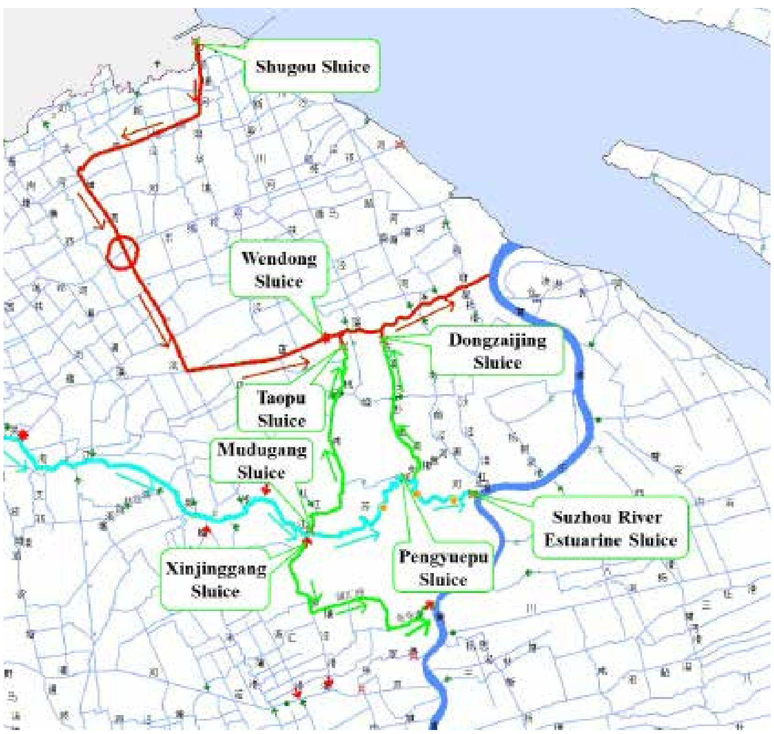


Figure 6-6 Sluice gates in Suzhou Creek

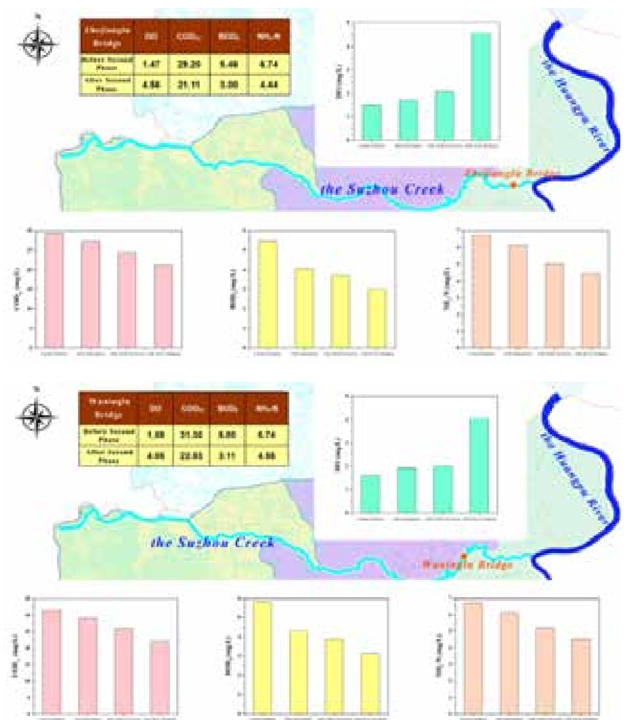


Figure 6-7 Water quality of sites at the Zhejianglu bridge and Wuninglu bridge

(4) Water Environment Decision Support System

Water environment management decision support systems (DSS) are an important supplementary tool in river pollution control planning. In order to establish a reliable decision support system, a survey of pollution point sources to the water environment was carried out in Shanghai in 2000 and completed the survey of pollution sources within 855km2 of Suzhou Creek basin. By using monitoring data of hydrology and water quality, systematic laboratory research and comparative analysis with foreign river research results in a synchronized manner, pollutant migration and transformation in Suzhou Creek was systematically studied. The Water Quality Analysis Simulation Program (WASP) model was redeveloped, and the mathematical model was calibrated and validated by using synchronized monitoring data for three consecutive years. The hydrodynamic and water quality models of Suzhou Creek, Yangtze River Estuary and Hangzhou Bay were then established, as well as the DSS for water environment management **(Figure 6-8).**

DSS uses model-based systems, pollution source database systems and human-computer interaction systems to integrate GIS, environmental information, prediction models and decision support into a unit. With information input of geographical areas and pollution sources, it generates computational grids, and can simulate hydrodynamic and water quality changes in a dynamic way. It also connects a hydrodynamic model, water quality model and engineering analysis model, based on the MapInfo platform. It has the following characteristics: (1) Visualization: visual graphics, animation or charts are used for interface operations, data processing and result expression; (2) Integration: Environmental GIS, Model-Based Systems, Pollution Source Database Systems and Engineering Analysis Systems are organically linked to ensure the function of the system; and (3) Scalability: users can input environmental models and data resources.

The DSS assists with evaluations at each point in time to enhance the decision-making process for the operations of the rehabilitated Suzhou Creek.

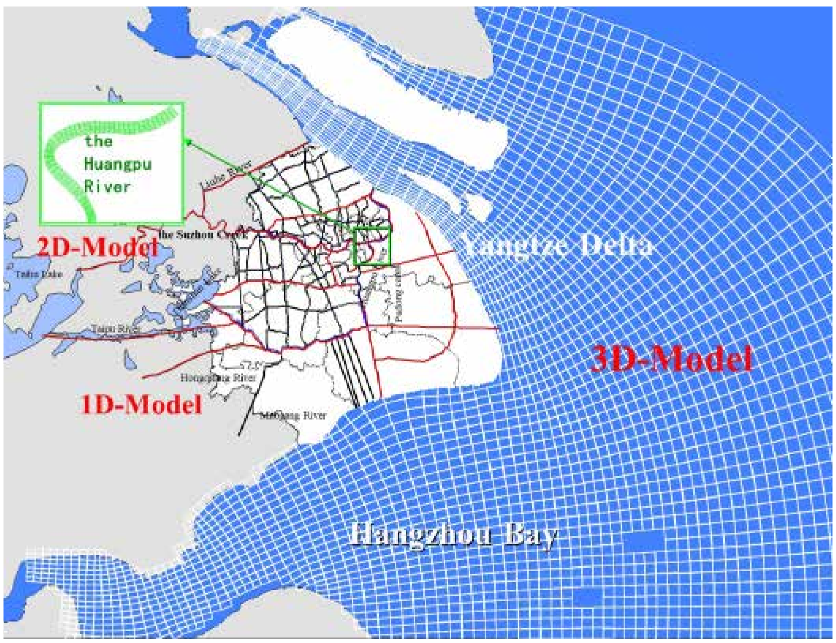


Figure 6-8 Schematic diagram of hydrodynamic and water quality models for Suzhou River, Yangtze River Estuary and Hangzhou Bay

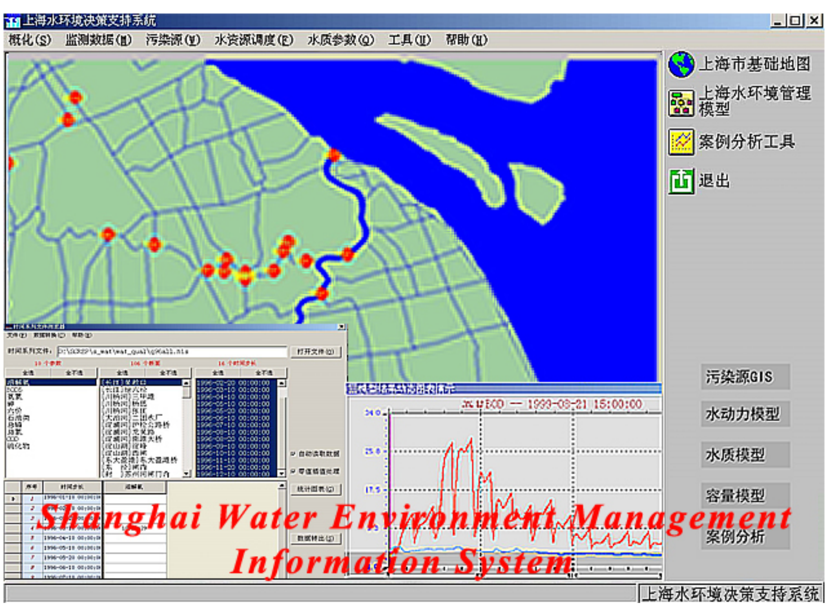


Figure 6-9 Decision support systems for water environment management in Shanghai

6.4 Management framework

The Suzhou Creek Rehabilitation Project established a comprehensive governance system, becoming one of the earliest demonstrations of the river chief system in China. This system appoints local government leaders as river chiefs, clarifying the need for these leaders to take overall responsibility for ensuring environmental quality, integrating the execution of relevant measures by Governments at all levels to the greatest extent thereby making up for fragmentation of management and resources, and forming a good atmosphere for water management for the whole society and ensuring effective water environment management.

The Suzhou Creek Rehabilitation Project has benefited from the practical application of the river chief system. In 1996, the Shanghai Government established a group to lead the Suzhou Creek rehabilitation. The mayor and deputy mayor of Shanghai were the group leader and deputy, respectively. The main leaders of the relevant government departments of Shanghai served as members of the leading group and participated in the coordination of the comprehensive rehabilitation of Suzhou Creek. The office of the leading group was also established as a special office to promote the rehabilitation of Suzhou Creek. For construction, the Shanghai Suzhou Creek Rehabilitation and Construction Company was established to be part of the joint effort to control pollution.

The remarkable achievements of the Suzhou Creek Rehabilitation Project have also benefited from the research and consulting work from a variety of experts from China and other parts of the world. The Shanghai Government hired a number of foreign agencies as consultants on specific aspects of the project. The Suzhou Creek Rehabilitation Leading Group set up a technical team to mobilize the wisdom of diverse experts and researchers and propose technical solutions. Shanghai Suzhou Creek Rehabilitation and Construction Company established an expert committee to provide advice on the construction and other technical plans for the project. The technical team listened carefully to the advice of the expert committee from research and proposed technical plans and reported to the leading group for decision-making.

The leading group, the expert committee, and the technical team were highly compatible and complementary, improving the level of scientific input to the rehabilitation of the Suzhou Creek. The Shanghai Government also set up a special science and technology project to organize research outputs from domestic and foreign universities on major issues. Top-level decision makers, management organizers, project builders, technical leaders, and consultants formed an effective organizational structure. Such a mechanism ensured that the rehabilitation of Suzhou Creek advanced efficiently during implementation and that the project achieved its stated goals on time and even in advance, thereby saving on engineering investment.

The successful experience of the Shanghai Municipal Party Committee and the Government in the early exploration of the rehabilitation of Suzhou Creek shows that the rehabilitation of heavily polluted river is an arduous task that requires a long term perspective. It is necessary to establish clear leadership, a team of responsible experts with clear responsibilities and to respect their expert opinions. Also needed is long term follow-up research, gathering a group of dedicated managers and builders familiar with the situation, integration of international experience and engineering practice, and the formulation of technical solutions.

6.5 Results and impacts

The Shanghai Suzhou Creek Rehabilitation Project has lasted for decades, with a total investment of about 14 billion RMB (US$ 2.08 billion). It has completed the comprehensive environmental rehabilitation task of the Suzhou Creek, known as the "first project" of Shanghai's ecological environment.

The Project achieved the medium-term goal of water quality improvement - meeting Class V water quality standards in the lower reach of Suzhou Creek and Class IV standards in the upper reach by 2004 (Figure 6-10). Discolored and foul-smelling waste flows were removed, future polluted discharges were prevented, and the handling and disposal practices for nightsoil and solid waste were improved.

This project makes a significant contribution to the world's river pollution control. The technical systems and measures adopted in the rehabilitation of Suzhou Creek are a good reference in global efforts to improving urban river environments, and can be an example for successful river rehabilitation in developing countries.

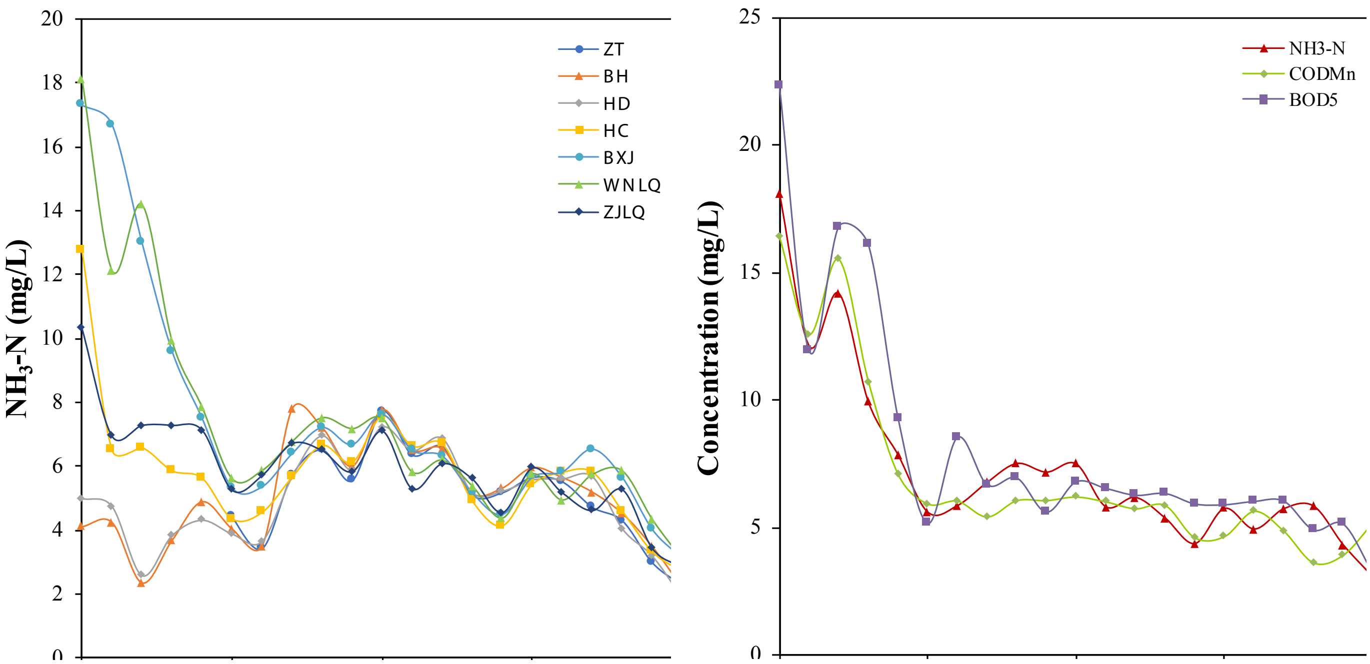


Figure 6-10 Water quality changes in Suzhou Creek (Left: Average annual water quality of a section of Wuninglu bridge in Suzhou Creek; right: Average annual change of ammonia nitrogen along Suzhou Creek)

Figure 6-11 Overview of Suzhou Creek environment

Landscape corridors along the sides of Suzhou creek were built, including more than 10 parks and public green spaces, covering an area of more than 230,000 m2, to make beautiful scenery and a suitable living environment for the citizens (Figure 6-11).

The Mengqing park of Suzhou Creek was completed as one of the large comprehensive parks with an area of 6.8 hectares, combining landscaping, science education, water environment improvement project measures and more. The original brewery building was restored as a historical exhibition center with a youth education basement.

Until now, the water quality of Suzhou Creek has continuously improved, and long-extinct life is returning. Four species of fish were found in the urban area of Suzhou Creek in 2001, suggesting that as river pollution levels continue to improve, other fish species will start to return. In 2008, the number of fish species reached 19 from five orders, and seven families, according to fish survey data. Seagulls frequently visit Suzhou creek, while egrets also come.

The rehabilitation of Suzhou Creek is not only improving the urban environment and Shanghai's international competitiveness, but also has produced great social and economic benefits. It has won wide acclaim in the country and the world. The Suzhou Creek Rehabilitation Project has been been recognized both nationally and internationally as a good example of an environmentally friendly practice with excellent considerations given to energy and water resources. [9]

9 For instance, China's nomination as a 'national environmentally friendly project', Austria's 'global energy and water resources award' and a recognition by the Asian Development Bank.

Chapter 7

Selected relevant international cases studies

7.0 Overview

The four case studies described in this Chapter represent international efforts spearheaded by UN-Habitat and its partners to support countries in the developing world to address the challenge of wastewater management, pollution control and restoration of polluted rivers and other water bodies. Like Suzhou Creek, the cases highlight how rapid population growth, unsustainable urbanisation and increasing industrialisation result in heavy pollution as large amounts of domestic sewage and industrial wastewater are discharged directly into rivers and other water bodies.

Although the Lake Victoria and the Mekong River cases demonstrate the regional approach in managing transboundary water resources, they highlight how pro-poor investments in water and sanitation facilities can improve the livelihood of the local population while restoring the quality of water in the receiving water body. The two cases also highlight the important role of community participation in the decision-making process. Partnership with regional financing institutions and bilateral donors such as the African Development Bank in the case of Lake Victoria and the Government of the Netherlands in the case of the Mekong, highlight the need for external support and other financing arrangements required by a number of countries in the developing world to support investments required to restore polluted water bodies.

The Densu River Basin in Ghana highlights the need to institutionalise a basin-wide Integrated Water Resources Management (IWRM) process involving in-depth baseline studies, establishment of basin-wide institutions such as the Densu Basin Board, stakeholder participation and environmental engineering. The elaborate institutional arrangements in the Densu River case with representation from district assemblies (local government structures) within the Basin, regional Coordinating Councils under which the basin falls, various decentralized government departments, the environmental protection agency, NGOs and the traditional authority underscore the need to establish a comprehensive governance system as highlighted in the Suzhou Creek Rehabilitation Project.

The Wastewater Master Plan and Drainage Strategy developed in the Bethlehem case highlights the institutional arrangements, capacity building and training, and environmental engineering measures taken by the Bethlehem Governorate and Water Supply and Sewerage Authority (WSSA) to improve wastewater management. The ultimate goal is a reliable, centralized, sustainable urban drainage service to all citizens which considers economic, environmental and social benefits including heritage preservation.

7.1 Responding to Environmental Impacts of Unsustainable Urbanization: The Case of the Lake Victoria Basin

- Urban pollution from secondary towns can have significant impacts on large water bodies affecting sustainable urban development.
- Wastewater has strong linkages to livelihoods.
- Collective action and regional approach to improve water quality is required in case of transboundary resources.
- Installation of appropriate wastewater management is key, however, this lags behind population growth and economic development

- Household and citizen participation is key to progressive improvement of water quality
- Monitoring of water quality is essential in order to measure progress.

7.1.1 Background

Lake Victoria is the world's second largest freshwater lake and the largest in Africa, with a surface area of 68,800 km2. It has a volume of 2,760 km^3 and an average depth of 40 meters. The maximum depth is 80 m. The lake is shared between Kenya (6%), Tanzania (51%) and Uganda (43%). The lake has a wide land catchment area, which is almost three times the size of the lake and extends over the three East African countries together with Rwanda and Burundi. This is the area from which rivers carry water, nutrients, sediments and pollutants into the lake, occupying about 193000 km^2. **Table 7-1** below shows the distribution of the land catchment area in the Lake Victoria Basin.

The Lake Victoria Basin has a population of about 35 million people. The gross economic product of the lake catchment is in the order of USD 5 billion annually, supports an estimated population of 30 million people, and incomes are in the range of USD 90-270 per capita p.a. The lake catchment thus provides the livelihood of about one third of the combined populations of Kenya, Tanzania and Uganda, and about the same proportion of the combined gross domestic product. It is estimated that more than 80% of the populations in the Lake Victoria basin are engaged in agricultural production, the majority as small-scale farmers and livestock owners producing maize and cash crops such as sugar, tea, coffee, cotton and meat. The fish resources of the lake sustain – directly or indirectly – livelihoods for about 3 million people engaged in subsistence and commercial fishing. The fisheries are very important as a source for foreign exchange earnings, with an annual landed value of USD 300-400 million.

Table 7-1 Land catchment area in the Lake Victoria Basin

Country	Catchment area (km^2)	Total Population (1,000)	Population density (persons/km2)	Catchment area per cent
Tanzania	84,920	5,200	61.2	44 per cent
Kenya	42,460	10,200	240.2	22 per cent
Uganda	30,880	5,600	181.3	16 per cent
Rwanda	21,230	5,900	263.8	11 per cent
Burundi	13,510	2,800	207.2	7 per cent
Total	193,000	29,700	-	100 per cent

7.1.2 Impact of rapid urbanization on Lake Victoria water quality

The rapidly growing secondary towns in the Lake Victoria basin are playing an increasingly important role in the development of the economy of the region and in providing non-agricultural employment to the population. But most of these towns are experiencing unplanned, spontaneous growth and the sustainability of these towns is seriously threatened by run-down and often non-existent basic infrastructure and services. The most affected are the poor living in urban and peri-urban areas, most of them remaining outside the reach of municipal services.

Rapid urbanization is also placing an enormous burden on the cities and towns around Lake Victoria and its catchments. However, the region has experienced rapid urbanization over the recent past with the towns, many of which concentrated along the lake edge, growing at rates far in excess of the regional average of 3% per year. The urbanization process has been accelerating under the impact of several factors, including rural poverty, land pressures and lack of job opportunities in the rural areas. In the larger municipalities in the Lake Victoria basin, urbanization rates are some of the highest in East Africa, but in the smaller urban centres, population growth is even more pronounced, reaching up to 10-12%. In addition to population growth, many of the small urban centres are located on trading routes, some across borders, and many experience huge population influxes during the day.

The cities and towns around Lake Victoria are sources of pollution for the basin due to their inadequate sewage treatment capacity **(Figure 7-4)**. Raw sewage from settlements, industries, market centres and towns around the lake contribute significantly to the pollution of the lake waters. Several municipalities, towns and urban centres on the shores and in the catchment areas discharge untreated sewerage effluent either directly or indirectly into the lake. The principal urban centres around the lake include Port Victoria, Kisumu and Homa Bay (Kenya), Masaka, Entebbe, Kampala and Jinja (Uganda); and Musoma, Mwanza and Bukoba (Tanzania). These centres have a variety of industries which discharge waste products into the lake largely due to the poor sewerage system, often dysfunctional sewage treatment facilities and overloading of sewage plants. Although legislation is in place for pollution control, no effective water quality monitoring or enforcement of the regulations is in place.

Moreover, population densities in the lake basin portions of Kenya, Tanzania, Uganda, Rwanda and Burundi are well above their respective national averages, indicating doubling times that are probably considerably shorter than the respective national averages. This is one of the major causes of the increased influx of untreated municipal waste-water and sewage **(Table 7-1).**

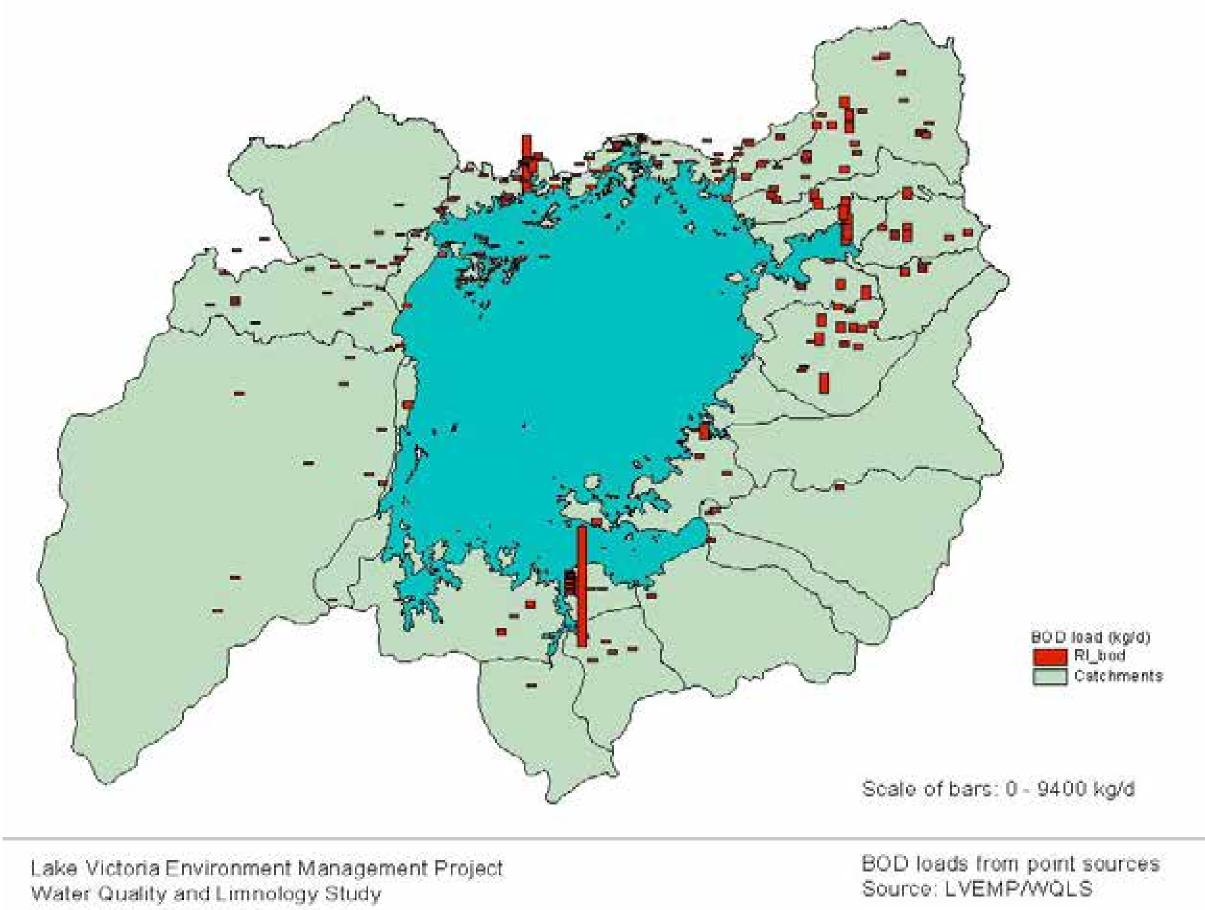


Figure 7-1 Map of Lake Victoria, showing point-sources of contamination

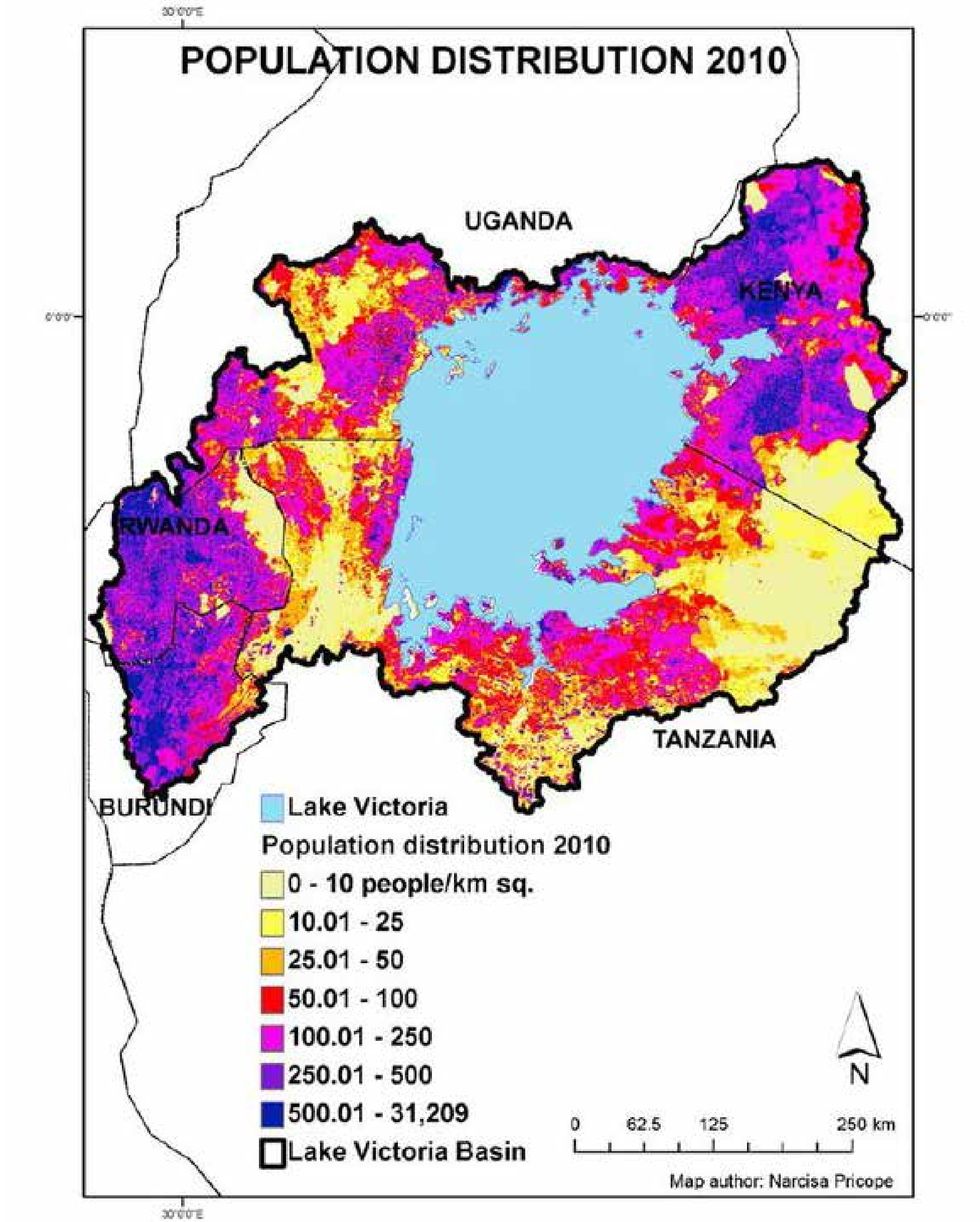


Figure 7-2 Lake Victoria Basin Population Density in 2010

Source: Jason Bremner, David Lopez-Carr Alex Zvoleff, Narcisa Pricope, Using New Methods and Data to Assess and Address Population, Fertility, and Environment links in the Lake Victoria Basin. Wilmington XXVII IUSSP International Population Conference Busan, South Korea, August 26 - 31, 2013.

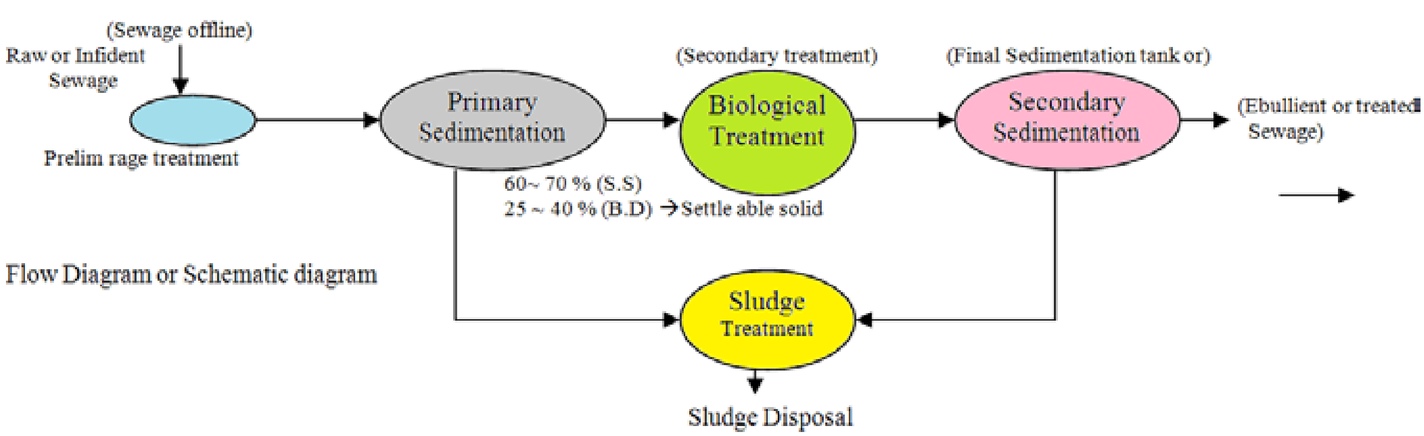
Table 7-2 Number of sewered and unsewered urban population in Lake Victoria basin

Country	Total population (1 000 people)	Sewered, urban population (per 1000)	Unsewered, urban population (per 1000)	Number of towns
Kenya	10 200	390	630	18
Uganda	5 600	210	870	9
Tanzania	5 200	27	340	4
Rwanda	5 900	-	400	5
Burundi	2 800	-	140	4
Total	**29 700**	**627**	**2380**	**40**

Source: Scheren, P. A. G. M., Zanting, H. A., and Lemmens, A. M. C. (2000). "Estimation of Water Pollution Sources in Lake Victoria, East Africa: Application and Elaboration of the Rapid Assessment Methodology.' Journal of Environment Management 58: 235-248.

Kisumu City has witnessed a population growth from 322,734 in 1999 census to 505,138 in 2015. The current estimated water demand for the City of Kisumu is estimated at over 50,000m3 /day against a production of approximately 18,700m3 /day (the demand is projected to increase to o about 68,000m3 /day). The current water supply deficit is about 37.4%. The capacity of the sewerage infrastructure is 17,800m3/day (if operating at full capacity), 30-32% less than what is required (LVSWSB, 2008) against an estimated sewage generation of 34,000m3. Only about 11,000m3 /day of the sewage generated reaches both facilities. Currently the plant at Kisat treats only 6,800m3/day at an efficiency of 89%, while Nyalenda treats 5,653m3/day at 52% efficiency. The average amount of wastewater treated is 11,788m3/day at an average efficiency of 66%. The service levels are way below the capacity because the plants serve about 10% of the city. The current sewered area is approximately 358 hectares against the 290 km2 total area of the city. Currently, the WWTP capacity has been operating below its design capacity, mainly due to low feed of raw sewage. Consequently, raw sewage was often discharged into Lake Victoria from unconnected sources through open drains or partially treated sewage from the treatment systems. In 2016 AFD rehabilitated and extended the sanitation systems by constructing a wastewater treatment plant at Otongolo, and creating a wastewater master plan for Kisumu County. This helped conserve water resources from pollution and improved sanitation for Kisumu City.

Figure 7- 3 Basic flow diagram for conventional wastewater treatment plant



Source: Lake Victoria Environmental Programme, Phase II (Study by Research on Environment and Development Planning (REDPLAN) Consultants Ltd, 2015)

Bukoba City in Tanzania has a population of about 100,000 without any sewerage treatment at all (Lake Victoria Region Water and Sanitation Initiative (LVWATSAN), Bukoba Fact Sheet). Kampala, the capital city of Uganda and thirteenth fastest growing city on the planet, with an annual population growth rate of 4.03%t *("City Mayors: World's fastest growing urban areas (1)". www.citymayors.com)*, has a population of 1.5 million and only 10% of the inhabitants are sewered (Kampala Capital City Authority, IWA City Water Stories, Kampala) (although the national audit in 2011 puts it at 6.4% and 6.7, and 90% of the collected wastewater was discharged into the Nakivubo wetland without any treatment (2012). Statistics also indicate that poor sanitation costs Uganda 389 billion shillings annually, which is about 1.1% of the National GDP. Estimates computed by WSP show that the losses due to poor sewerage/sanitation range between 1.0 and 3% of GDP of many developing countries. Fast growing secondary towns are major sources of pollution.

Figure 7- 4 Treated effluents to River Kisat in Kisumu City

Source: Lake Victoria Environmental Programme, Phase II (Study by Research on Environment and Development Planning (REDPLAN) Consultants Ltd, 2015)

Table 7-3 Population, capacity of WWTP and percent sewered for selected towns in East Africa

Country	Town	Population	WWTP Capacity m3/day	per cent sewered
Kenya	Kisumu	600,000	6,800	8-16
	Homa Bay	53,684	750	>10
Uganda	Kampala	1,507,080		10
	Jinja	80,000		
	Entebbe	79,700		
Tanzania	Mwanza	781,819		23.7[10]
	Musoma			
	Bukoba	100,000		

Sources: Uganda Bureau of Statistics, Mwanza Urban Water Supply and Sanitation Authority (MWAUWASA)

In Homa Bay, with a total population 23,000, sewage treatment works was constructed in 1982, with a design capacity of 750 m3/day. Presently the estimated sewer flow is 5,338 m3/d (2013), serving a population of 53,684 people. The plant receives an average influent of 2,013 m3/d and effluent of 1,579.94 m3/d, far beyond its design capacity. The plant currently serves 52% of the population in the Central Business District, which excludes new and informal settlements. The ratio of sewer length is 0.47km/km2. The treatment works thus produce a final effluent which is of a very poor quality and is discharged directly into the lake. Besides illegal/mislocated sewer lines, only 22% of the population are officially connected to the sewage network. If this connection rate is increased, the capacity of the treatment works becomes even more limited.

10 The official percentage is 6.1% to 7.0% in ODI. Case Study: Mwanza. Annex AI

Figure 7-5 Sewerage network for Homa Bay Town
Source: HOMAWASCO, 2019

Storm drainage

In a number of secondary towns there is no sewerage system, only a basic surface water drainage facility. Although the surface water drainage system is supposed to be separated from sewage lines, this often is not the case. Consequently, all wastewater (and some solid waste) is discharged directly to these drains and flows to the lake untreated. Industries in these towns also discharge their wastewater uncontrolled directly to the Lake. In periods of heavy rain, there is a huge pollution load to the Lake resulting in severe eutrophication in the vicinity of the sewer outfall (Eutrophication of the Lake Victoria Ecosystem P. Gikuma-Njuru1, D.K. Rutagemwa, R. Mugidde , R.E. Hecky , L. MwebazaNdawula , P.M. Mwirigi, 1 , J.O.Z. Abuodha , R.K. Waya , A. Matovu J. Kinobe: LVEMP, Water Quality and Ecosystem Report. Lake Victoria Environment Report). Results shows that 75% of the BOD load is from domestic pollution, and Uganda's contribution is 75% from Kampala, while 50% of Kenya's contribution is from Kisumu City (Sheren et al, 2000).

The stormwater (and other wastewater) follows natural paths and finds its way to the Lake via gullies, or occasionally through a swamp, which acts like a filter. The stormwater drainage network is poor and inadequate. The Homa Bay municipality does not have a comprehensive stormwater drainage system neither does it have any buffering from wetlands (Figure below). Some settlements have been established on these wetland areas and as a result of poor drainage, become water logged when it rains. The natural ecosystem in some of the wetlands has been totally devastated.

Figure 7-6 Stormwater drainage in Homa Bay draining into Lake Victoria

Quality of effluents

Nutrients (phosphorus and nitrogen), mainly emanating from human and industrial wastes inflow from the secondary towns around the lake have given rise to five-fold increase in algae growth since 1960s causing de-oxygenation of the water that threatens the survival of deep water fish species. The additional sewerage facility increased the processing of sewage by more than 2,500 m3/day from the current 4,000 m3/day. Currently, there is no flooding at the Kisat compound with its raw sewer, no foul smell is being emitted, 50-70% of the sewerage is treated and 50% of the system is now operational. This increased the capacity to 6800 m3/day, which is very low compared to the available sewage produced. The plant receives domestic and commercial sewage mainly from the Central Business District and industrial area, and it receives heavy amounts of oils from garages and factories, such as fish factories, on the lower shores .

A review by the Tongji University team for a period of two years from January 2011 to December 2012 revealed that the treated effluents were below the acceptable standards by the National Environment Authority (NEMA) of Kenya **(see table below).**

Table 7-4 Water Quality in Kisat wastewater treatment plant and Nyalenda wastewater treatment plant, 2012.12

	Kisat		Nyalenda Lagoons		Discharge Standards
Indices	Influent	Effluent	Influent	Effluent	
BOD(mg/L)	900	145*	120	43*	30
COD(mg/L)	2,400	340*	624	64*	50
TDS(mg/L)	559	479	421	261	1,200
TSS(mg/L)	400	90*	91	44*	30
TN(mg/L)	3.75	1.98	4.6	3.8	13
TP(mg/L)	1.48	1.06	1.68	0.87	30
pH	7.2	7.7	7.20	7.11	6-9

Note: * means value exceeding the discharge standard.

Source: East African wastewater treatment and reusage. chinagate.cn, March 24, 2015

The expected water quality changes in the Lake are manifested through the harmonization of various policies, strategies, legislations and regulatory frameworks, construction and rehabilitation of wastewater treatment facilities in Bomet, Homa Bay, Kisumu, Bukoba and Kirinya to reduce levels of pollution in the Lake, and the construction of 93 public and ecological sanitation toilets in Kenya, Uganda, Tanzania and Burundi serving over 171,558 people. These interventions are expected to reduce the high cost of water supply, as polluted water is expensive to treat, reduce waterborne disease contamination of the lake ecosystem, which includes loss of fish habitat and biodiversity.

7.1.3 The Lake Victoria Water Supply and Sanitation (LVWATSAN) Programme

In 2004, UN-Habitat, in association with the Governments of Kenya, Tanzania and Uganda, launched a major programme to address the water and sanitation needs of the population, particularly the poor, in the secondary urban centres around Lake Victoria. Phase I of the Lake Victoria Water Supply and Sanitation (LVWATSAN I) Programme aimed at supporting participating governments to achieve the Millennium Development Goals for water supply and sanitation, with emphasis on innovative solutions and speedy delivery. It had a clear pro-poor focus and was intended to generate desirable outcomes that would have a lasting effect on the poor in the population.

The LVWATSAN I Programme focused on capacity building; project design, planning and implementation; and follow-up investments. With a growing awareness of the benefits of a regional approach among East African Community countries, regional training and capacity building was initiated, with emphasis on regional networking, and cooperation in protecting and managing a shared resource – Lake Victoria.

7.1.4 Objectives

Funded by the African Development Bank (AfDB) in partnership with the East African Community (EAC) through its institution of the Lake Victoria Basin Commission (LVBC), the overriding goal of the Programme was to improve living conditions of the urban poor in the Lake Victoria Region and protect local and regional environments. In order to meet this goal, LVWATSAN I aimed to reduce the adverse environmental impact of urbanization, enhance pro-poor water and sanitation investments in the Lake Victoria Basin and institutional and human resource capacities at local and regional levels, and support the cooperation between East African countries.

UN-Habitat, through its Lake Victoria Region City Development Strategies Programme identified serious and increasing gaps in sanitation, waste management and access to safe drinking water as issues for priority attention in the largest cities on the Lake; Kampala (Uganda), Kisumu (Kenya) and Mwanza (Tanzania). Moreover, dealing with public municipal pollution in the largest towns served as an essential step towards a more credible enforcement of environmental performance by commercial polluters as well as in the smaller and secondary towns.

The Programme activities undertaken in Phase I were implemented in 10 urban centres in Kenya (Kisii, Homa Bay and Bondo), Tanzania (Bukoba, Bunda, Muleba and the border town Mutukula) and Uganda (Nyendo/Ssenyange, Bugemebe and Kyotera). In most towns short-term interventions involved rehabilitation and expansion of existing infrastructure. Long-term interventions included significant investments in infrastructure to reach the unserved parts of the population.

In order to achieve the objectives of the Programme, LVWATSAN was designed to deliver an integrated package of interventions: rehabilitation and extension of physical infrastructure; extending access to basic sanitation through micro-credit facilities; interventions to improve the water supply; sanitation and hygiene promotion in schools; and capacity development for local authorities, service providers and community-based organizations. Implementation by multiple agencies including the LVBC delivered the services very well.

Phase II

African Development Bank led a Project Formulation Study for the 15 new secondary towns. The towns were across several East African countries, including in Burundi (Ngozi, Muyinga and Kayanza), Kenya, (Keroka, Kericho and Isebania), Rwanda (Kayonza, Nyagatare and Nyanza), Tanzania (Geita, Sengerema and Nansio) and Uganda (Mayuge, Buwama-Kayabwe-Bukakata and Ntungamo). The implementation was set to be launched in 2011 with approx. USD 110 million in grant funding from the African Water Facility. This component was called LVWATSAN Phase II. Africa Development Bank entered into a Contribution Agreement with UN-Habitat to offer a technical assistance and capacity building component to the Programme.

The overall objective of the Programme was to support the secondary urban centres in the Lake Victoria region to meet internationally agreed sustainable development goals on water and sanitation and to contribute to the improvement of the livelihoods and health of communities in the basin and to reduce the pollution of Lake Victoria.

Interventions were packaged into five components: i) water supply, ii) hygiene and sanitation, iii) urban drainage improvement, iv) training and capacity building and v) program management. Components (i) to (iii) involving physical infrastructure were delivered by the Implementing Agency (IA) in each country. Component (iv) involved establishment and strengthening the capacity of the program management structures to ensure smooth program implementation and to strengthen the town water and sanitation institutions for effective and efficient operations and sustainability of the physical infrastructure. The training and capacity building component was delivered by UN-Habitat on behalf of the EAC. Component (v) supported the implementation and management of the program and was delivered by the LVBC at the regional level in collaboration with the IAs at the country level.

7.1.5 Achievements from Phases I &II

The water and sanitation facilities in the 15 towns were upgraded and expanded through the implementation of a wide range of infrastructure works. These comprised mainly of the short-term interventions such as installations of new pumps to modernize and expand old pumping stations, rehabilitation of treatment plants and extension of water distribution networks. Long-term interventions included construction of new water supply infrastructure, landfill sites and faecal sludge treatment plants and construction of sanitation facilities in public institutions such as schools and hospitals, public markets and selected informal areas of the towns. Over 1 million people directly benefitted from increased access to safe drinking water and improved sanitation.

7.1.6 Environmental sustainability

Environmental sustainability was built into the programme by integrating mitigation measures, which will be complemented with activities that create awareness. The quality and quantity of the natural resources is monitored and this data serve as a planning tool. Special attention was paid to the Lake Victoria water resources, and key safeguards such as protection from pollutants were built into the programme. Provision was also made to rehabilitate and protect the groundwater recharge areas in order to contribute to the sustainability of the resources.

7.1.7 Institutional environment

The institutional environment ranges from transboundary institutions handling water issues across national boundaries to national, regional and local public bodies in charge of developing and setting policies and standards for water management, issuing permits, ensuring compliance, and taking appropriate enforcement actions. The EAC has developed several protocols of which the first was the Protocol for Sustainable Development of Lake Victoria Basin (2003) that led to the establishment and operationalization of the LVBC in 2005 as an apex institution of the EAC. The LVBC functions in the countries through the Sectoral Council of Ministers for Lake Victoria (SECOM) and Regional Policy Steering Committee (RPSC) that provide oversight and guidance.

LVBC rehabilitated 5 treatment plants and is currently operational in Kenya and Tanzania with construction for 14 more for all the designated towns, except Kericho where rehabilitation was done under Short Term Interventions. Water treatment plants have been constructed in Uganda, while construction for 11 more have commenced and are ongoing. Additionally, 88 public toilets have been constructed to ensure hygiene and sanitation in the EAC Partner States from the five countries. Clearly, the institutional arrangements dealing with wastewater are complex and huge.

7.2 Challenges and Opportunities in Improving Wastewater Management - Bethlehem, Palestine

- Comprehensive understanding of challenges and opportunities in drainage management informs a long-term perspective in the planning of: the collection and disposal infrastructure network, financial, technical and human resource needs, as well as capacity building requirements.
- Data monitoring and evaluation tools in drainage systems allows for rapid planning as well as efficient service delivery informed by real time needs.
- Investments in downstream infrastructure is equally important as upstream infrastructure as it offers opportunities for recycling, reuse, integrated urban water management as well as environmental and social benefits.
- Full-scale service coverage for both wastewater and stormwater networks ensure effective functioning of the systems and reduce overload of existing design capacities.
- Cities should aim at high wastewater collection coverage, as well as sewerage connections with treatment to ultimately create cities that are livable, competitive and sustainable.
- Centralized systems reduce costs (socio-economic, environmental) and increases options available to water management such as recycling, reuse and multi-purpose water use

- The costs of wastewater management are greatly outweighed by the benefits to human health and economic development i.e. business opportunities and 'green' jobs, protection of heritage and environmental sustainability.

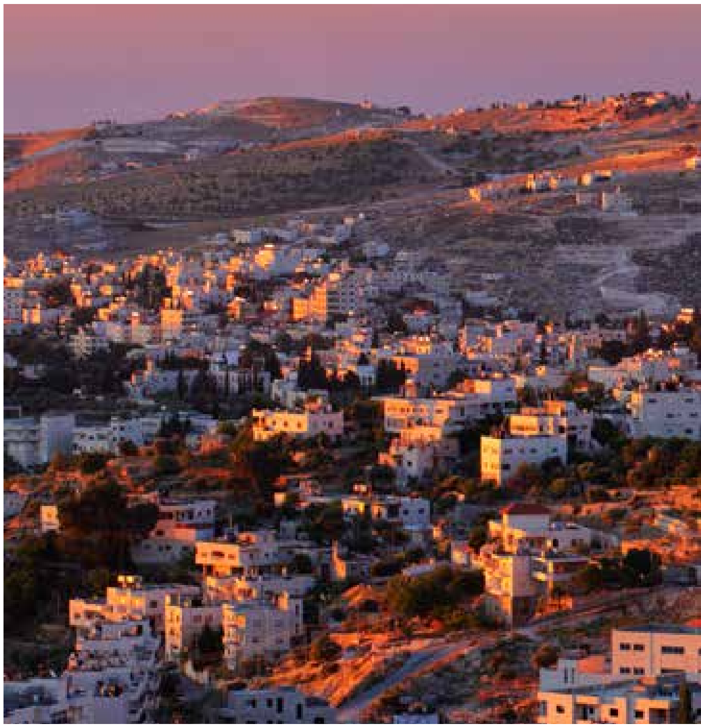
7.2.1 Background

Bethlehem is a Palestinian city, located in the West Bank in Palestine, about 10 km to the south of Jerusalem, with a population of approximately 32,000 inhabitants. Bethlehem is the centre of culture and tourism in Palestine, receiving 1.5 million tourists per year. Since it is identified by Christian tradition as the birthplace of Jesus, Bethlehem has many churches, most notably the Church of the Nativity, which is registered within the UNESCO World Heritage List in 2012. The city has a dense and rich concentration of historical, heritage and religious sites which are of international importance and since 2012, the Old Town was declared a World Heritage Site .[11]

From the east, the city of Bethlehem is bounded by the town of Beit Sahour and from the west by the towns of Beit Jala and Al-Doha. From the north it is bordered by Jerusalem and the village of Sur Bahir and from the south by Solomon's Pools and the villages of al-Khader and Artas. The city is situated on a mountainous site, 772 meters above the level of the Mediterranean Sea. It has a Mediterranean climate, with hot and dry summers and cold and rainy winters. Bethlehem receives an average of 501 millimetres of rainfall annually, while the average temperature reaches 16.3°C, and humidity rate ranges between 50-75 per cent .[12]

According to Oslo Interim Agreement, signed in September 1995, the Westbank is classified into Areas A, Area B where Palestine sovereignty is absolute; and Area C which is under the full control of Israeli government. This operating environment is unique and is characterized by a fragile security situation; numerous restrictions on movement, on access to large areas of the West Bank and the entirety of Gaza, and on the ability of Palestinians to build and develop in Area C and East Jerusalem; an ongoing settlement enterprise taking over private Palestinian land. Restrictions in Area C also impact development in Areas A and B, as residential or commercial and infrastructure projects require connections to service infrastructure such as water, land and energy that depends on access to Area C[13] .

In the rural Area C of the West Bank, including Bethlehem Governorate rapid transformations have been witnessed, in light of the ever-increasing urbanization rates, where more than three-quarters of Palestinians are living now in urban areas. The annual population increase in 2016 was 2.63 per cent (Palestinian Central Bureau of Statistics). The migration from rural to urban areas and the displacement of Palestinians into refugee camps have been the main drivers of the rapid population increase in Bethlehem city. The population in the three refugee camps was 10,563 in 1997 and increased to 26,140 in 2017 (Palestinian Central Bureau of Statistics, Census Report of 2017). Moreover, the total number of registered refugees in Bethlehem city-region (Governorate) is much larger with about 52.3 per cent living in urban areas; 22.5 per cent living in rural areas; and 25.2 per cent living in refugee camps. In Bethlehem City the urban population was 24,949 in 2007 which increased by 28 per cent to 31,799 by 2016. In Bethlehem Governorate the urban population increased by 25 per cent to 215,514 in 2017 from 174,022 in 2007. To accommodate the needs of the growing population, Bethlehem has expanded its municipal boundaries to the north and south in 2017. The municipal jurisdiction in 2018 covers 7.38 km2 compared to 5.4 km2 in 2014[14] .



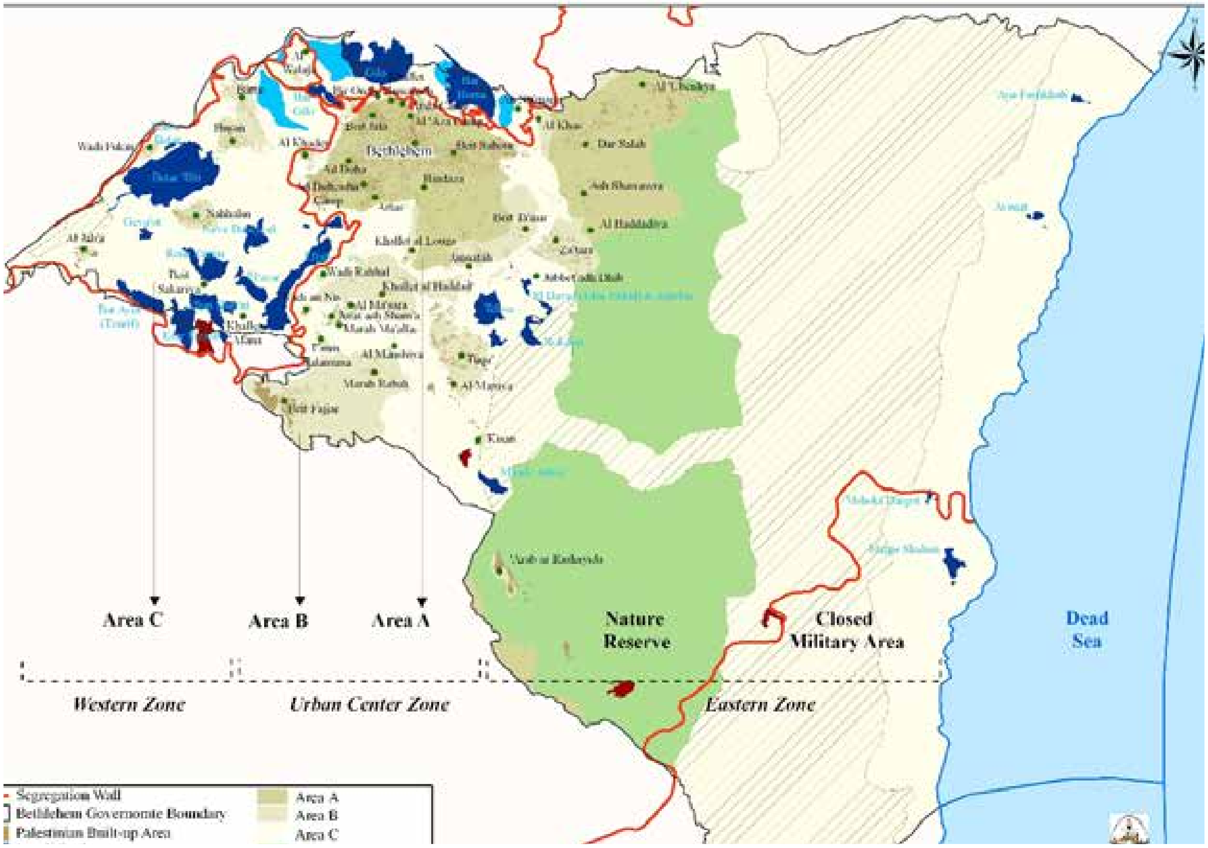
11 Bethlehem City Website. Available at http://www.bethlehem-city.org/en

12 Bethlehem City Website. Available at http://www.bethlehem-city.org/en

13 UN-Habitat (2018) Rapid Assessment on current status of Drainage Management in Bethlehem city (Drainage, Transport, Solid Waste management) - Unpublished

14 UN-Habitat (2018) Rapid Assessment on current status of Drainage Management in Bethlehem city (Drainage, Transport, Solid Waste management) - Unpublished

Figure 7-7 Geopolitical Context of Bethlehem, Palestine



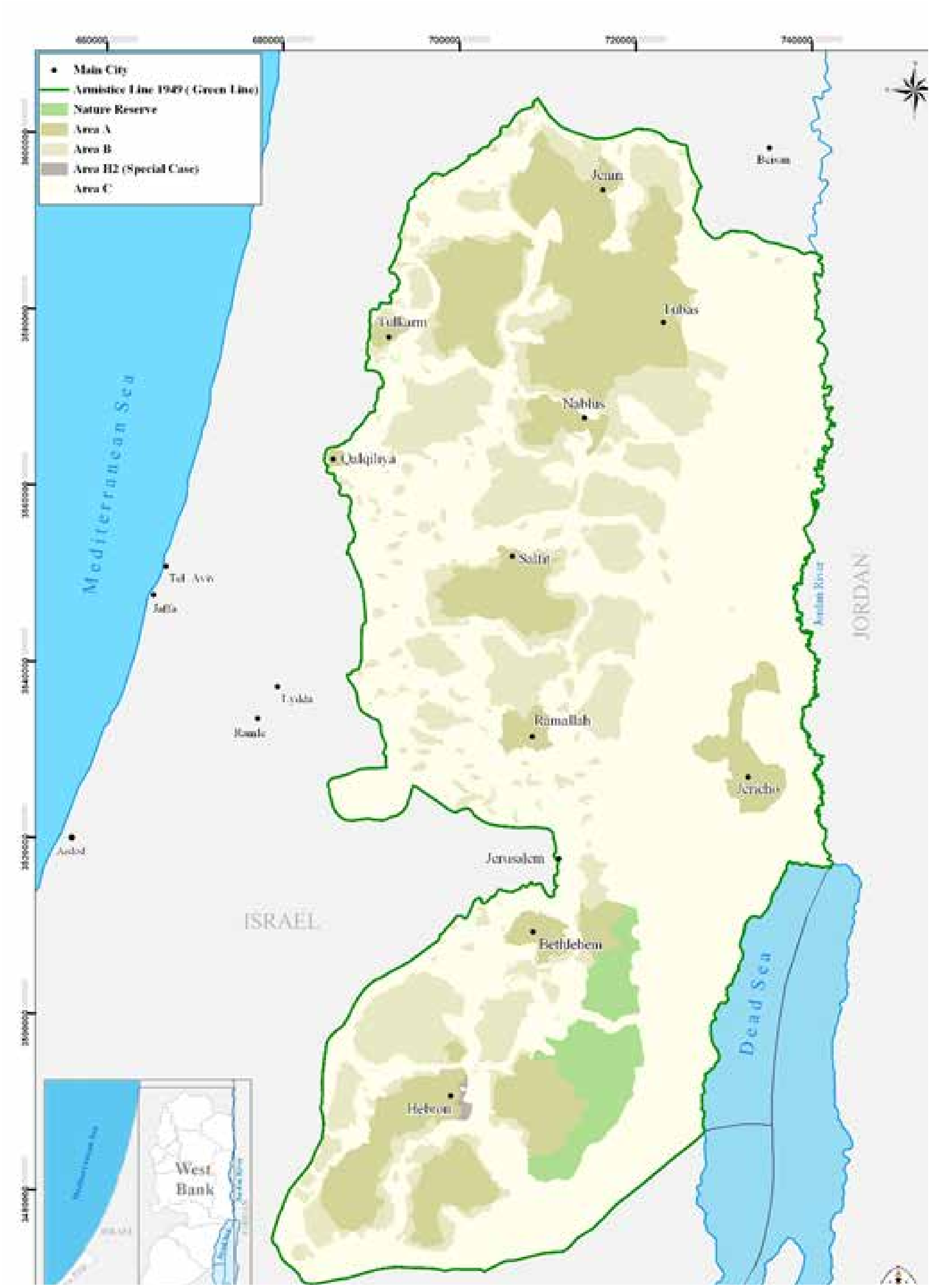


Figure 7-8 Oslo Designations in West Bank, Palestine

7.2.2 Drainage Service Level and Coverage

79% of the total population in Bethlehem governorate is connected to a central wastewater network. The Bethlehem sewerage system service covers Bethlehem Governorate, consisting of the three cities of Bethlehem, Beit Jala and Beit Sahour with a land area size of 25 km^2 and a total length of 200km of sewerage drainage network. According to WSSA, the total population served in Bethlehem - Beit Jala - Beit Sahour is 120 000, consisting of five cities, two villages and the three refugee camps of Aida, Beit Jibrin ('Azza), and Dheisheh. The total wastewater network coverage in the Governorate is 65%, meaning that 35% of the service area is uncovered. 22% use cesspits, and 0.1% lack wastewater collection and disposal services. [15]

City wide service coverage for stormwater drainage is 35%, leaving 65% uncovered. 30% of the present stormwater drainage network in Bethlehem Municipality is connected to the sewerage drainage system with a capacity of 18,000 m^3. It has been implemented at different times and by different institutions, as emergency answers to recurring problems and according to the funds available. This has resulted in a makeshift network composed of different shapes and sizes creating flooding issues at their interfaces. The main gaps and outfalls in the continuity of the existing network structure appear in the West Basin and are the sources of the main drainage network challenges. [16]

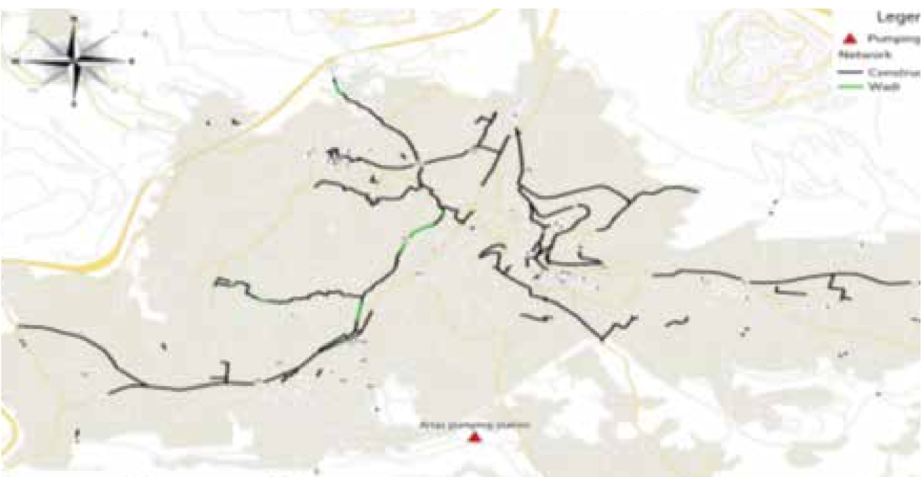


Figure 7-9 Existing Storm water network in Bethlehem[17]

Figure 7-10 Wastewater network in the project area, per condition [18]

15 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

16 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

17 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

18 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

7.2.3 Drainage Management Investigation - Methodology

An investigation of wastewater and stormwater management in Bethlehem, Palestine was conducted from 2016 – 2018. Information regarding drainage network functionality including structure, operation of downstream facilities, financial and institutional capacity, legal and administrative context, population and urban development and land use planning, was gathered through appraisals.

Technical data gathering utilized field visits, video inspection, observation, and key informant interviews. Technical investigations were carried out through a measurement campaign using Hydreka Integrated Measuring Systems from France. Data gathered included rainfall patterns through hydraulic modelling and flow measurements i.e. dry and wet weather measures, wastewater systems (main catchment basins, wastewater network pumping stations), stormwater systems (stormwater network, stormwater catchment diagnosis), mapping of network operation (wastewater and stormwater systems maps, operating anomalies and malfunctions) and hydraulic modelling.

Appraisal of data evolution and assumptions was carried out through assessments of drinking water supply and demand, wastewater flows and rainfall data. Sewage/wastewater and stormwater drainage diagnosis and mapping of network operations was carried out using ArcGIS, network condition assessment, and diagnosis of current and future operation was done using projections.

Based on data gathered, improvement possibilities were identified and selected through scenario analysis and modelling. Improvement possibilities for implementation are recommended through *Wastewater and Storm Water Master Plan 2040.*

7.2.4 Wastewater /Sewerage and Stormwater Drainage Network Challenges

Information from the investigation indicated that the WSSA in Bethlehem Governorate had invested a lot in upstream infrastructure (collection, and transportation) reaching 79% of the population with a centralized wastewater network. However, huge investments are needed in the downstream infrastructure for treatment and disposal focusing on wastewater recycling and reuse (central wastewater treatment plants, storage of runoff in ponds and bio-filtration treatment to promote integrated water resources management).

Figure 7-11 Overflows into open drainage channel discharged into Wadi al Nar Valley in Bethlehem

The physical layout and spatial planning of the city indicates good urban planning. In as much as land use planning is appropriately implemented; in terms of wastewater management, the Governorate still utilized traditional a drainage system i.e. a mixed drainage system where stormwater drainage heavily relies on the wastewater/sewerage drainage network. Broadly, the existing drainage infrastructure has become outdated facing network capacity challenges characterized by flooding and overflows in wet weather conditions, back wash, sewer pipe damage, leakages and bursts due to overload in wet weather, and a mix of solid waste and sediments in the drainage network. Wastewater disposal into Wadi al Nar (valley) without any treatment was ending up in the Dead Sea and resulted in social and environmental risks.

Figure 7-12 Open discharge of Untreated Wastewater and Solid waste mix in polluted valley in Bethlehem leading to the Dead Sea

Key drainage management challenges faced in Bethlehem Governorate are severe network capacity problems mainly associated with traditional drainage systems which are meant to collect and transport water runoff from urban areas as quickly as possible via sewer networks and water treatment facilities (which are inefficient due to limited capacity) to nearby receiving valleys just outside the city. In coping with the increased amount of water run-off during winter rains (mainly due to urbanization where green and open spaces are increasingly covered by concrete surfaces); water run-off enters into the sewerage drainage network causing back wash and overflow of the sewage network; sewerage pipe damage resulting in leakages and bursts due to capacity overload; and a mix of solid waste and sediments in sewerage drainage network resulting in system malfunction.

Other significant challenges include the environmental risks of sewerage being openly disposed in valleys without treatment and significant changes in runoff patterns in both peak flow volumes and speed of runoff which causes flash floods. Vulnerabilities to flood hazards in Bethlehem are due to the change in urban density and distribution, which has resulted in a lack of green, open and public spaces. The existing design of the conventional drainage system has limited concern for water quality issues and even less for its amenity, recreational and environmental values, which has resulted in an urban environment impact which threatens destruction to international heritage sites.

Figure 7-13 Intrusion of storm water in Sewerage Network through a manhole

7.2.5 Environmental Impacts of High Wastewater Collection without Treatment

The investigation further revealed several social and environmental threats including risks of heritage destruction such as Olive Trees orchards and Old Town which are a UNESCO World Heritage Sites.

Through investigation, it was found that the stormwater drainage network in Bethlehem Governorate is patchy and is connected to the sewerage drainage system at many locations by design. The capacity of the sewer network is 18,000 m^3 and is overloaded, especially in wet weather conditions. The pollution loads estimated, based on Nablus WWTP mean concentration, indicated that the average dry weather wastewater flow is 12,716 m3/day whilst the average wet weather wastewater flow is 45,987 m3/day. The existing network hence faces capacity challenges resulting in mal-functionality, especially in wet weather conditions (WSSA, 2016).

Table 7-5 Flow and pollution loads discharged into the environment during dry weather [19]

Outlet	Total Dry weather flow (m3/ day)	COD		BOD5		TSS		TN		TP	
		mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d	mg/l	kg/d
East Catchment (Wadi Nar)	7,512	900	6,761	400	3,005	400	3,005	90	677	20	151
West catchment	5,204	900	4,684	400	2,082	400	2,082	90	469	20	105

Note: As stormwater also carries pollution, a multiplying factor, applied to the wastewater's concentrations, is used in order to take into account this additional pollution during wet weather. The multiplying factor varies for the different parameters since stormwater mostly conveys suspended solids and COD, and less BOD5, nitrogen or phosphorus.

19 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

20 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

Table 7-6 Flow and pollution loads discharged into the environment during wet weather[20]

Outlet	Total Wet weather flow (m3/ day)	COD			BOD5			TSS			TN			TP		
		mg/l	Wet weather multiplier coefficient	kg/d	mg/l	Wet weather multiplier coefficient	kg/d	mg/l	Wet weather multiplier coefficient	kg/d	mg/l	Wet weather multiplier coefficient	kg/d	mg/l	Wet weather multiplier coefficient	kg/d
East catchment outlet (Wadi Nar)	10,383	900	1.8	16,820	400	1.5	6,230	400	2.2	9,137	90	1.3	1,215	20	1.3	270

North PS overflow	5,331	900	1.8	8,636	400	1.5	3,199	400	2.2	4,692	90	1.3	624	20	1.3	139
South PS overflow	10,663	900	1.8	17,225	400	1.5	6,380	400	2.2	9,357	90	1.3	1,245	20	1.3	277
West Catchment Outlet	19,640	900	1.8	31,816	400	1.5	11,784	400	2.2	17,283	90	1.3	2,298	20	1.3	511

In 2016, the pumping stations only overflowed during wet weather. While the West catchment flows were treated downstream in Jerusalem, the flows from the East catchment and the pumping stations' overflows (in wet weather) were not treated, and resulted in unsanitary conditions and the degradation of the environment nearby and downstream. Untreated wastewater partly flowed through moderate to highly sensitive environmental areas in terms of biodiversity.

Wadi Nar(valley) catchment is one of the major surface water catchments in the southern region of the West Bank. The catchment extends from Jerusalem in the West to the Dead Sea shoreline in the East. It overlaps the districts of Jerusalem and Bethlehem and covers a wide range of different landscapes and topographic environments. In addition to draining the wastewater from Bethlehem area's East catchment, it also drains the wastewater from the southern part of Jerusalem, including from the Old City, and from Al-'Ubeidia, Al Khas and other Bedouins communities.

The current wastewater flows discharged in Wadi Nar (valley) contaminate the soils, flora, fauna, and all ecosystems. Patterns of land use also affect all of the above. The uncontrolled flows of wastewater might be conductive to the spread of invasive species of plants at the outfall and along wadi Nar's course. This in turn attracts invasive animals and contaminate the indigenous fauna such as birds, since they are breeding on a contaminated ecosystem. In addition, the emergence of invasive species of flora and fauna in the ecosystem would also inhibit indigenous species, reduce their habitat and thus reduce their presence. Due to rainfall or to technical failure, the North and South pumping stations regularly have overflow events. This causes pollution to the nearby stream and flooding zones, and results in frequent bad smells, mosquitoes, and soil and surface runoff contamination. The nearby communities also are affected and highly sensitive to these social problems, and are always requesting WSSA and the Municipality of Bethlehem find an immediate solution to the problem.[21]

Currently inputs are characterized by high level of organic concentrations in the raw wastewater, which leads to a high level of contamination at the outfalls (East and West main catchments). During rain events, stormwater gets mixed with wastewater and floods the lower zones of Beit Jala, resulting in a health hazard, a nuisance for the community, and a source of environmental contamination. In the East the outfall at Wadi Nar (valley) results in high pollution which impacts the local soil, flora, fauna and other biotic factors. The open channels of raw wastewater are considered a serious surface contamination source: it can attract mosquitos and rats, produce bad smells and is a continuous source of pollution. In addition, wadi Nar (valley) flows next to one of the most renowned monasteries, Mar Saba, an outstanding historic and religious site in the Jerusalem wilderness of Bethlehem Governorate. The impact of the raw wastewater discharged into wadi Nar (valley) on ground and subsurface water is not major since, with the exception for a few specific locations, the area along the wadi is classified as not sensitive. [22]

As for the West catchment, the mix of wastewater and stormwater resulting from rain events in the East catchment is problematic, and has a major negative impact on the environment and the population, especially in Beit Sahour and Dar Salah areas where the mixed water floods, which is a major source of nuisance for nearby communities. The same pollution and nuisance also occur during dysfunctions of the South or North pumping stations. The existing breaks in the system in the west catchments also result in permanent contamination of the environment. [23]

21 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

22 UN-Habitat (2018) Rapid Assessment on current status of Drainage Management in Bethlehem city (Drainage, Transport, Solid Waste management) - Unpublished

23 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

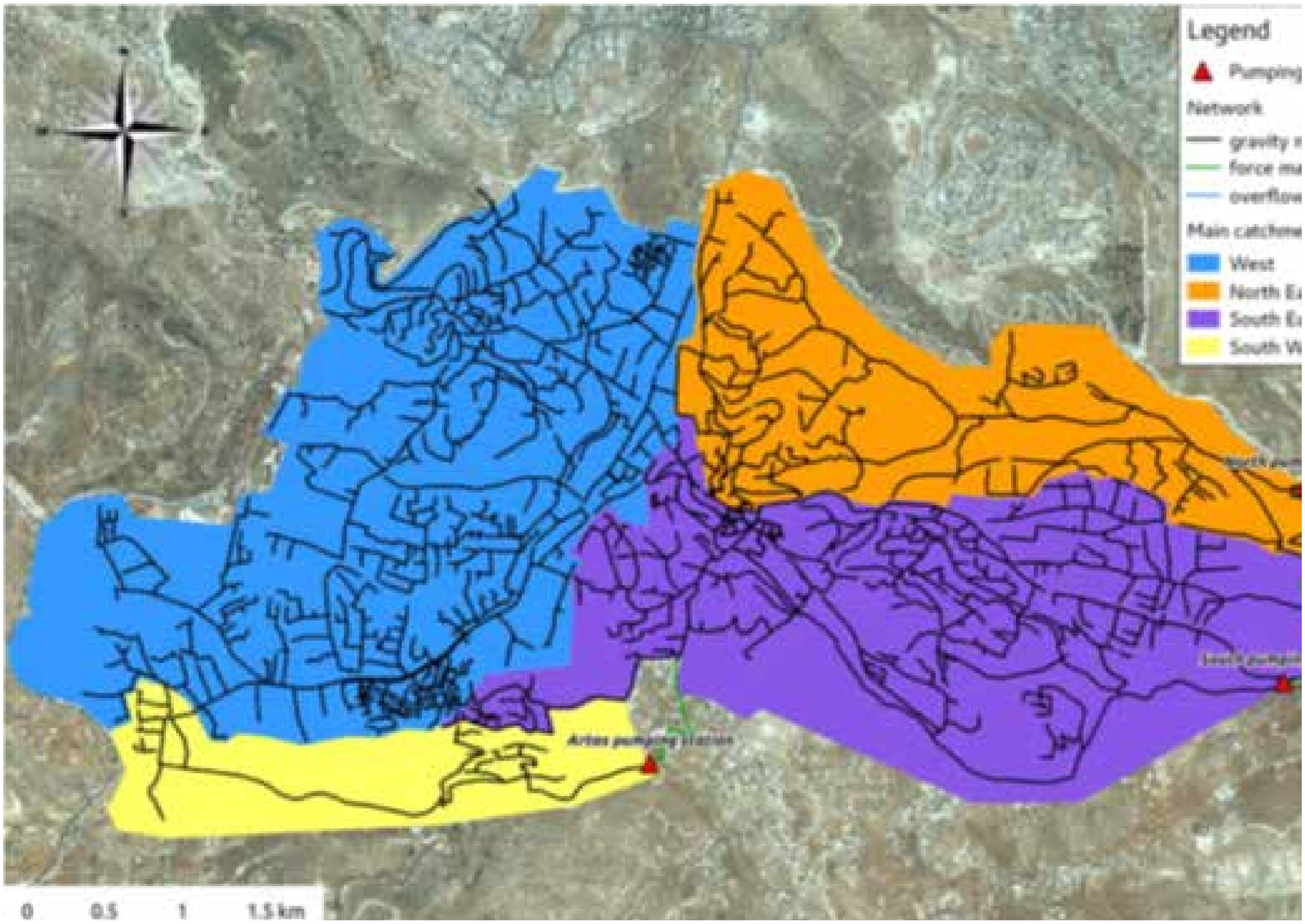


Figure 7-14 Waste water catchments

7.2.6 Proposed Interventions - Opportunities

Through the 2018-2040 Wastewater and Storm Water Master Plan for Bethlehem Governorate, downstream investments for treatment facilities as well as consideration of water for multi-uses has been given priority. Funding has been secured from the Agence Française de Développement (AFD) for a feasibility study on Wastewater Disposal and Reuse in South-East Bethlehem. Construction of a WWTP has been given the highest priority, however, it requires funding estimated at USD 89 million. Multi-lateral funding will be required for full implementation of new WWTPs.

Some key factors considered during investigation planned for implementation through the Wastewater Master Plan and Drainage Strategy, include measures in the *short-medium-long terms*. In the *short to medium term*, Bethlehem Governorate and WSSA to engage in an institutional technical competence transfer (legal and administrative) of stormwater drainage management from Bethlehem Municipality to WSSA through a capacity building initiative. Other measures include awareness raising and advocacy on wastewater management to eliminate uncontrolled solid waste dumping and open burning; an agro-environmental and plot development measures campaign; the installation of screen filters upstream where open stormwater drains into sewerage drainage; and sediments traps in upstream of stormwater drainage system as well as small scale and large-scale green landscape development. *Long term* measures include separation of stormwater and sewerage drainage systems; central wastewater treatment plant installation; rehabilitation of existing sewerage drainage network related to downstream facilities (pumping stations, wastewater treatment plants); capacity expansion of the existing stormwater and sewerage drainage network at key locations affected by floods; sewerage and stormwater network service expansion; development of Policy/Regulation code for drainage management; construction of runoff storage ponds and bio-filtration treatment to promote integrated water resources management, and wastewater recycling and reuse. The ultimate goal is a reliable, centralized, sustainable urban drainage service available to all, which considers economic, environmental and social benefits including heritage preservation.

7.2.7 Main Outcomes

After the investigation on drainage network infrastructure, institutional, financial, and technical capacity, and a human resources appraisal in Bethlehem, the following major outcomes resulted:

- Wastewater and Stormwater Master Plan for Bethlehem Governorate 2040
- Integrated Strategy for Sustainable Basic Services Provision in Bethlehem City 2040 (Drainage, Transport, Solid Waste Management)

The total investment cost required for master plan implementation in phases is summarized in **Table 7-7 below:**

Table 7-7: Summary: CAPEX for the different phases[24]

Type	Total Cost including consulting, supervision and contingencies (EUR)
PHASE 1	
Wastewater works	203,821
Stormwater works	281,375
Institutional changes and capacity building activities	325,128
Total	**810,324**
PHASE 2	
Wastewater works	3,281,172
Storm water works without land acquisition	6,980,227
Institutional changes and capacity building activities	483,000
Subtotal	10,744,399
Land acquisition for storm water works	38,400,000
Total	**49,144,399**
PHASE 3	
Wastewater works	41,667,584
Stormwater works	7,517,862
Institutional changes and capacity building activities	0
Subtotal	49,185,447
Land acquisition for wastewater works	1,330,000
Land acquisition for stormwater works	9,999,000
Total	**60,514,447**

24 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

Figure 7-15 Stormwater works Implementation Plan 2040, Bethlehem

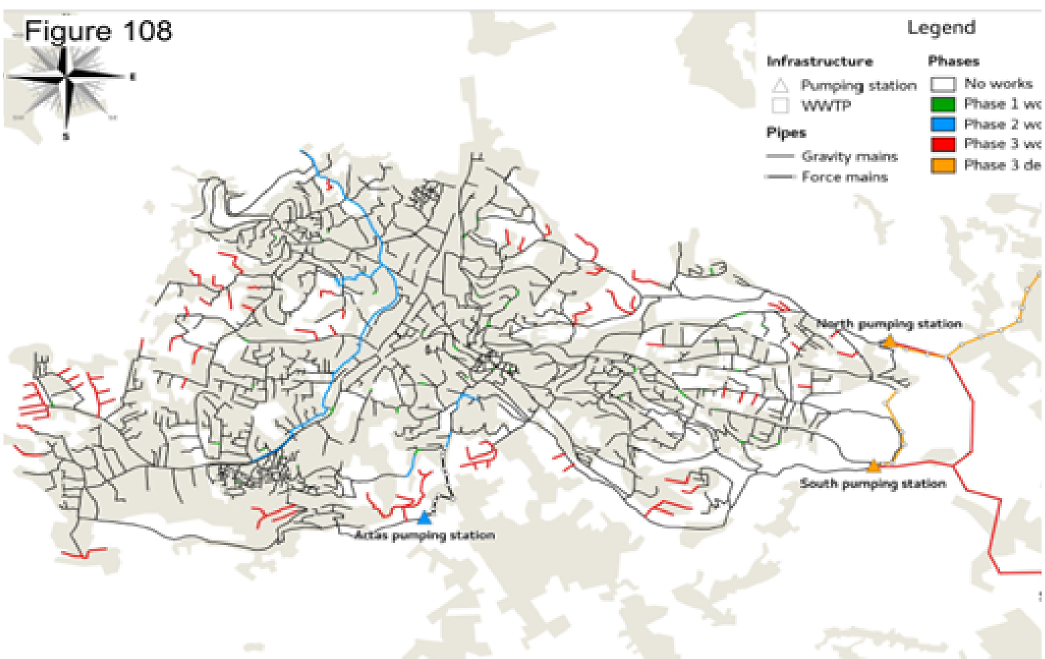


Figure 7-16 Wastewater implementation Plan 2040, Bethlehem[25]

25 Wastewater and Stormwater Master plan for Bethlehem 2040 (2018), Water Supply and Sewerage Authority-Bethlehem-Beit Jala-Beit Sahour

7.3 Urban river basin and catchment management: The Case of Densu Basin in Ghana

- Sustainable management of a river basin system requires that adequate measures are in place to develop and protect the resources in the basin, and manage the use, while at the same time allowing people to meet their needs.
- An IWRM is a cyclic and a long-term process but is a very important approach in efforts to restore degraded river basins. The status of an IWRM plan must be documented, and kept up-to-date when new knowledge surfaces, e.g. new knowledge related to changes in the ecological/hydrological regime and projections of future water requirements.
- River basin restoration problems may be grouped according to categories in line with local criteria for the description of the sustainable development, e.g. natural resources, social and cultural conditions, economic, regulatory, administrative and institutional conditions.
- An increase in water extraction for various uses could imply a multiple increase in wastewater discharge to the river system above the prevailing load.

7.3.1 Background

Population estimates by the Ghana Water Resources Commission (WRC) show that by 2020 the Densu River in Ghana will be supplying about 2.7 million people living within (and outside) of its catchment area with water for potable purposes, irrigation, industrial and other uses. Over time, the water quality of the river had deteriorated as a result of rapid urbanization and improper waste management practices in the basin. Implications of these deteriorations included the high cost of water treatment, loss of biodiversity, loss of livelihoods and income, a high disease prevalence rate and water use conflicts.

In response to this situation, the WRC, which is responsible for the regulation and management of the country's water resources, and the coordination of related government policies, began a process to institutionalise an Integrated Water Resources Management (IWRM) process in the basin in the late nineties when it was established. This was in keeping with one of its main responsibilities, as specified in the WRC Act (Act 522 of 1996), to "*propose comprehensive plans for utilisation, conservation, development and improvement of water resources*".

Currently, the IWRM activities are actively being pursued, which include coordinating the Densu Basin Board and the roles of the various stakeholders under the decentralized arrangement, as well as monitoring the water quality and ecology.

This case study highlights the current status of implementation of the IWRM activities, including the institutional arrangements put in place for the IWRM activities, the major activities undertaken, and the resultant impacts on the water environment. Support to the Commission for the processes and activities undertaken were provided at various stages by Danida, the UN-Habitat Water for Cities Programme, the World Bank and others.

There are lessons from the Chinese examples of this publication, particularly those lessons that could be adaptable for the planned wastewater treatment plants in the basin, e.g. at Nsawam, one of the main pollution hot spots within the basin.

7.3.2 The Densu River Basin

Ghana is well endowed with water resources and has three main river systems. The Volta River system basin, covering about 70% of the entire country, the Southwestern River System covering 22%, and the remaining 8% comprised of the Coastal River System.

The Densu River Basin (Fig. 7.2.1) forms part of the Coastal River System. The river itself stretches 116 km from its source in the Atiwa range in the eastern region to the Sakumo Lagoon in the Greater Accra region where it enters the sea. The catchment covers an area of 2600 km2. There are four reservoirs along its course of which the Weija reservoir, located at the lower course of the river, is the largest. The administrative fabric of this relatively small Densu River Basin is characterised by 3 administrative regions and 17 District Assemblies, including part of the Accra Metropolitan Area.

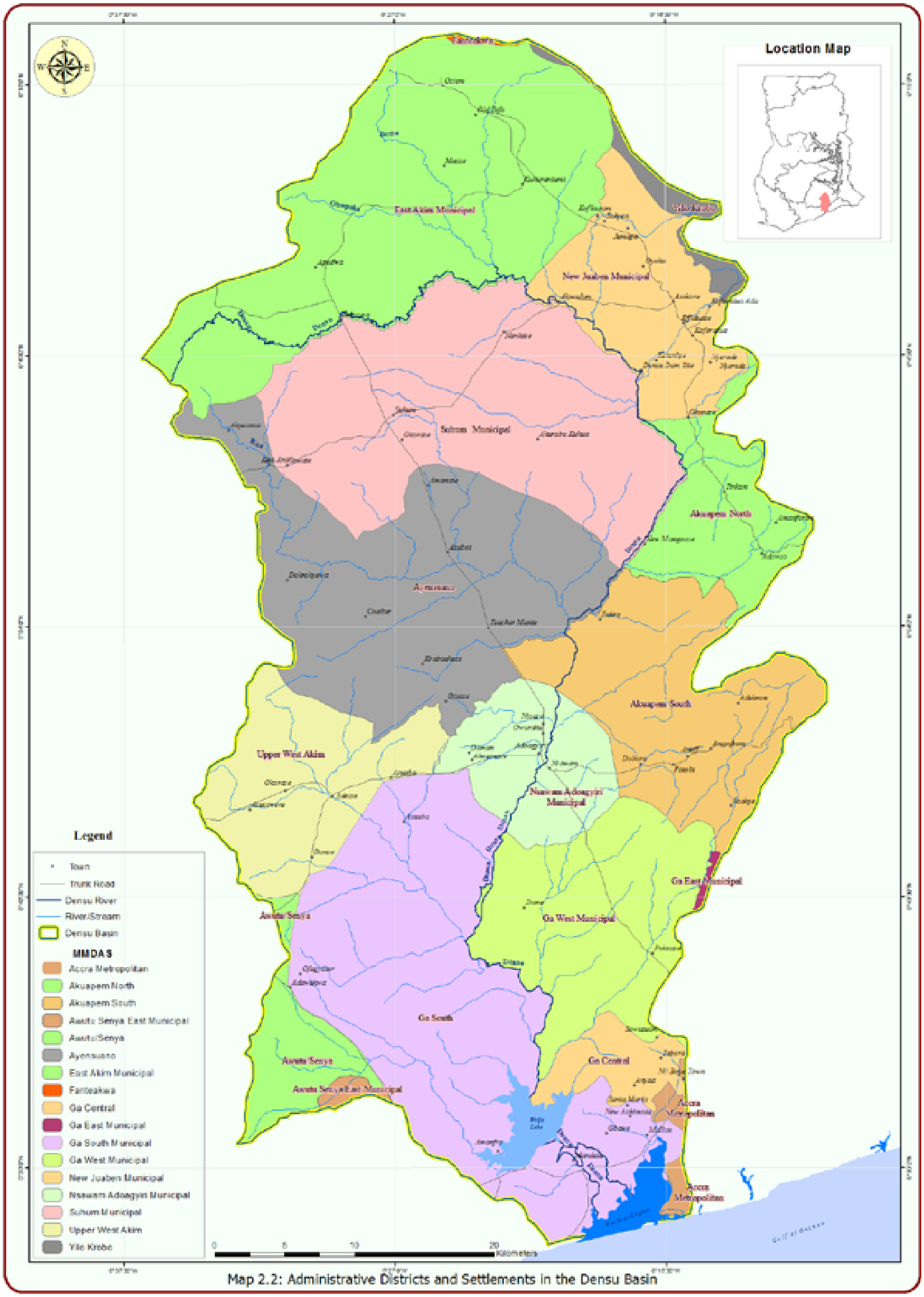


Figure 7-17 Densu River Network, Administrative Districts and Settlements in the Basin

7.3.3 Urbanisation in the Densu Basin

Ghana has experienced a very rapid rate of urban growth since the middle of the twentieth century. The proportion of the country's population living in towns, as officially defined (any settlement with at least 5,000 people), has increased rapidly over the years: it rose from 9% in 1931 to 31.3 % in 1984 and 43.8% in 2000[26], and it is estimated to be around 57.3% in 2020.[27] Modern urbanization in Ghana, however, is focused mainly on Accra– Tema and two other urban nuclei in the country.

Based on the 2000[28] Census results, population projections by WRC in accordance with the settlement classification, i.e. whether people live in rural or urban settings, showed that the estimated total population for 2020 was 2.72 million with an urban population of 1.845 million people (equivalent to 67.7% urban).

Internal migration from rural areas is the most important determinant of the marked population growth in the urban parts of the Densu Basin. As the localities are becoming relatively attractive for migrants, new waves of migrants are likely to gravitate to the urban areas to swell up the existing population. The driving force behind this vibrant development is the urban sprawl phenomenon of Accra. This "urbanisation" trend is expected to continue unabated in the foreseeable future, and hence, will gradually affect larger and larger areas in the Basin, particularly of the Ga Central, Ga South and Ga West Districts.

As an average for the entire Densu Basin, the population density in 2000 was 387 pop/ km2,five times larger than the national average of 77 pop/ km2 at the time, and is estimated to reach 1047 pop/ km2 by 2020. The location of a number of the major settlements and towns within the Basin is also indicated on the map in Fig. 7.2.1. The rapid population growth, poor planning schemes, outmoded technologies and practices for managing waste, inappropriate land use (including farming, sandwinning and quarrying), and fragmented and overlapping institutional functions, led to the degradation of the riparian zone within the basin.

A major challenge is how to remove the strain on the limited social infrastructure resulting from the congestion, overcrowding and the emergence of slums. Other related challenges include haphazard, uncontrolled and uncoordinated urban development; and a need to assign clear roles to towns and cities to ensure the sustainable management of the Basin resources within their jurisdictions, as part of the national development framework.

Public outcry over the quality of water supplied from the Weija Reservoir starting from the mid-nineties, and advocacy measures by the WRC, with support from Danida and UN-Habitat amongst others, resulted in a ban on farming activities along the Densu River buffer by the Government of Ghana in the year 2001, and a call to use water resources within the Basin judiciously. A priority task at the time was therefore to introduce the principles of Integrated Water Resources Management (IWRM) in this river basin.

7.3.4 Managing Water for African Cities Programme

As a result of the growing public concern, the Government of Ghana signed a Memorandum of Understanding (MOU) in 1999 with the United Nations Human Settlements Programme (UN-Habitat) to collaborate in the Water for African Cities Programme. The Programme is the first comprehensive initiative to support African countries to effectively manage the growing urban water crisis and protect the continent's threatened water resources and aquatic ecosystems from the increasing volume of land-based pollution from the cities. It aims to reduce the urban water crisis in African cities through efficient and effective water demand management, minimize the environmental impact of urbanization on freshwater resources and boost awareness and information exchange on water management and conservation. The Programme is part of the wider efforts of UN-Habitat to meet International Development Goal targets for water and sanitation and promoting environmental sustainability.

As part of the Programme in Accra, UN-Habitat and the Government of Ghana identified the Densu River Basin as the focal point for the environmental component, emphasizing the mitigation of environmental impacts of urbanization in the basin. It was recommended that the Densu River Basin needed a wider basin planning approach that involved stakeholder participation, awareness raising, public meetings, capacity building and training, as well as environmental engineering.

7.3.5 Baseline Studies

A comprehensive study of the Coastal River Systems in Ghana[29] was completed in May 1998 following the passage of the WRC Act 522 of 1996, and was part of the process to establish the WRC Secretariat for the Commission.

In 2000, the WRC, embarked on a study to identify and prioritize water resources problems in Ghana, which led to the conclusion that the Densu River Basin was

26 Paul W.K. Yankson and Monique Bertrand, Challenges of Urbanization in Ghana, 2012

27 UN-Habitat, State of African Cities Report 2014, Re-imagining sustainable urban transitions, 2014

28 Ghana Statistical Service: 2000 Population and Housing Census (official results, January 2002)

29 This formed part of an overall Water Resources Management Study for all the River Systems of Ghana

the most stressed river of economic importance (Water Research Institute, 2001).

A number of key studies further informed the eventual framework and structure that emerged for a Densu Basin decentralized IWRM structure. These included amongst others, those directly carried out under the auspices of the Water Resources Commission, and those supported by Danida and the UN-Habitat Water for Cities Programme. These included:

- Water Resources Management Problems Identification, Analysis and Prioritization Study, September, 2000;
- Rapid Environmental Assessment of the Densu River Basin, July, 2001;
- Identification of Major Trends in the Socio-economic Development in the Basin of Relevance to Integrated Water Resources Management (IWRM) and Compilation of Participatory Methods of Relevance to IWRM in the Densu Basin, February, 2003;
- Groundwater Assessment of the Densu Basin, July, 2003;
- Training Needs Assessment of Stakeholders in the Densu Basin and Vegetation Cover Survey, October, 2004; and
- Towards the establishment of an IWRM Structure for the Densu Basin, June, 2004

It was clear from these studies that the Densu river basin presented a classic case of an area in need of a basin-wide planning approach involving stakeholder participation, awareness raising, public meetings, capacity building and training, and environmental engineering.

In an effort to restore the ecology and improve the quality of its waters, the Densu River Basin was chosen as the first IWRM pilot area, following on the recommendations from these baseline studies. It is believed that IWRM approach could lead to the sustainable implementation of effective measures to improve land use and watershed management.

7.3.6 Water Quality and Pollution

Water quality monitoring in the Densu Basin started in the early 1960's by the then Public Works Department. Results from that time showed high levels of dissolved oxygen for most parts of the year – a situation which persisted also in the early years after construction of the Weija reservoir. However, By the early 1990's the dissolved oxygen content in the Densu River system was found to have been reduced by almost half of the values of the 1960's. A special Weija lake water quality survey was conducted in 1996, which - among other objectives - aimed at generating data to determine whether stratification had developed in the lake, and also for determining requirements related to the water treatment process in light of the degrading water quality situation.

As part of a Rapid Environmental Assessment Study covering the Densu Basin under the UN-Habitat Water for African Cities Programme[30] a water sampling exercise, which included 14 locations in the river system, was carried out in 2001. The sampling sites were visited once and thus, the exercise could only provide a "snapshot" picture of the water quality situation in the basin as it prevailed at that time.

Furthermore, the previous water quality monitoring activities related mostly to the physico-chemical parameters, and the data records were scarce with considerable gaps in time and space.

A revived countrywide annual water quality monitoring programme targeting both surface water and groundwater sources, was initiated by WRC in 2005. This programme also included monitoring of trace metals, pesticides and biological parameters as well as phytoplankton and micro-pollutants as may be detected in bio-tissue (fish). The Commission has continued the monitoring activities of the basins (in particular the Densu river basin) to date.

The surface water monitoring in the Densu Basin incorporates four sampling stations along the river, i.e. at Potroase (representing the upstream section of the river), Mangoase and Nsawam (representing the mid-stream conditions) and the Weija reservoir at its downstream.

7.3.7 Water Quality Index

The Water Quality Index (WQI), adopted by WRC in 2003, is used to describe the state of water quality as a whole instead of looking at individual parameters, and can provide indications how polluted the water is. The methodology incorporates selected key physical, chemical and microbiological determinants, and aggregates them to calculate a WQI value at a specific water quality monitoring/sampling site. The index classifies water quality into four categories as presented in **Table 7.8**, with a descriptive note concerning the pollution level of the water body in question. The aim

30 UN-Habitat: Water for African Cities Programme, Rapid Environmental Assessment and Action Planning for the Densu River Basin. Nii Consult (July 2001)

is to protect natural waters from pollution such that the water falls at least in the upper portion of Class II - and more desirably in Class I.

Class	WQI - range	Description
I	> 80	Good - unpolluted water
II	50 – 80	Fairly good quality
III	25 – 50	Poor quality
IV	< 25	Grossly polluted water

Table 7-8: Criteria for WQI classification of surface waters

7.3.8 Sources of Pollution and Sanitary Conditions

Degradation of the water quality of the Densu river poses a range of threats, including eutrophication, algal toxicity **(see Figure 7-18 below)** with related health hazards, resulting from indiscriminate disposal of waste, flooding, improper use of agro-chemicals from the predominant vegetable and pineapple farmers, illegal fishing methods, and leaching from waste dumps.

Figure 7-18 Algal Bloom at the Weija Dam site

Effluent discharge and accidental spills from industries currently do not seem to be very significant, even though occasional reports from the Ghana Water Company Ltd (GWCL) indicate some industrial pollution.

A potential risk related to further contamination of the surface water system would be the impact of a likely exploitation (mining) of bauxite in the Atewa range where the Densu takes its source. Lumbering activities in the Densu Basin cause sheet and gully erosion as well as leaching of soil nutrients - all of which end up contaminating the water sources.

In general, sanitary and waste disposal facilities are inadequate leading to disposal of domestic sewage and garbage into the river system. Until 2006, at Nsawam for example, an estimated 30-40 metric tons of waste were generated annually much of which were disposed of in farms sited on the fringes of the town and close to the river. Furthermore, toilet facilities are inadequate for inhabitants living close to the river in Nsawam, Koforidua and other communities, hence there is open defecation along the river banks and directly in the river.

Sewage treatment ponds serving Koforidua are located close to the river. For lack of proper operation and maintenance, untreated wastewater from the sedimentation tanks find its way directly into the river. The old waste treatment facility at Nsawam Prisons is out of order.

Some health facilities in the Basin have septic tanks that are emptied from time to time. Incinerators are used for other waste. The Blue Skies Company Limited, a fruit processing company, has a waste treatment facility onsite at Nsawam.

Garbage collection and disposal is very poor, and garbage is piled up in huge heaps. As such, leachate from the heaps drains into the river or groundwater aquifers. Landfill sites are most often not managed properly and pose a threat to the river, as garbage and leach end up in it.

The collective impacts of these adverse effects manifests in: high water treatment cost; loss of biodiversity; loss of livelihoods and income; high disease prevalence rate and associated high medical cost; diminishing water availability; and water use conflicts.

None of the urban centres within the basin area have a comprehensive storm drainage network. In the face of the rapid and haphazard growth of these urban centres over the past decades, serious shortfalls in storm drainage infrastructure persist. This results in significant flooding problems with the attendant pollution of the river course and damage to life and property during the rainy seasons. The situation is worse in low lying flood prone areas, where the urban poor live. Recent urban development projects have made substantial investments in roadside drainage in the major urban centres, but have paid little or no attention to primary and secondary drains.

7.3.9 Institutional arrangements

The studies highlighted in the last section were followed by activities initiated by the Water Resources Commission between 2003 and 2004 to establish a Densu Basin Coordination structure, and the institution of initial interventions to introduce IWRM in the Densu Basin. The Coordination structure comprised the establishment in 2004 of a Densu Basin Board (DBB), which administratively is a sub-committee of the WRC, to coordinate activities within the basin and manage it in a holistic manner. It is serviced by the WRC Basin Office at Koforidua (the capital of the Eastern Region of Ghana) as the Secretariat. Membership of the DBB includes representatives from district assemblies (local government structures) within the Basin, regional Coordinating Councils under which the basin falls, various decentralized government departments, the environmental protection agency, NGO and the traditional authority. Currently, the Board is undertaking major activities to restore the ecological health of the Densu.

7.3.10: Responses

The findings of the various studies referred to in earlier sections tended to reveal that land degradation, water quality degradation and water shortages were problems in the basin, and were caused by:

- Use of agrochemicals in farming and harmful chemicals in fishing, (food crops and rearing of animals) on the banks of the river;
- Indiscriminate harvesting of wood from the micro-catchments of the river;
- Encroachment and expansion of urban settlement within the riparian buffer of the river;
- Eutrophication of Weija Reservoir waters as shown in **Figure 7-18**
- Infrastructure development including the siting of industries at unauthorized locations;
- Inappropriate disposal of solid and liquid waste from all sources (including from farms, domestic and industrial sources) into the river;
- Inappropriate behavioral attitudes in communities that pollute the river; and
- Mining, including sand mining and quarrying in and around the riparian buffer.

The initial rapid environmental assessment process was essentially based on technical assessments and description of the water resource-related challenges. This was subsequently subjected to a consultative process involving the basin-based stakeholders aimed at revising the water management issues and problem areas and the actions required in addressing them. Strategic Environmental Assessment (SEA) procedures and tools[31] were adapted and applied at this stage as part of the IWRM planning process for the Basin.

In summary, the problems can be grouped according to the following categories that are applied in accordance with commonly used criteria for description of the sustainable development in Ghana, viz: natural resources; social and cultural conditions; economy, and regulatory, administrative and institutional conditions. These are summarized in **Table 7-9.**

Figure 7-19 Section of the Weija Dam and Reservoir

31 Support and Capacity Building to apply SEA Principles and Tools in preparing IWRM Plans at River Basin Level. WRC (October 2006).

Category of Problem
Natural Resources
Protection of river banks
Forests and protected areas
Farming and farming methods
Inappropriate fishing and fishing methods
Effects of small-scale mining
Water quality, pollution of water and waste disposal
Water weeds infestation
Flooding
Availability/ insecurity of water resources
Socio-cultural conditions
Water-borne diseases and sanitation
Livelihood, land tenure and land use planning
Women's participation in water management
Economy
Economy, financing and lack of resources / capacity
Regulatory, administrative and institutional
Enforcement and good governance
Prevention and resolution of water related conflicts

Table 7-9: Main Categories of Identified Problems

It was further concluded that:

- most attention is paid to problems related to management of natural resources;
- awareness of existing regulatory instruments and delegated responsibilities may be obvious, but their enforcement is the issue; and
- lack of resources and capacity are to some extent seen as the reason for management problems within the basin.

From the existing legal and institutional mandates, responsibilities, and enforcement practices, the procedures and actions needed for an efficient implementation of the IWRM plan were identified, particularly as they relate to the roles of the various involved partners (institutions, agencies, departments.

Based on the findings from this process, an action plan was developed for the implementation of interventions targeted at the rehabilitation and preservation of the ecological stability of the Densu River Basin. This action plan set as an objective, to ensure improvement of water quality of the river system and hence improve public health, while at the same time maintaining livelihoods.

7.3.11 Programme Activities undertaken to contribute to the restoration of the ecological integrity of the Basin

Sustained activities that have been embarked upon to contribute to the restoration of the ecological integrity of the Basin are:

- Awareness creation, education and training of stakeholders through radio and television programmes, newspaper articles/communiqué, community durbars, seminars, workshops and consultations to induce understanding and change of attitudes;
- Provision of information to students for their theses and consultants working on various Densu Basin-based assignments;
- Collaboration between key stakeholder institutions such as the Environmental Protection Agency, Local Government Assemblies, Fisheries Commission, Forestry Commission, Minerals Commission the Ghana Water Company Ltd. and the Community Water and Sanitation Agency, among others, to:
  - o Carry out field operations to control pollution;
  - o Check illegal mining activities;
  - o Stop encroachments;
  - o Dredge sections of the river to curb flooding:
  - o Execute basin-wide projects or micro projects such as the Urban Catchment Management Project which was implemented within the Weija micro-catchment, under the Phase II of the Water for African Cities Programme with support from UN-HABITAT; and
  - o Assist with the identification and registration of major water users and well drillers within the Basin
- Ecological monitoring (3 times/year) and water quality monitoring (5 times/year)

with Board members to have contemporary knowledge about ecological trends within the Basin. Four monitoring sites were included in the monitoring program, including Potroase, which is at the source of the river, Mangoase and Nsawam at the midstream, and Weija Lake at the downstream. A Water Quality Index (WQI) was used to interpret measurements of ambient water quality parameters (dissolved oxygen, biochemical oxygen demand, ammonia, faecal coliform, pH, nitrate, phosphate, suspended solids, electrical conductivity and temperature).

- Organization of quarterly Board meetings to strategize and institute interventions to ensure the sustainability and development of the Basin.

7.3.12 Achievements in Implementing IWRM in Densu Basin

The following represents the key achievements so far in implementing IWRM in the Densu Basin:

- An Integrated Water Resources Management Plan for the Densu Basin has been developed and is being implemented that informs the drawing up of annual work programmes;
- As a result of intensified and sustained awareness creation, various entities are contributing to protect the riverine and lake environments by growing appropriate plant species to serve as vegetative cover to protect against erosion and siltation;
- An ongoing waste-to-value project, the "Special Treat Project", is being implemented in the basin. The project is driven by a PPP from Ghana and the Netherlands, and comprises. measures for improved sanitation, wastewater treatment and re-use in the Nsawam-Adoagyiri, Ga Central and Ga West districts within the basin.

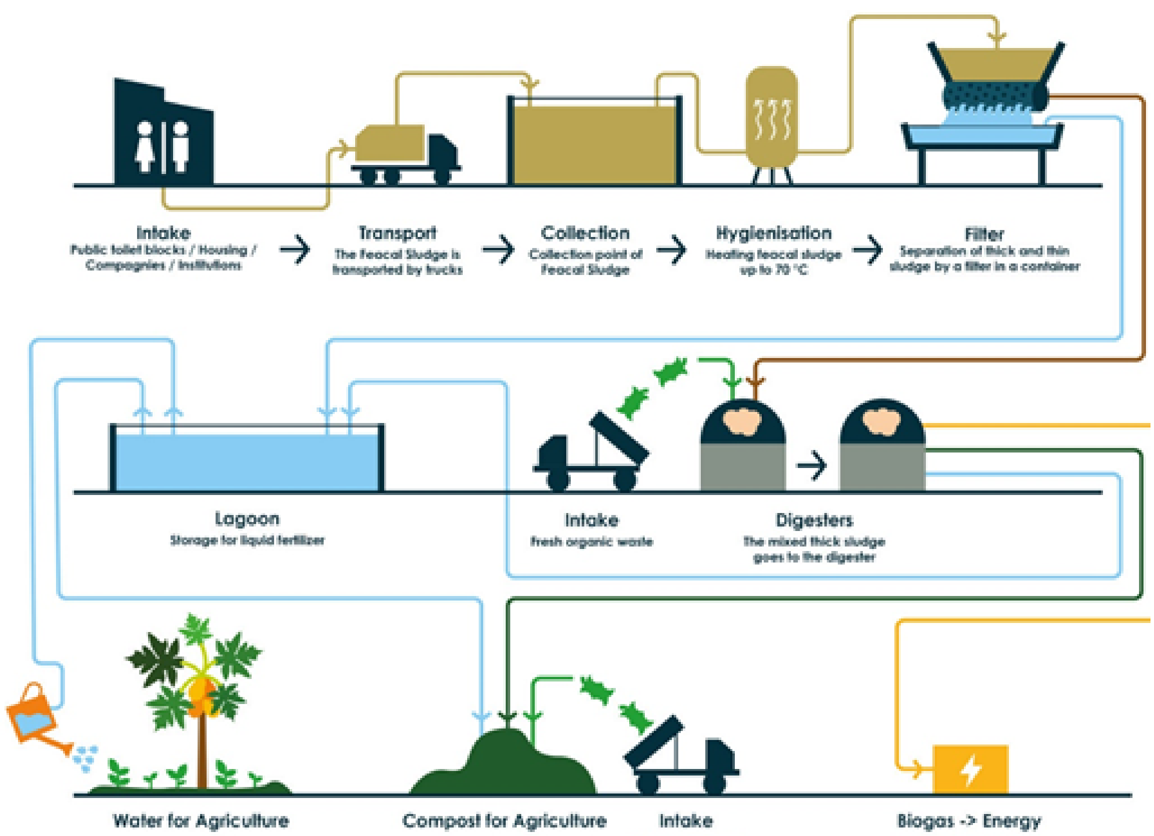


Figure 7-20: The Waste Recycling Chain of the Special Treat Project

(Source: https://www.greenenergyghana.com/th-chaine accessed on 27/2/2019)

The aim is to improve the living conditions of the about 300,000 people in these hot spots in the basin in terms of health, economy and environment. The project became operational in 2018 and includes the construction of 6 public sanitation blocks, a wastewater transfer station and a wastewater treatment & re-use plant (see a schematic in **Figure 7-20**). At the end of the treatment and recycling chain, there will be the production of irrigation water and compost from the liquid and organic wastes treated by the plant.

- The annual average WQI for the Densu Basin (and the Weija Reservoir) for the period from 2005 to 2018 tended to hover between 60 and 45. This falls essentially within the "fairly good water quality" bracket in Table 7-8

It is observed however that the water quality within the Basin seemed to improve initially at all four stations from 2005 (with an average WQI value of 54) to 2006 (with an average WQI value of 64), maybe due in part to improving sanitation and changing attitudes within the Basin as shown in **Figure 7-21** below. This was an indication that the various IWRM activities initiated during that period, e.g. relocation of solid waste dump sites, river bank protection, tree-planting and public awareness raising activities, had an impact on the state of the Densu River at the time. However, the gains made during that period were not sustained. The water quality after 2010 steadily declined and seems to be tailing off on average around a value of 50 in 2018, the lower limit of the "fairly good quality water classification. This calls for intensification of efforts to reverse the trends. The highest WQI during the period between 2005 and 2018 was 82 at Potroase in 2006, while the minimum was 27 in 2012 at Mangoase. The water quality at Potroase being the most upstream station was continuously higher than all the other stations. The decrease from around 82 in 2006 to 61.5 in 2018 for this station could be attributed to heightened illegal mining activities in the Atewa range forests, the headwaters of the river.

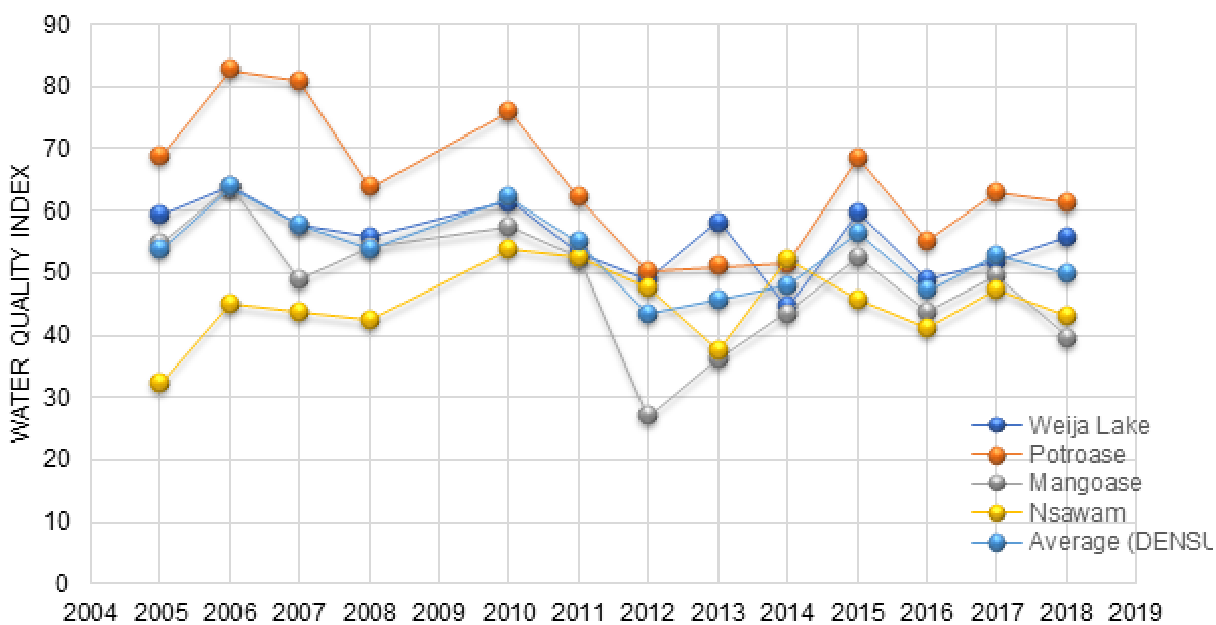


Figure 7-21 Water Quality Index from 2005 to 2018

- Sections of the midstream of the Basin have been dredged to curb flooding, as shown for instance in **Figure 7-22** below for the Nsawam area.

Figure 7-22 . Dredging of the Densu River Channel at Nsawam

- Over fifty licensed well drillers and raw water users are complying with the Water Use Regulations (L.I. 1692 of 2001) and the Drilling Licence and Groundwater Development Regulations (L. I. 1827 of 2006) of the Water Resources Commission, which is contributing to the environmental quality of the River Basin.

Figure 7-23: A view of the Weija Dam and Reservoir post interventions

- As a result of these interventions (and even though the WQI values still seem to be stabilizing), there has been some improvement in odours, algal blooms and turbidity, particularly near the Weija intake, where previously these occured on a regular basis. Furthermore, the Ghana Water Company Limited is now experiencing reduction in treatment costs of the water from the Weija reservoir

7.3.13 Conclusion and Recommendations

In step with further urbanisation and industrialisation, and a very strong likelihood of an increase in demands for water for various uses in the basin, the envisaged increase in the pollution load and its impact on the water quality of the Densu river is bound to increase markedly. Undoubtedly, introduction of wastewater treatment schemes on a broader scale will be required in parallel with further improvement and expansion of the water supply infrastructure for the various envisaged uses.

Given the above situation, it will be necessary to look into replicating projects such as the ongoing PPP "Special Treat Project" to places like Koforidua and other fast growing urban centres in the basin. This will go a long way to ensure that the river basin restoration efforts are sustained. Such approaches, if adopted by the WRC, could provide an opportunity to further explore the Chinese experiences highlighted in earlier sections of this publication, to identify those measures that could be adaptable to the Ghanaian context.

Another area worthy of further investigations is the potential negative impacts of the heightened and increasing mineral exploitation in the upper reaches of the basin in the Atewa Mountain forest range, the headwaters of the Densu river. Despite the rather comprehensive efforts to improve the water quality situation through an IWRM approach, the WQI trends shown in **Figure 7-23** do not seem very encouraging. The attribution to increased pollution from the illegal mining activities is to say the least inconclusive, and could benefit from an in depth investigation.

Successful implementation of IWRM in the Densu Basin through the establishment of basin boards led the WRC to adopt the same principles to other river basins in the country. Currently, an additional five basin secretariats have been set up with fully established boards to protect and conserve water resources in the country. These include the White Volta and Black Volta Basins (which are transboundary basin in the Volta River System), and the Pra, Tano and Ankobra Basins in the South Western River System. All the basin boards have their individual IWRM Plans using the same process adopted for the Densu.

Source: Water Resources Commission of Ghana and UN-Habitat.

7.4 Reducing the adverse environmental impacts of urbanization on local environment: The case of the Mekong River Basin

- Addressing the water pollution in urban rivers is linked to efforts of poverty reduction, improving living conditions as well as environmental protection, especially in water bodies as a whole.
- With rapid urbanization, water pollution from domestic and industrial waste has become a serious environmental and public health problem, especially in cities and towns, where gutters and canals are open sewers for untreated fecal waste from septic tanks and hanging latrines. They are also convenient places to dump garbage. There is a need to focus on the sanitation needs of the poor to achieve urban river environmental objectives;
- The regional approach supports evidence of the transboundary nature of environmental management;
- It is important to strengthen the capacities of institutional and human resources at the local and regional levels, which includes leaders and staff in different organizations, for the sustainability of improved water and sanitation services, and to develop leadership and stakeholder engagement, capacity building and co-production approaches;
- Awareness and a participatory approach is also needed to ensure sustainability.
- UN-Habitat investments played a catalytic role in creating better opportunities to mobilize resources required to realize the development of resilient cities; for example, the Quang Nam Province Development Orientation was improved to become the main socio-economic development planning orientation for Quang Nam Province until 2020

7.4.1 Background

Rapid urbanisation has been an important characteristic of the Greater Mekong Sub-region (GMS). The Mekong region is subjected to similar sorts of challenges as experienced by other developing countries – rapid urbanisation without adequate capital investments leading to lack of infrastructure or access to basic services, such as water and sanitation. Operations and maintenance of existing infrastructure are also affected due to lack of capital, thus exacerbating the situation further. These affect the socio-economic well-being of the people living in such urban settlements.

The Mekong River Basin covers the catchment area of the main Mekong River and its tributaries in six countries, including the Kingdom of Cambodia, the People's Republic of China (Yunnan Province), the Lao People's Democratic Republic, and the Socialist Republic of Vietnam. Over a length of 4200 km, the Mekong river passes from its origins in the Highlands of Tibet to its estuary in the South China Sea (the Mekong delta) through the Yunnan Province of the People's Republic of China, Cambodia, Lao PDR, Myanmar, Thailand and Vietnam.

Figure 7-24 Map of the Greater Mekong subregion

The GMS, comprising of Cambodia, Laos, Myanmar, PRC (Guangxi and Yunnan), Thailand and Vietnam, is home to over 250 million people with social, cultural and economic linkages dating back many centuries. During the 1990s and early 2000s, the GMS region recorded high rates of urbanization (refer to Table below). In Vietnam, the urban population is expected to grow from the current figure of 23% of total population to over 53% by the year 2050.

Table 7-10: Percentage of urban population in selected countries in the GMS

	1950	1975	2000	2025	2050
Cambodia	10,2	4.5	18.6	23.6	36.2
Laos	7.2	11.1	22.0	47.7	60.8
Myanmar	10.2	23.9	27.0	39.8	54.9
PRC (Guangxi)	-	-	28.2	52.4	62.6
PRC (Yunnan)	-	-	23.4	45.0	55.8
Thailand	16.5	23.8	31.4	60.4	71.8
Vietnam	11.6	18.8	24.4	39.9	53.8

Source: Urban Development in the Greater Mekong Subregion, ADB, 2016

7.4.2 Challenges facing the Mekong River Basin

Urbanisation

Urbanization is placing an enormous burden in many secondary towns in the Mekong Region, which will become even more onerous with the ambitious targets of SDG 11. Urban areas are growing at rates of 4.3% in Cambodia, 4.9% in Lao PDR and 3.6% in Vietnam along some of the economic corridors of the GMS. These rates are around 2.5 times the national population growth averages in some countries. It is projected that the urban population in Mekong Region will be over 50% by the year 2050 in all the countries except Cambodia. The vast majority of the new urban citizens are the poor, newly arrived rural migrants. These poor people will end up paying higher prices for their water, use unsafe water, and endure unsanitary conditions.

Although urbanization drives economic growth, it brings with it serious challenges. Without policy and institutional reforms, there is a real risk of urban services becoming unsustainable, leading to environmental degradation and serious health problems. These outcomes ultimately undermine the competitiveness of towns and cities, making them less livable.

Poverty

Although relatively high economic growth rates are making inroads into reducing poverty, the statistics indicate that there are still major concerns. The percentage of people living below the poverty line (less than one dollar a day) is still as high as 29% in Vietnam and 36% in Cambodia. In addition, poverty undermines access to basic services such as water supply and sanitation.

Secondary towns' coverage rates are invariably much lower than the national averages. The poor not only have low incomes, but they have little or no access to safe water and basic sanitation, which adversely impacts their health and productivity, and perpetuates poverty. The opportunity to rise out of this poverty trap is constrained by the limited capacity of local governments and authorities to sustain or expand access to safe water and basic sanitation.

Environment

As cities and towns in the Mekong Region have grown over the past decades, so has the level of pollution that these settlements discharge into the local waterways. Governments, both local and central, as well as service providers, have not been able to adequately manage wastewater discharge from urban centers, especially secondary towns. Low levels of revenue generation that barely support operation and maintenance undermine the institutional and human resource capacities necessary to sustain the delivery of services, whilst protecting local environments. Gross Domestic Product

(GDP) growth in the Mekong Region is now heavily biased towards industry and services, reflecting the urbanization trend. Without adequate consideration of the potential adverse impacts of inadequate sanitation, local waterways may become unusable as raw water sources.

7.4.3 The Mekong Water and Sanitation Initiative

In response to requests from several governments in the GMS, UN-HABITAT developed a three phased strategy for a Mekong Region Water and Sanitation Initiative (MEK-WATSAN) in 2005, to be implemented under the Water for Asian Cities Programme. The term **Mekong Region**, which is now home to some 340 million people, generally refers to the geographical area centered around the world's 12th largest river, the Mekong.

The MEK-WATSAN Initiative was to support participating governments to achieve the Millennium Development Goals for water supply and sanitation, with emphasis on innovative solutions and speedy delivery. The initiative's focus was on capacity building; project design, planning and implementation; and follow-up investments. With a growing awareness of the benefits of a regional approach among Programme countries, participants at an Inception Workshop shared ideas on benchmarking, regional training and capacity building initiatives, regional networking, and cooperation in protecting and managing a shared resource; namely, the Mekong River. One critical issue that seems to affect every country is that of sustainability of services for the poor, especially in terms of cost recovery and subsidy arrangements.

The fundamental goal of the programme is to improve the living conditions of the urban poor in the Mekong Region and protect the local environments. In order to meet its overall goal, MEKWATSAN specifically aimed to:

- Reduce the adverse environmental impact of urbanization on local environment;
- Expedite pro-poor water and sanitation investments in secondary towns;
- Enhance institutional and human resource capacities at local and regional levels;
- Operationalize sector reforms;
- Enhance capacities of local private sector entities in service delivery;
- Support economic development in secondary towns through improved water and sanitation and related income generating activities; and

  Support cooperation between the countries of the Mekong Region.

7.4.4 Achievements of the MEKWATSAN Initiative

The MEKWATSAN Initiative achieved the following:

- Provided to approximately 350,000 urban poor with improved sanitation services;
- Provided over 200,000 urban poor with improved water supply services;
- Assisted over 40 towns/cities in the Mekong region with pro-poor water and sanitation projects.
- Developed Environmental and Social Management Plans for 20 settlements spread across 4 countries of the Greater Mekong Subregion.

Chapter 8

Conclusions

This publication aims to address the challenges of rapidly growing cities around the world challenged by water pollution. Although national and urban planning advocates the importance of comprehensively investing in urban development, investing in pollution control facilities such as sewerage pipe networks and wastewater treatment facilities is often overlooked when addressing diverse challenges associated with rapid urban growth. This leads to a high number of discharges of wastewater and solid waste directly into the environment resulting in gradual degradation of the urban river environment. Prioritizing the construction, maintenance and quality control of facilities that reduce direct discharges of pollutants into the water is key to urban river rehabilitation in developing countries.

The publication describes the key technologies and practices from China where the rehabilitation of selected urban water systems benefited from improving aspects such as the drainage networks; solving sewage cross-connections and reducing overflow pollution in wet weather conditions. These are fundamental to improving the quality of the water body, as well as the environment of the whole river basin.

What becomes evident from the case studies and other evidence in the publication is that rapid urbanization in most parts of the world often overwhelms the resource capacity of local and national governments to adequately manage and therefore guarantee the water quality of urban rivers. Due to lack of attention by cities, many wastewater systems are not comprehensive and the collection networks remain underdeveloped which results in pollutants being discharged directly into water bodies. One of the consequences of not addressing the planning and construction of drainage systems is that urban rivers become heavily polluted. Rehabilitating them becomes a great challenge due to the complexity of systems, engineering and the resultant high expenses of the required technologies and operations.

Some of the major lessons drawn from this publication are:

1. **Pollution control systems such as well-functioning drainage systems and their maintenance, require adequate funding** that is not just derived from one institution but is drawn from broad partnerships. Models such as Public-Private-Partnerships (PPPs) represent a good solution in certain contexts, based on some of the Chinese examples from this report.

2. **Good leadership and governance are a solid foundation to avoid pollution of rivers.** This leadership must be composed of a diverse range of actors, and an accountability system must be in place to ensure quality control and commitments. In China, for instance, the adoption of a "river chief" system has turned out to be an effective management model to prevent pollution and take ownership of the river's water condition. It should be explored if such a model can be replicated successfully in other countries and cities. The international case studies on the other hand, illustrate the value of engaging stakeholders in catchment management and the protection of water bodies.

3. **Urban planners and municipal officials play an important role in managing environmental resources.** If they are trained in environmental assessments and integrated urban and environmental planning and are aware of diverse technologies, they will be much better placed to prioritize the protection of urban water resources and manage and supervise service infrastructure, engineering works such as piping, wastewater treatment and more.

4. **More work needs to be done on collecting data on urban river pollution and associated drainage systems.** Often, cities and counties

know that the levels of water pollution are high, but do not collect the required data over time. Based on such data, the right systems and technologies need to be identified and installed – which is impossible in the case of no data collection and analysis.

5. **Cities should use opportunities to learn from each other**. Cities all around the world are facing similar challenges with regards to wastewater management and urban river environment. However, some have identified mechanisms, technologies and management systems that have led to a significant reduction in river pollution. This publication shares this knowledge that can be adapted to different local conditions. It presents examples from China that can be replicated. The publication is a contribution to the south-south knowledge exchange.

6. **Cities must be frontrunners in improving the quality of all their water bodies.** Through investing in wastewater management and protecting urban rivers, cities and countries will achieve the targets laid out in the SDGs that are linked to environmental sustainability and pollution control, thereby creating liveable environments for their residents. The publication demonstrates that the significant investment by Chinese cities in resources and technologies to improve wastewater management and reduce pollution in urban rivers is a successful case contributing towards achieving the SDGs.

The publication highlights the economic, environmental and social benefits that accrue to the urban populations when urban rivers are kept clean. Some of the economic benefits of reducing urban river pollution include increases in property values along the rehabilitated rivers, the establishment of waterways as opportunities for recreation and other activities that citizens can undertake - fishing, cycling and watching wildlife. Social benefits include the possibility and attractiveness for public parks and public spaces along the riverfront, as well as activities such as sports and games that encourage social interaction and bonding. Lastly, apart from improved aesthetics, restoring the water ecosystem has numerous environmental benefits. The natural ecosystems serve both as a natural buffer from potential flooding, while it has the capacity to regenerate on its own, increasing the overall resilience of the city. Furthermore, a healthy ecosystem is rich in biodiversity, both on land and in water. Noteworthy too is that rivers impact wide areas, thus it is imperative to conserve ecosystem within cities thereby positively impacting ecosystems downstream.




Annex I

Definitions

	Definition	Source
Ammonia nitrogen	Ammonia nitrogen is a measure for the amount of ammonia, a toxic pollutant often found in landfill leachate and in waste products, such as sewage, liquid manure and other liquid organic waste products. It can also be used as a measure of the health of water in natural bodies such as rivers or lakes, or in manmade water reservoirs. The term is used widely in waste treatment and water purification systems.	https://en.wikipedia.org/w/index.php?title=Ammoniacal_nitrogen&action=edit
Best management practices	Schedules of activities, prohibitions of practices, general good housekeeping practices, pollution prevention and educational practices, maintenance procedures, and other management practices to prevent or reduce the discharge of pollutants directly or indirectly to stormwater, receiving waters, or stormwater conveyance systems. BMPs also include treatment practices, operating procedures, and practices to control site runoff, spillage or leaks, sludge or water disposal, or drainage from raw materials storage.	https://www.epa.gov/sites/production/files/2015-12/documents/modelillicit.pdf
Black and odourous water body	Black and odourous water body refers to the water body that presents unpleasant colour and/or emits unpleasant odour in the built-up area of a city.	Guide for the renovation of urban Black and Odourous Water Bodies [000013338/2015-00231]
Closed circuit television	Closed-circuit television, also known as video surveillance, is the use of video cameras to transmit a signal to a specific place, on a limited set of monitors.	https://en.wikipedia.org/wiki/Closed-circuit_television
Chemical oxygen demand	In environmental chemistry, the chemical oxygen demand is an indicative measure of the amount of oxygen that can be consumed by reactions in a measured solution. It is commonly expressed in mass of oxygen consumed over volume of solution which in SI units is milligrams per litre (mg/L).	https://en.wikipedia.org/wiki/Chemical_oxygen_demand
Collecting sewer	A collecting sewer together with all the house sewers by which sewage is conveyed into the collecting sewer.	https://www.lawinsider.com/dictionary/collecting-sewer-system
Combined sewer overflows	Combined sewer overflows are constructed in combined sewer systems to divert flows in excess of the peak design flow of the sewage treatment plant.	https://en.wikipedia.org/wiki/Combined_sewer
Combined sewer system	A sewage collection system of pipes and tunnels designed to simultaneously collect surface runoff water in a shared system.	https://en.wikipedia.org/wiki/Combined_sewer
Coverage of sewer system	It is the ratio between the service area of the established sewage pipe network and the planned construction area.	
Cyclone separator	A method of removing particulates from an air, gas or liquid stream, without the use of filters, through vortex separation.	https://en.wikipedia.org/wiki/Cyclonic_separation

Decision support system	An information system that supports business or organizational decision-making activities.	https://en.wikipedia.org/wiki/Decision_support_system
Density of sewer system	It is the ratio between the length of the constructed sewage pipe network and the planned construction area.	https://baike.baidu.com/item/%E6%8E%92%E6%B0%B4%E7%AE%A1%E9%81%93%E5%AF%86%E5%BA%A6/1253395
Ecological civilization	Ecological civilization is the final goal of social and environmental reform within a given society. It implies that the changes required in response to global climate disruption and social injustices are so extensive as to represent another form of human civilization, one based on ecological principles. Broadly construed, ecological civilization involves a synthesis of economic, educational, political, agricultural, and other societal reforms toward sustainability.	https://en.wikipedia.org/wiki/Ecological_civilization
Event mean concentration	EMCs are an essential component of most storm water pollutant load estimation procedures. In practice, EMCs are considered to be the flow proportional concentration of a given pollutant parameter during storm events. That is, the total mass discharged divided by the total runoff volume. The multiplication of observed or model simulated runoff (flow) by an EMC for a particular pollutant generates a pollutant load.	http://dcstormwaterplan.org/wp-content/uploads/AppD_EMCs_FinalCBA_12222014.pdf
First flush	First flush is the initial surface runoff of a rainstorm. During this phase, water pollution entering storm drains in areas with high proportions of impervious surfaces is typically more concentrated compared to the remainder of the storm. Consequently, these high concentrations of urban runoff result in high levels of pollutants discharged from storm sewers to surface waters	https://en.wikipedia.org/wiki/First_flush
Hydrodynamic Vortex Separators	Hydrodynamic vortex separators are stormwater management devices that use cyclonic separation to control water pollution. They are designed as flow-through structures with a settling or separation unit to remove sediment and other pollutants.	https://cn.bing.com/search?q=Hydrodynamic Vortex Separators&qs=n&form=QBRE&sp=-1&pq=hydrodynamic vortex separators&sc=1-30&sk=&cvid=12096B47DD7E46198683426BD28EF299
Illicit connection	An illicit connection is defined as either of the following: Any drain or conveyance, whether on the surface or subsurface, which allows an illegal discharge to enter the storm drain system including but not limited to any conveyances which allow any non-storm water discharge including sewage, process wastewater, and wash water to enter the storm drain system and any connections to the storm drain system from indoor drains and sinks, regardless of whether said drain or connection had been previously allowed, permitted, or approved by an authorized enforcement agency or, Any drain or conveyance connected from a commercial or industrial land use to the storm drain system which has not been documented in plans, maps, or equivalent records and approved by an authorized enforcement agency.	https://www.epa.gov/sites/production/files/2015-12/documents/modelillicit.pdf
Illicit discharges	Any direct or indirect non-storm water discharge to the storm drain system, except as exempted in Section X of this ordinance.	https://www.epa.gov/sites/production/files/2015-14/documents/modelillicit.pdf
Low Impact Development	The term low impact development (LID) refers to systems and practices that use or mimic natural processes that result in the infiltration, evapotranspiration or use of stormwater in order to protect water quality and associated aquatic habitat.	https://www.epa.gov/nps/urban-runoff-low-impact-development

Point source pollution	A point source of pollution is a single identifiable source of air, water, thermal, noise or light pollution. The sources are called point sources because in mathematical modeling, they can be approximated as a mathematical point to simplify analysis.	van Leeuwen, C.J. (2010). Risk Assessment of Chemicals: An Introduction, 2nd Ed. Dordrecht, The Netherlands: Springer. ISBN 978-1-4020-6101-1. https://en.m.wikipedia.org/wiki/Point_source_pollution
Public-Private Partnership	A public–public partnership is a partnership between a government body or public authority and another such body or a non-profit organization to provide services and/or facilities, sometimes with the goal of transferring technical skills and expertise within international development projects.	https://en.wikipedia.org/wiki/Public%E2%80%93public_partnership
Pumping station	A pumping station is, by definition, an integral part of a pumped-storage hydroelectricity installation.	https://en.wikipedia.org/wiki/Pumping_station
Raw sewage	Sewage that has not yet been processed or treated to separate and remove contaminants.	https://en.wiktionary.org/wiki/raw_sewage
River chief	The river chief refers to the "river leader" system, in which the leading party and government officials at all levels in China serve as the "river leader", who is responsible for organizing and leading the management and protection of the corresponding rivers and lakes.	https://baike.baidu.com/item/河长制/5983406?fr=aladdin
Separate sewer system	A class of sewer system, which only collects wastewater in a separate sanitary sewer pipeline and transports to a wastewater treatment plant.	https://en.wiktionary.org/wiki/raw_sewage
Sewer system	A sewer system comprises a network of pipelines and technical installations (e.g. pumping stations). The system collects and transports waste- and stormwater from more than one source to a wastewater treatment plant or the receiving waters.	https://www.grundfos.com/service-support/encyclopedia-search/sewer-system.html
Stormwater Management Model	EPA's Stormwater Management Model (SWMM) is used for single event or long-term simulations of water runoff quantity and quality in primarily urban areas–although there are also many applications that can be used for drainage systems in non-urban areas	https://www.epa.gov/water-research/storm-water-management-model-swmm
Sobol sequences (algorithm)	Sobol sequences (also called LPτ sequences or (t, s) sequences in base 2) are an example of quasi-random low-discrepancy sequences. They were first introduced by the Russian mathematician Ilya M. Sobol (**Илья Меерович Соболь**) in 1967.	Sobol,I.M. (1967), "Distribution of points in a cube and approximate evaluation of integrals". Zh. Vych. Mat. Mat. Fiz. 7: 784–802 (in Russian); U.S.S.R Comput. Maths. Math. Phys. 7: 86–112 (in English).
Sponge City (SC)	A sponge city is a city that is designed to passively absorb, clean and use rainfall in an ecologically friendly way that reduces dangerous and polluted runoff	https://cn.bing.com/search?q=sponge+city&qs=n&form=QBLHCN&scope=web&sp=-1&pq=sponge+city&sc=8-11&sk=&cvid=450134018A084C658602F16FC4C4F33F
Storage tank	Spherical gas tank farm in the petroleum refinery in Karlsruhe MiRO Storage tanks are containers that hold liquids, compressed gases (gas tank; or in U.S.A "pressure vessel", which is not typically labeled or regulated as a storage tank) or mediums used for the short- or long-term storage of heat or cold.	"Tank - Definition of Tank by Merriam-Webster". Archived from the original on 2015-02-16.

Stormwater runoff	Stormwater runoff is rainfall that flows over the ground surface. It is created when rain falls on roads, driveways, parking lots, rooftops and other paved surfaces that do not allow water to soak into the ground	https://cn.bing.com/search?q=stormwater+runoff&qs=AS&pq=stormwater&sk=EP1AS1&sc=8-10&cvid=65BDD8C5B4C648509B0C53A1CF9A4079&FORM=QBRE&sp=4
Suspended Solid	Suspended solid refers to small solid particles which remain in suspension in water as a colloid or due to the motion of the water. It is used as one indicator of water quality. It is sometimes abbreviated SS, but is not to be confused with settleable solids, also abbreviated SS, which contribute to the blocking of sewer pipes.	https://en.wikipedia.org/wiki/Suspended_solids http://in.grundfos.com/service-support/encyclopedia-search/suspended-solids.html
Sustainable Development Goals	Sustainable Development Goals (SDGs) (or Global Goals for Sustainable Development, the 17 Global Goals, the Global Goals or simply the Goals") are a collection of 17 global goals set by the United Nations General Assembly in 2015. The SDGs are part of Resolution 70/1 of the United Nations General Assembly: "Transforming our World: the 2030 Agenda for Sustainable Development." That has been shortened to "2030 Agenda." The goals are broad and interdependent, yet each has a separate list of targets to achieve. Achieving all 169 targets would signal accomplishing all 17 goals. The SDGs cover social and economic development issues including poverty, hunger, health, education, global warming, gender equality, water, sanitation, energy, urbanization, environment and social justice	https://en.wikipedia.org/wiki/Sustainable_Development_Goals
Total Nitrogen	Total nitrogen is the sum of total kjeldahl nitrogen (ammonia, organic and reduced nitrogen) and nitrate-nitrite	EPA https://www.epa.gov/sites/production/files/2015-09/documents/totalnitrogen.pdf
Total Phosphate	Total Phosphorus (P)--all of the phosphorus present in the sample, regardless of form, as measured by the persulfate digestion procedure.	https://www.epa.gov/sites/production/files/2015-08/documents/method_365-3_1978.pdf
Trunk sewer	A sewer line that receives wastewater from many tributary branches and sewer lines and serves as an outlet for a large territory or is used to feed an intercepting sewer. Also called main sewer.	http://www.owp.csus.edu/glossary/trunk-sewer.php
Trenchless Pipeline Repair	Trenchless Pipeline Repair technology is a type of subsurface construction work that requires few trenches or no continuous trenches.	https://en.wikipedia.org/wiki/Trenchless_technology
Urbanization	Urbanization refers to the population shift from rural to urban residency, the gradual increase in the proportion of people living in urban areas, and the ways in which each society adapts to this change	https://en.wikipedia.org/wiki/Urbanization
Vortex separator	Vortex separators (alternatively,swirl concentrators) are gravity separators, and in principle are essentially wet vaults.	https://www.casqa.org/sites/default/files/BMPHandbooks/mp-51_from_2003_newdevelopmentredevelopment_handbook.pdf
Wastewater treatment	Waste water treatment is a process used to convert wastewater into an effluent that can be returned to the water cycle with minimum impact on the environment, or directly reused.	https://en.wikipedia.org/wiki/Wastewater_treatment
water environmental capacity	Water environment capacity (WEC) is the load quantity of certain pollutants during certain times, in acertain unit of water, given the condition that water can fulfill certain environmental objectives. WEC is indicative of the capacity of the body of water to accept pollutants without destroying its own function.	Liu, R.M., et al., Water environmental capacity calculation based on uncertainty analysis: a case study in the Baixi watershed area, China. Procedia Environmental Sciences, 2012. 13: p. 1728-1738.

Annex II

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Making cities sustainable through rehabilitating polluted urban rivers:

Lessons from China and other developing countries

The pollution of urban rivers is increasingly becoming a global challenge. It is estimated that more than half of the world's 500 biggest rivers are seriously polluted. Keeping urban rivers clean is not only important for good ecological functioning (of nearby land and in water) but also for human health and the blue economy.

This publication, a joint effort of UN-Habitat and Tongji University, shares the rich experiences of China and other countries in addressing the enormous challenges faced during rapid population growth, urbanization and industrialization, and demonstrates the technical, managerial and financial solutions developed to improve water quality and the general environment of urban rivers through well-developed wastewater management systems. It is hoped that these solutions will be a catalyst for better practices globally.

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