Water and Urban Initiative Report

Future Outlook of Urban Water Environment in Asian Cities

Summary for Decision Makers

United Nations University
Institute for the Advanced Study of Sustainability

THE GLOBAL GOALS
For Sustainable Development

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This document summarizes the key findings from the Water and Urban Initiative Project. The full report can be accessed from here: http://www.water-urban.org/

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Future Outlook of Urban Water Environment in Asian Cities

Summary for Decision Makers

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Preface

Worldwide more and more freshwater resources are being used to satisfy growing demands of rapidly increasing populations and growing economies. Meanwhile, urban centers in developing countries are suffering from a scarcity of clean water because most domestic wastewater (speculated at more than 80% (WWAP, 2017)) is discharged into oceans, lakes, rivers, and streams without appropriate treatment. Recent rapid population with fast industrial expansion and economic development has resulted in unfavorable hydrological, ecological, and environmental changes in urban water systems.

In addition, many Asian megacities, especially those in coastal areas, are prone to urban flooding caused by short-term heavy precipitation. Rapid urbanization with insufficient drainage systems, which is often observed in large cities in developing countries, increases the risk of urban flooding. It is projected that such extreme precipitation will be more frequent and more intense due to climate change.

In order to enhance the capacity of local governments and to improve and raise their knowledge and technical preparation in applying the latest techniques in managing urban water, the United Nations University – Institute for the Advanced Study of Sustainability initiated a project titled "Water and Urban Initiative (WUI)". The project aims to contribute to sustainable urban development by creating scientific tools to project the future state of urban water environments. The project also seeks to contribute to capacity development aiming at improving urban water environments in developing countries in Asia. The research findings generated through the interdisciplinary approach of WUI fill an important gap in the global understanding of urban water environments and contribute to improving policymaking in this key area.

This report showcases the scientific findings and policy recommendations of research by WUI conducted in eight Asian cities. The interdisciplinary approach of the research includes studies of future projections of water environment using technical models, analyzing people's perceptions on water-related issues and willingness to contribute to improve the situation, and analyzing mitigation measures for climate change in wastewater management. The results, lessons, and practical recommendations highlighted in this report are important to successfully implement sustainable water management strategies and improve decision-making processes in water-related sectors in those countries. The full report will be available on the WUI website (http://www.water-urban.org/).

Background

Urbanizing Asian Cities

The urban population has almost doubled since the 1950s, with 54% of the world's population in 2014 living in urban areas. The United Nations Department of Economic and Social Affairs (UN DESA) projected that this percentage will continuously increase and reach 60% in 2030 (UN DESA, 2014). It was also estimated that the number of megacities with more than 10 million people in the world will increase from 28 in 2014 to 41 in 2030; and the majority of the megacities will be in Asia (24 cities). Comparing to rural areas, urban areas provide better business opportunities, education, health care, and a more diverse culture. For this reason, rural populations have migrated to urban areas to seek a better life and to benefit from more valuable basic services (UN-HABITAT and ESCAP, 2010). Such migration can be the main driving factor behind rapid urbanization. In this context, the governments are challenged to meet demands for housing, transportation, and basic services (UN-HABITAT and ESCAP, 2015).

However, the economic progress of the Asian region has not positively impacted all of its population, and resulted in economic disparity in some urban areas. Due to economic success in the Asian region, hundreds of millions of people have been lifted out of poverty, and an urban middle class that is estimated at 2 billion people has been created (UN-HABITAT and ESCAP, 2015). On the contrary, the world's largest urban slum population and largest concentration of people living below the poverty line are in the Asian region (UN-HABITAT and ESCAP, 2015). Furthermore, population growth in urban areas is often associated with an expansion of informal settlements in which basic infrastructure and housing are inadequate.

Due to this rapid urbanization combined with rapid economic development, cities are experiencing degradation and depletion of water and other natural resources, which has detrimentally impacted human health, economic productivity, the quality of freshwater resources, and ecosystems. Asian cities are the most vulnerable to natural disasters, which can affect not only people and infrastructures, but also the GDP of the country. In recognition of these challenges associated with urbanization, the New Urban Agenda, which was adopted at the UN Conference on Housing and Sustainable Urban Development (Habitat III) in 2016, calls for action to promote sustainable urbanization.

Water-Related Issues in Asian Cities

Growing urban areas are facing various water-related issues. These issues hamper sustaining valuable water environments, protecting citizen's lifestyles and health, and sustainable urban development. Cities in many Asian countries, especially those in monsoon regions where extreme precipitation events occur frequently, are suffering from the following problems due to an inappropriate quantity or quality of water.

Urban Flooding: In recent decades, we are experiencing an increase in the frequency of flooding events, which threaten human lives and infrastructure. Flooding is the most frequent and most devastating type of natural disaster that affects lives and property in vulnerable areas (CRED-UNISDR 2015, IPCC 2014). Many urban centers have been developed in lowland flat areas adjacent to rivers. These areas are prone to flooding, especially the ones in regions with high precipitation, such as Southeast and South Asia. As examples of these, the 2009 Ondoy typhoon flood in Manila, Philippines and the 2015 South Indian floods in India caused deaths of many people and destroyed a large amount of properties. Urbanization usually increases vulnerability to flooding because altering land cover from bare soil or forest to buildings or pavement reduces the permeability of water to soil aquifers. In addition, insufficient drainage systems are often observed in urbanized areas in developing countries, which increases the risk of urban flooding.

Water Pollution: Water is vital to human life, but it is vital only when it meets quality requirements for the intended use (e.g., drinking, bathing, or irrigation). In urban areas, a huge amount of wastewater is generated due to rapidly increasing populations and lifestyle changes. This leads to a deterioration of the water environment, partly because rapid industrialization, urbanization, and population growth have not been followed by the development of sufficient wastewater management system.

One consequence of polluted water is an elevated risk of waterborne infectious diseases. Municipal wastewater is known as the major source of human pathogens. Humans, especially those in developing countries, have been suffering from water-related diseases, such as cholera, typhoid, and hepatitis, for many years. An estimated 88% of cases of diarrhea are attributable to unsafe water, inadequate sanitation, or insufficient hygiene (Prüss-Üstün et al., 2008). These cases result in 1.5 million deaths each year, most of which are children. Severe urban flooding events are often followed by outbreaks of waterborne infectious diseases (Cann et al. 2013), such as a cholera epidemic in West Bengal, India (Sur et al., 2000) and a massive outbreak of leptospirosis in Manila, Philippines after Typhoon Ketsana (local name: Ondoy; NDCC, 2009) . Human pathogens in rivers, lakes, and sewage have the potential to infect humans when they overflow during flooding events and people are exposed to the floodwater.

Greenhouse Gas Emission: Once a city has grown and developed in an inappropriate manner, it will continuously generate a certain environmental burden over the long term. Emission of greenhouse gases (GHG), such as carbon dioxide, methane, and nitrous oxide, into the atmosphere is one of those burdens. Therefore, it is essential to take measures to mitigate this environmental burden by applying low carbon technology (e.g., reducing fossil fuel consumption and producing renewable energy) at an early stage of the development process. One major type of infrastructure needing expansion in growing urban areas is the wastewater management system. Appropriate mitigation measures should be taken in planning sewerage facilities to reduce GHG emissions.

Sustainable Development Goals

The world has met the target of halving the proportion of people without access to improved sources of water five years ahead of the schedule stated by the UN Millennium Development Goals. However, in 2017, almost 840 million people still remained without access to an improved source of drinking water, and 2.5 billion in developing countries still lack access to basic sanitation (WHO and UNICEF, 2017). Hence, the Sustainable Development Goals (SDGs), which were endorsed by the 70th General Assembly in September 2015, recognized access to water and sanitation as a human right. In particular, Goal 6 is dedicated to water: "Ensure availability and sustainable management of water and sanitation for all". As a research initiative under the UNU-IAS, the Water and Urban Initiative's (WUI) research is directed towards achievements of SDGs as well as the New Urban Agenda, which set the new standard for sustainable urban development. The WUI aims to develop policy tools for sustainable urban water environments, assisting developing countries in Asia to achieve mainly SDG 6 (water and sanitation), SDG 7 (clean energy), SDG 9 (infrastructure), SDG 11 (safe, resilient, and sustainable cities) and SDG 13 (climate change) as well as the New Urban Agenda's transformative commitments on "environmentally sustainable and resilient urban development".

Drivers Affecting Urban Water

Climate Change

Human activities, primarily the burning of fossil fuels and changes in land cover and use, are believed to be increasing GHG concentrations. This alters energy balances and leads to atmospheric warming, which will result in climate change. Climate change is projected to increase rain intensity during rainy periods and the number of non-rain days (Mishra and Herath, 2015; Saraswat et al., 2016). The resulting impact of this is increased direct runoff and less replenishment of groundwater, which in turn lead to increased storm runoff and decreased river low flows.

Hydrologic cycle alteration by climate change will result in undesirable impacts on water resources both in quantity and quality, and hence water-related infrastructures will face a greater risk of damage. The increase in frequency and intensity of extreme rainfall events will lead to larger surface runoff and inundation. Additionally, the decrease in rainfall during lean season affects river water quality. Governments, planners, and water managers have to therefore examine development processes of urban water services and adopt strategies to incorporate climate change into infrastructure design, capital investment projects, service planning, operation, and maintenance.

Population Increase

Although average water availability per capita is sufficient enough, spatio-temporal scarcity is a matter of concern. The growing population increases not only water demand, but also demand for food and consequently agricultural activities. Since the agriculture sector utilizes much more water than the industrial or domestic sectors, water scarcity problems in Asian cities will become more severe. In addition, because a wide variety of chemicals (pesticides, herbicides, antibiotics, etc.) are used extensively on farmlands, water pollution-related problems and health issues will increase. As a result, water that has been used for a variety of purposes contains harmful constituents, including sewage, that pose threats to the environment and to the public health. The quality of water is being degraded due to growing human activities, such as dumping garbage and other waste, and discharging excreta into rivers. Ultimately, by using polluted water, people become the victim of various types of disease.

Land Use Change

Many megacities have high-density settlements and often have a large number of settlements located in flood-prone areas. These are the main causes of increasing flood damage and people's vulnerability in an extreme climatologic event. In order to improve their livelihood, people migrate to cities, which results in the growth of informal settlements in disaster prone areas, such as along large rivers or floodplains.
The increase of built-up areas will increase the frequency and magnitude of flood events. Urbanization changes hydrological processes within watersheds, for example, by fluctuating surface infiltration characteristics. Moreover, in urban areas, permeable soil will be replaced by impervious lands that will reduce infiltration and increase runoff. Additionally, natural water bodies, such as lakes, wetlands, and waterways, which can hold a considerable amount of flood water, have been largely reduced or filled in. Consequently, the frequency of severe floods is increasing.

Development Plans

It has been argued that the effect of climate change, population increase, and changes in land use will each significantly increase the risk of flood events and deterioration of the water environment in the future. Indeed, managing urban flooding and wastewater, especially in rapidly developing cities, with limited infrastructures poses a major challenge to many policy makers.

To cope with these problems, national and local governments in Asian cities have been developing mitigation policies and measures, including master plans, for flood control and wastewater management. The master plans often include plans for water-related infrastructures, such as dams, pumping stations, and sewerage.

Designing countermeasures for flood control and wastewater management by taking into account different projection scenarios for climate change and urbanization will be effective in managing risks in a timely manner. Furthermore, it is important to take into account local policies and strategies such that projections will be able to better describe future urban water environments, and it is important to assess whether current strategies can minimize the anticipated adverse effects of climate change and population growth.

Research Framework

The primary goal of the WUI project is to develop and use science-based research to assess the value of sustainable water environments in urban areas with a focus on Asia. Simulation models accompanied with scenario analysis were developed to project various elements of future urban water environments (e.g., water quality and urban flooding), and to estimate the benefits of improving them. A scenario-based planning approach helps WUI experts to answer "what-if" questions by predicting and analyzing future water outlook. The analysis of water problems relies on scenarios that look at trends under current conditions and possible future situations (with various degrees of intervention). Predictive models make it possible to simulate future water environments by considering changes in land use, population, climate, water infrastructure, and other factors. The research findings generated through the interdisciplinary approach fill an important gap in the global understanding of water-related changes in urban water environments and contribute to improved policymaking in this key area.

The main dimensions of the interdisciplinary approach to addressing issues confronting Asian cities and, consequently, those of the initiated research program, can be briefly outlined as follows: a) flood risk assessment, including the economic assessment of physical damage caused by urban flooding; b) water quality assessment; c) floodwater-related health risk assessment; and d) economic evaluation of water quality improvement (Fig. 1). A series of scenarios were developed for each city to simulate the situation of urban flooding, water quality deterioration, and floodwater-related health risk under the current situation as of 2015 (current scenario), the future situation targeting the year 2030 without considering mitigation measures (business-as-usual scenario), and the future situation with mitigation measures (mitigation scenario). The systems analysis is the core of the research framework, which aims to integrate outcomes from one study into another and analyze results with respect to a series of comprehensive goals and objectives. Procedures used in studies that utilize systems analysis include studying different selected cities, technical models, and future scenarios affecting the water infrastructure in a city.

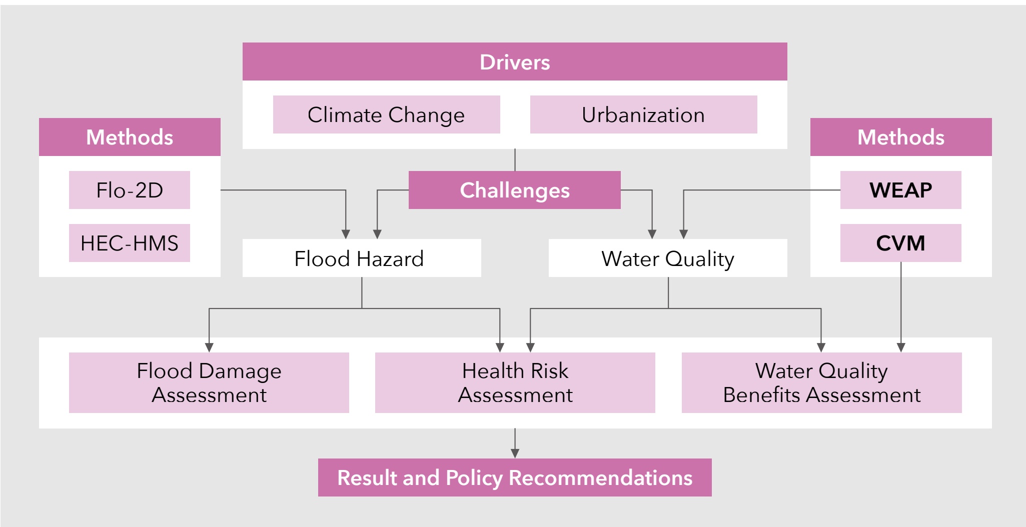

Figure 1. Research framework implemented in the study
Notes: Flo-2D – Hydrologic and hydraulic modelling software; HEC-HMS – Hydrologic Modelling System; WEAP – Water evaluation and planning system; CVM – Contingent valuation method

Flood Risk and Damage Assessment

Flood risk assessment consists of three main components: hazard assessment, exposure, and vulnerability. Water depth, which is generated using inundation models, was applied as the main factor in the flood hazard assessment. Urban flood inundation simulation requires a combination of hydrologic and hydraulic models. HEC-HMS, a hydrologic model, was used for river discharge estimations; and FLO-2D, a hydraulic model, was applied for inundation simulations. Hydrologic modeling was limited to cities where it was necessary to provide the model with a flood entering the city from an upper region. These models predict flood inundation under different conditions of return periods, multiple land use, and climate change scenarios. In this analysis, future climate scenarios were set up by the integration of three Global Climate Models (GCMs) (namely MRI-CGCM3.2, MIROC5, and HadGEM2-ES) and two representative concentration pathways (RCP), RCP4.5 and RCP8.5. Outputs of flood simulations can be added to Geographic Information Systems (GIS) environments to provide comprehensive information about spatial flood hazards, and that information was used as an input for flood damage assessment.

Damage by flooding can be classified as tangible and intangible damage, and direct and indirect damage (Jonkman et al., 2008). This research mainly targets evaluating tangible direct flood damage by taking into consideration the physical impacts of flood hazards. The exposure component represents the element at risk, and this component is correlated to land-use. Furthermore, the vulnerability component was evaluated based on the susceptibility of exposed assets to come in contact with water, and this component is represented by the flood-depth damage function, which is useful for direct damage assessment. These three components were integrated in GIS environments to assess direct flood damage and to identify spatial distribution of damaged areas. These analyses can raise policy-makers' awareness and can be useful for developing effective strategies for flood risk prevention and reduction. Additionally, flood risk and damage loss maps can be used when making policy recommendations to local stakeholders to prioritize their flood mitigation strategies. For this reason, scenarios that implement flood mitigation measures generated by the local master plan were also developed to ascertain the impact of flood reduction measures.

Water Quality Assessment

Predictive models for surface water quality in urban areas were developed using the Water Evaluation and Planning System (WEAP), which is numerical modelling software. After replicating the real situation of a water environment in a simulation, impacts of different key factors (urbanization, climate change, and population growth along with an existing master plan) were taken into consideration to predict water quality in the future with the target year set at 2030. The models visualized future wastewater generation and indicated where additional appropriate countermeasures are needed in addition to the current master plan.

Health Risk Assessment

Urban flooding and heavy rainfall are often associated with waterborne infectious diseases. Flooding causes municipal wastewater to overflow from urban sewerage, septic tanks, and latrines, each of which contain pathogenic microorganisms. To describe the health risks caused by pathogens in floodwater, numerical simulation models were developed using the quantitative microbial risk assessment (QMRA) framework. Norovirus, the major agent causing acute gastroenteritis worldwide, was selected as a reference pathogen to represent many types of pathogens found in water. The effects of urban flooding and water quality deterioration on a number of gastroenteritis cases among residents in flooded areas were examined by using the results of the flood simulation model and the water quality simulation model. Health risk maps generated under different scenarios aimed to provide useful guidance for local policymakers and urban planners.

Benefits of Improving Water Quality

A clean water environment provides important amenity values that contribute to the quality of urban life. The majority of urban water benefits represent non-consumptive use values, which include benefits derived from pleasant views, clean air, as well as recreational activities. Damage to, and pollution of, urban watercourses, rivers, canals, and wetlands causes negative externalities (e.g., the loss of non-priced benefits). Therefore, in urban planning, amenity values should be systematically assessed and measured accordingly (i.e., in monetary terms). Empirical study used the contingent valuation method (CVM) to examine benefits of a clean urban environment associated with willingness to pay (WTP). The study designed to measure the use- and non-use values of a clean urban water environment for two water quality standards: swimmable and fishable. Use values include direct consumptive uses, such as drinking water, irrigation, input to industry and include indirect uses, such as flood control, nutrient retention, and storm protection. While non-use values include existence value (never use), bequest value (future generations), and altruistic value (to others and the current generation). The results of the study were used in assessing benefit and costs analyses of current and future water-related management issues and various urban planning decisions.

Target Cities

The WUI focused on eight cities in Asian countries (Fig. 2) that are facing rapid population growth and urbanization, and, consequently, serious water-related problems, such as urban flooding and water pollution. Data and information necessary to develop our simulation models and to conduct analyses was collected in collaboration with research institutes and agencies in the target areas. The scientific results and research findings were shared with local stakeholders and researchers through workshops in selected cities to develop policy recommendations to further improve the situation.

Figure 2. Target cities of the case studies

Key Findings

Urban Flood

Implications of Climate Change: Comparing past and future precipitation data revealed that extreme precipitation events for all return periods and durations will be more frequent and intense in the future. However, a master plan report was found in several cities with little or no mention of climate change with respect to urban flood risk management systems. The climate change projections revealed significant variation in both the 50-year and 100-year daily maximum precipitation under moderate and extreme conditions. Climate change will increase peak discharge entering metropolis as well as surface runoff over the city, resulting in higher flood inundation. Thus, incorporating climate change consideration in the future and in revising plans is of great significance.

Promotion of Non-Structural Measures: Although structural flood control measures, such as river flow capacity improvement, river bank walls, and improved upstream diversion and storage, effectively reduced flood inundation, the measures might take a long time to complete and require a huge investment. Also, there is a large uncertainty (risk) in climate change projections. Thus, to quickly realize the effects of flood mitigation and avoid investment risk in expensive structural countermeasures, it is important to promote non-structural measures (runoff control measures) by taking into consideration Water Sensitive Urban Design (WSUD) philosophies, such as installing rainwater storage and infiltration facilities, conservation and rehabilitating ponds (in situ), and other philosophies due to their ability to reduce flooding by 15-20%.

Land Use Change Regulation: Land use changes causing urban flood events reflects that currently employed design standards and guidelines need revision. Increased peak flows and flood inundation should be considered in future flood management systems, and flexible, adaptive measures should be adopted because of the uncertainty of land use changes.

Community Engagement: The risk of urban floods and river pollution is closely linked with the community's level of awareness and education. Community participation is a key to implementing non-structural measures, such as infiltration ponds and trenches that can effectively alter surface water runoff processes and thereby mitigate the problems of excessive floods and river pollution.

Scientific Recommendations: High resolution input data (e.g., land use, precipitation, and discharge) for a longer period, which was not realized in various cities that were studied, is essential for calibration and validation of simulation models for reliable prediction. Additionally, use of multiple GCMs and emission scenarios are necessary to minimize uncertainty associated with climate change projections to properly assess water environments.

Contributions to SDGs: Non-structural countermeasures like WSUD, which are focused on promoting community engagement, providing vegetation, and landscape changes, will help in achieving the 11.3 and 11.5 targets, which are targets aimed at making cities safe. Similarly, recommendations on including climate impacts and adaptation strategies in a city's master plan will contribute in achieving the 13.1 and 13.2 targets, which are targets aimed at addressing climate change issues.

Economic Damage by Urban Flood

Effect of Climate Change: The assessment of flood damage in urban watersheds showed that direct flood damage will be more serious in future. The comparison between current and future business-as-usual scenarios showed that damage may increase by 26%, 83%, 212%, 78%, and 56% in Hanoi, Jakarta, Manila, Chennai, and Lucknow, respectively. The impacts of climate change and rapid urbanization may affect the level of flood loss. A high degree of urbanization and the property value of assets may conduct to high flood damage assessment.

Assessing Flood Damage: Quantifying flood damage can be an important indicator in increasing local decision makers' awareness of improving the efficiency of regional flood risk reduction strategies. In addition, local people's perception of flood risk can also change, and they can contribute efficiently to flood reduction, such as by not living in flood prone areas.

Flood Mitigation Measures: Appropriate flood mitigation will be helpful in reducing the impacts of loss due to flooding. The implementation and maintenance of the existing blue and green infrastructure, such as restoring and preserving waterbodies, may contribute not only to reducing flood damage, but also to protecting the environment. Flood mitigation scenarios, as compared with the current situation, showed that 29%, 35%, and 70% of flood damage in Hanoi, Manila, and Chennai, respectively, will be reduced. However, cost-benefit analysis can be useful to support decision makers in taking suitable decisions related to flood protection strategies.

Urban Resilience and Governance: Adopting effective urban resilience strategies can decrease the vulnerability of people and infrastructures. Therefore, land reform in the future urban planning of the cities is essential, and it will contribute to reducing exposure to flooding and, consequently, to reducing flood loss. People living in flood prone areas can be relocated to safer areas with better basic services, which potentially reduces inequality at the city level. Improving flood governance in megacities by launching national flood insurance programs can be an interesting tool for decision makers and can benefit affected people.

Scientific Recommendations: Assessing flood damage is characterized by a high degree of uncertainty due to a lack of data or insufficient knowledge about the flood risk analysis process. The improvement of flood databases, monitoring systems, and partnerships with scientists can help improve accuracy when quantifying flood loss. And the incorporation of better data may enhance policy decision-making.

Contributions to SDGs: Flood loss evaluations can be a relevant and practical indicator of implementing several SDGs. It may contribute to evaluating and achieving the 1.5 target and the 11.5 target of SDGs.

Urban Water Quality

Tracing Factors: Based on the simulated results for the water quality parameters, the water quality for the year 2030 (business-as-usual scenario) is worse than that in 2015 (current scenario) due to the addition of sewage discharge caused by population increase (Fig. 3). Furthermore, the combined effect of climate change and population growth had a negative impact on water quality. The effect of rapid population growth can be simply linked with the increased release of wastewater. Extended dry periods in the dry season raised concentrations of pollutants, and concentrated wet periods may add additional pollutants from combined sewer overflow and increased surface runoff.

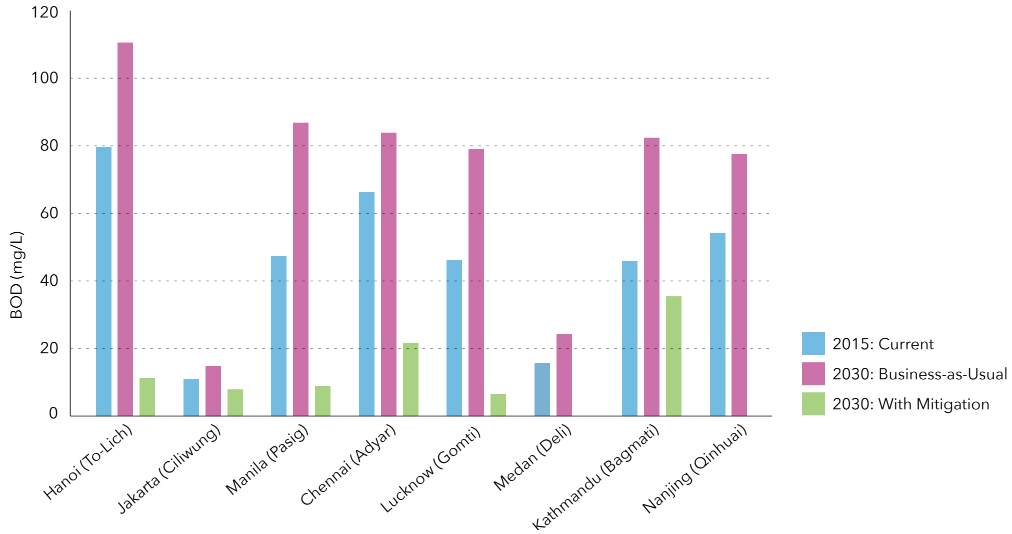

Figure 3. Projected concentrations of biochemical oxygen matter (BOD) in river water

Non-Inclusive Nature of Master Plan: After implementing the master plan for enhancing the capacity of wastewater treatment facilities, water quality will improve by many folds (Fig. 3), which is an encouraging sign. However, looking into target water quality set by local governments, it is found that many of the locations, especially downstream locations, will not comply with the standards. The reason behind this varies depending on the socio-economic setup or technical plan. Therefore, some additional measures that can be considered to overcome this gap are as follows:

i. Spreading awareness among local residences about sewage generation and its impact on the environment
ii. Considering a combined system of decentralized and centralized wastewater treatment
iii. Encouraging local residents to connect their house to the main sewerage pipelines

Transboundary Approach: Looking at the complex nature of waste water management, it is highly recommended to adopt transboundary approaches (hydrological, meteorological, and participatory) to achieve sustainable urban water environment.

Scientific Recommendations: A way to improve this study could be to keep updating the input data with data on (i) implementing new wastewater infrastructures, (ii) changing patterns in water consumption, and (iii) changing trends in reusing wastewater for something else.

Contributions to SDGs: The result of this study will be helpful as a torchbearer for local stakeholders in target cities to develop strategies in achieving the 6.3 Target (improving water quality by reducing pollution, halving the proportion of untreated wastewater).

Benefits of Improving Water Quality

Willingness to Pay for Wastewater Management: This study identifies and presents critical information: How much residents in Metro Manila, Hanoi, Jakarta, and Chennai are willing to pay for policies that are designed to improve water quality in the city's waterbodies (Fig. 4). Based on these values, the total by which Metro Manila might benefit if water quality is improved is around USD190M. The amount for Hanoi is around USD87M, the amount for Jakarta is USD89M, and the amount for Chennai is USD64M per year. These estimates could help policy-makers in planning and promoting new, or upgrading existing, wastewater treatment plants in those cities.

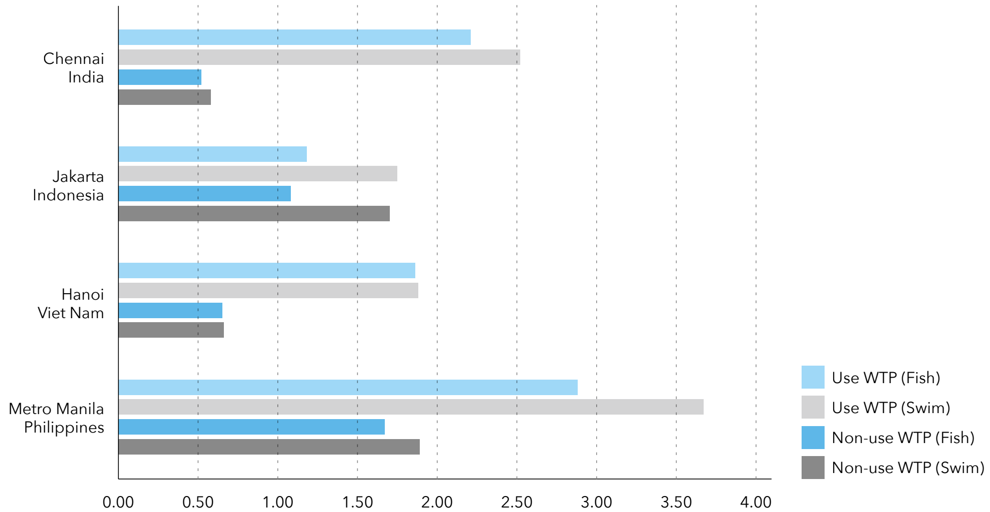

Figure 4. Estimates of use- and non-use WTP for swimmable and fishable water quality obtained by study in four target cities (in US dollars per capita)

Cost-Benefit Analysis: To foster these actions, the study undertook a cost-benefit analysis. Based on the cities' master plans, we concluded that benefits could cover approximately 45-66% of capital expenditures needed to build new, and upgrade existing, wastewater infrastructures depending on the city. However, it should be mentioned that in almost no case in the developed or developing countries was the direct user charged a high enough price to cover all capital and operating costs of the wastewater infrastructure. Most countries provide subsidies from the national and local government budgets.

Recommendations: To prevent further deterioration of waterbodies and improve the overall environmental situation in cities, policy-makers should attract private investors, offer rebate programs and small-scale credits, attract external donors' funds, and, most importantly, raise people's understanding and awareness of the environmental issues facing the area through school programs and public information campaigns.

Scientific Recommendations: These studies employed contingent valuation method (CVM) method, which is a non-market valuation instrument used to reveal the benefits of water quality and other environmental benefits. While CVM is under continuous debate, this method is the only one with which use and non-use values can be assessed. We recommend, together with the results obtained by this particular method, also using other valuation techniques, such as methods for travel cost, hedonic valuation, and cost-of-illness to compare results (use value).

Contributions to SDGs: Water pollution due to rapid urbanization, continuous economic growth, and lack of funds is becoming a big problem in many countries globally. Building a sanitation infrastructure to improve current water quality and mitigating its dangerous impacts is a significant development problem for many developing countries. This study showed policy-makers how much monetary benefits could be secured if a clean water environment is provided. By implementing actions toward this goal, they would achieve SDG 6.3, which clearly addresses water-quality issues.

Low Carbon Technology Assessment

Scenario Development: Four low carbon technologies applicable to the target cities have been identified, as listed in Table 1. The reduction in the emissions of three GHGs (carbon dioxide, methane, and nitrous oxide) by introducing the technologies was calculated using two scenarios: Wastewater treatment plants planned in the master plans, and/or other wastewater management plans, to be implemented by 2030 with common technologies used in the country; and low carbon technologies to be applied in implementing the above plans.

Estimation of GHG Emission Reduction: In total, 196,707 tCO_2/year was reduced by applying low carbon technologies to the implementation of master plans and/or relevant government plans of three target cities, namely Hanoi, Manila, and Jakarta (Table 2). Among the low carbon technologies proposed, utilization of biogas for power generation was most effective in reducing GHG emissions, which account for 69% of the total reduction (Fig. 5).

Contributions to SDGs: Applying these low-carbon technologies will directly contribute to reducing GHG emissions, which is the main mitigation measure against climate change (Goal 13). Introducing renewable energy in wastewater facilities will increase the share of renewable energy (Target 7.2), improve energy efficiency (Target 7.3), and providing access to modern energy services (Target 7.1).

Table 1. Low carbon technologies assessed for wastewater management in target cities

Process	Technologies
Wastewater Treatment	1) Introduction of high efficiency pump 2) Introduction of high efficiency blower
Sludge Treatment	3) Utilization of biogas for power generation
Others	4) Introduction of solar power system in the wastewater treatment plant site

Table 2. GHG emission reduction by application of low carbon technologies to master plans or relevant plans of wastewater management in target cities

Target City	Capacity of Wastewater Treatment Plants listed in Master Plans (m^3/day)	GHG Emission Reduction (tCO_2/year)
Hanoi	661,000	36,151
Jakarta	2,654,032	104,466
Manila	1,516,100	56,089
Total	4,831,132	196,707

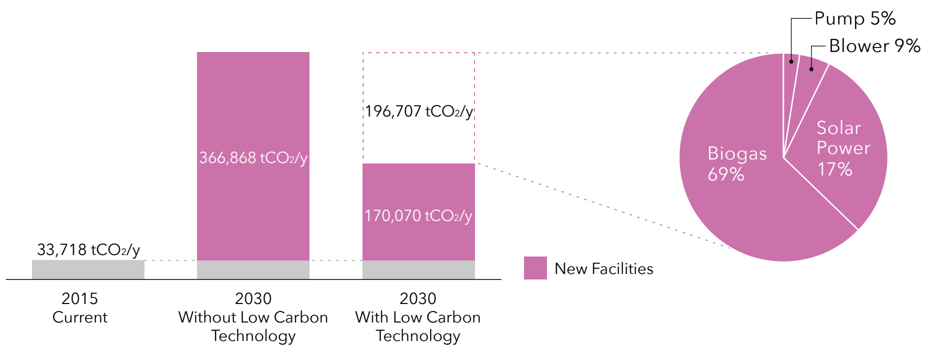

Figure 5. GHG emission reduction by application of low carbon technologies to the master plans of the target cities

Flood-Related Infectious Diseases

High-Risk Areas in Terms of Floodwater-Borne Infectious Diseases: The risk maps based on our simulation showed geographical distribution of the health risk caused by pathogens in floodwater. In some cities, large number of gastroenteritis cases were expected under the current scenario (e.g. 2,528 cases in Manila) due to insufficient wastewater treatment system and a severe urban flooding situation. Within cities, high-risk areas are clustered in populated areas and where severe inundation is expected. Attention should be paid to prevent the spread of infectious diseases in such areas.

Health Risks in 2030: The estimated total number of gastroenteritis showed a remarkable increase of 41-239% over the 15 years from 2015 (current scenario) to 2030 (business-as-usual scenario), depending on the city. The reason for the increase is a combination of the enhanced severity of flooding, a further deterioration in the quality of river water, and the projected increase in population by 2030. Since these factors each independently affect the health risk, the total increase in health risk was larger than that of each input parameter. When considering countermeasures to reduce the flood risk or water pollution in the simulation (mitigation scenario), the health risk decreased significantly below the current risk level. The mitigation measures were found to be very effective in reducing the health risk of floodwater-borne infectious diseases.

Measures to Prevent Outbreaks: These results warrant immediate measures to prevent infectious diseases following flooding events, in addition to measures to prevent adversely affecting the physical health of residents (e.g. drowning). Possible measures in the health sector include distributing disinfectants and soap to residents in high-risk areas, advising people to avoid coming in contact with floodwater, raising public awareness about contaminated floodwater, and monitoring key pathogens in urban water and sewage.

Scientific recommendations: In developing the risk assessment model, several assumptions had to be set because of insufficient data. Filling such data gaps (e.g., concentrations of pathogens in floodwater and their temporal changes during flood events, and people's behavior (e.g., evaluation, contact with floodwater) during and after flooding events) further enhances understanding of health risks related to urban floods.

Contribution to SDGs: The risk assessment model can evaluate the effect of climate change, urbanization, and development of water-related infrastructure on health outcomes (infectious gastroenteritis during and after urban flooding). Implementing appropriate measures to reduce such risks would lead to a reduction in water-borne diseases (Target 3.3), deaths and illnesses resulting from water pollution (Target 3.9) or water-related disasters (Target 11.5), and achieving targets directly related to water (e.g., Target 6.3).

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Summary of Case Studies

Hanoi

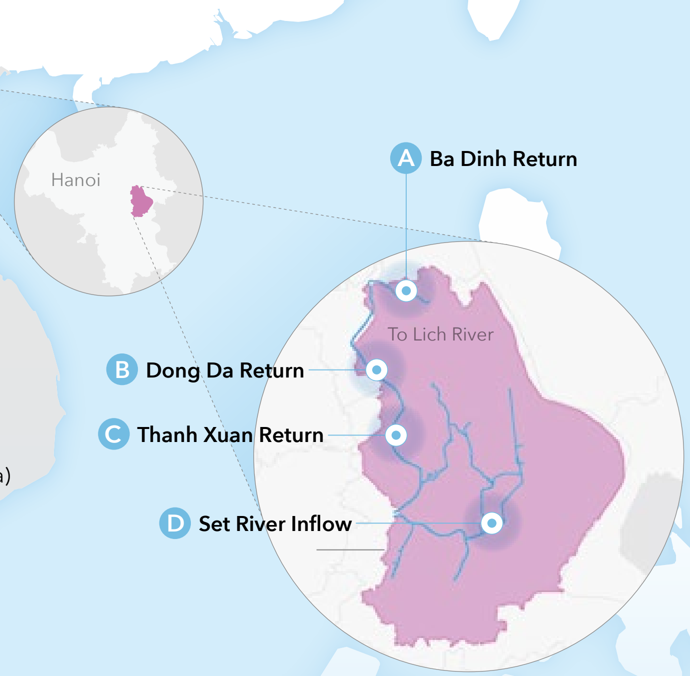
Country
Viet Nam

Area
3,324.92 km^2

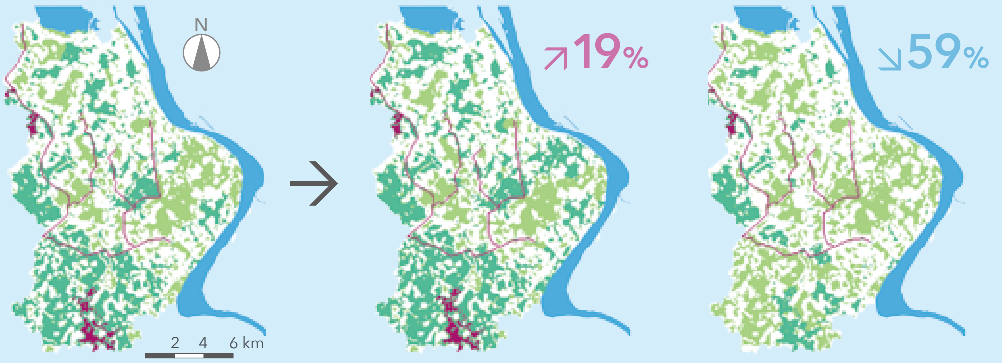
Location
21°04' N, 105°53' E
Elevation: 1.0 m to 11.0 m (Central Area)

Population
7,587,800 (2015)

Climate
Annual Rainfall: 1,676 mm
Temperature: 3˚C to 43˚C



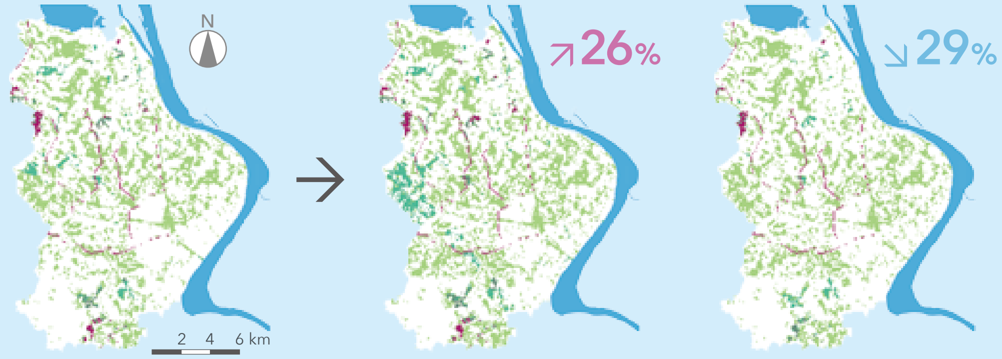
Urban Flood Risk



Flood Depth (m) No Flood (< 0.2) Low (0.2-0.5) Moderate (0.5-1.5) High (>1.5)

Precipitation outputs of multiple GCMs and RCPs were applied for understanding the impacts of climate change on flood inundation. Overall, an increase of 19% in inundated areas with a flood depth of more than 0.5 m has been projected. Implementation of Water-sensitive urban design (WSUD) oriented flood control measures combined with lake preservation will help in reducing inundation areas by 59% compared to the current scenario. The identification of flood-prone areas will be useful in the detection and prioritization of exposed areas for appropriate countermeasures.

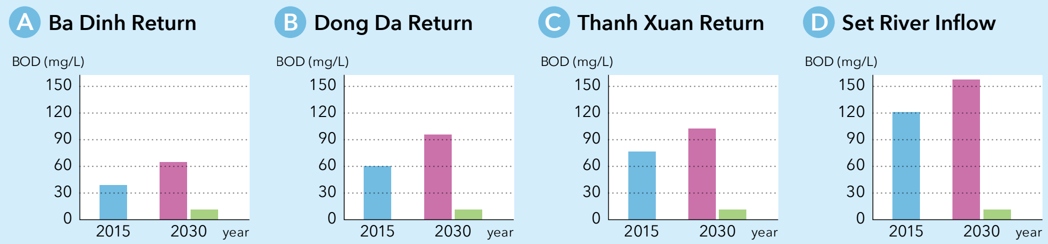
Flood Damage



Flood Damage (USD) Per Grid
No Damage < 5,000 5,000-15,000 15,000-25,000 >25,000

The comparison between current and future scenarios without mitigation indicated a 26% increase in the total damage resulting from climate change. However, the combined flood measures scenario based on lake restoration and implementation of WSUD will decrease flood losses by 29% compared to the current scenario. The results reveal that the spatial distribution of flood damage is correlated with water depth and inundated areas. Indeed, the estimation of the total damage due to flooding in an urban area is very important for urban planning and decision-makers. Damage assessment can be useful for detecting the susceptibility of an area to flood risk. Consequently, the quantification of flood damage can be an important indicator to enhance awareness of local decision makers for improving the efficiency of regional flood risk reduction strategies.

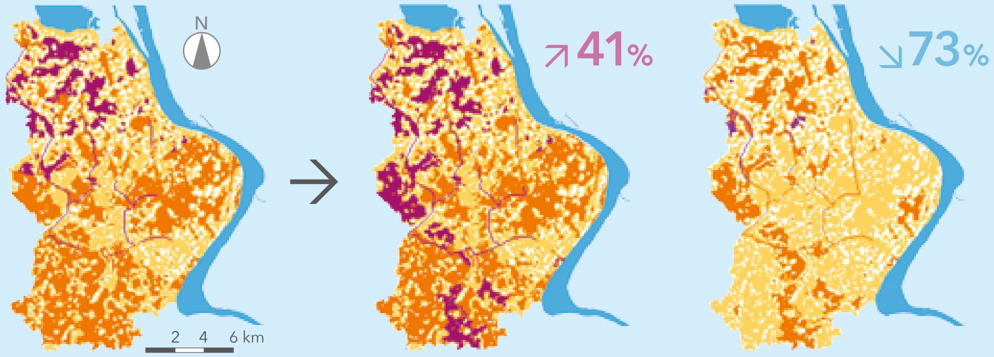
Water Quality



2015: Current 2030: Business-as-Usual 2030: With Mitigation

Two scenarios (business-as-usual and with mitigation plan) were developed to project the river water quality in 2030. Due to climate change and population changes, the water quality (expressed as BOD) will have deteriorated by a further 53.1% on average in 2030 when compared to the current situation. According to their master plan, all domestic wastewater currently flowing into the rivers, except for the Kim Nguu River, will be transferred to new wastewater treatment plants. We suggest that the rivers be supplemented with treated wastewater from surrounding wastewater treatment plants or water from other sources to maintain the river flow and to significantly improve the water quality, as shown in the mitigation plan scenario (85.8% reduction compared to the business-as-usual scenario).

Health Risk



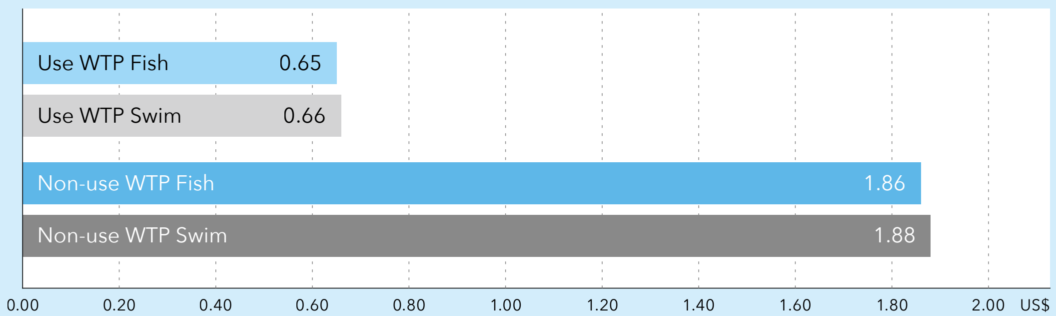
Number of Gastroenteritis Cases Per Grid

No risk | Low risk (< 0.01) | Medium risk (0.01-0.1) | High risk (> 0.1)

The number of floodwater-borne infectious gastroenteritis cases by Norovirus will increase by 41% due to changes in flood pattern, river water quality, and population. By implementing the master plan to reduce urban flooding and utilizing the mitigation plan suggested in the water quality analysis to enhance wastewater treatment, the number of gastroenteritis cases will decrease by 73% and 81% compared to the current scenario and the business-as-usual scenario, respectively.

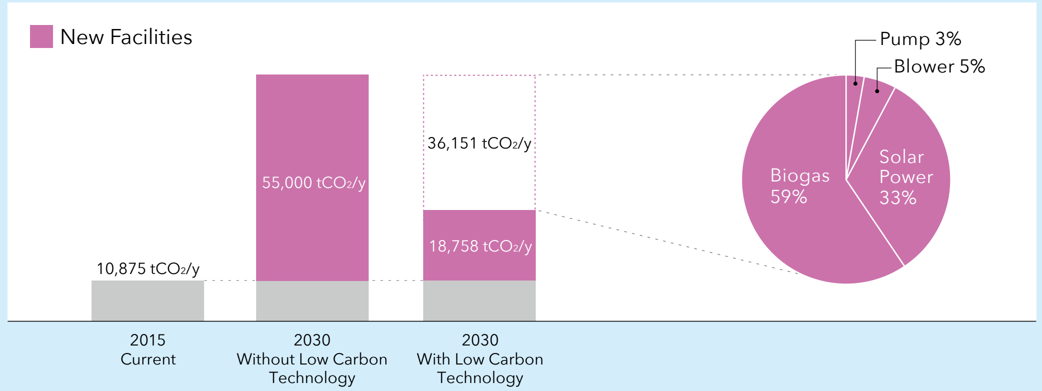
Willingness to Contribute for Improved Water Quality

Use and non-use WTP estimates for swimmable and fishable water quality standards, Hanoi, Viet Nam (Use WTP in US$/month, non-use - one time payment)



Based on our sampling, 75% of Hanoi residents are willing to contribute to the measures, which could improve existing surface water quality in the city. After aggregation of the obtained WTP from across the whole population of Hanoi, the total economic value of water quality improvements is estimated to be equal to approximately US$87 million per year. The estimated benefits of a clean water environment in Hanoi are not enough to sufficiently cover either losses due to poor sanitation or the costs of new WWTPs construction and operation (i.e., losses and costs are higher than the benefits.).

Low Carbon Technology



With the aim of mitigating the possible adverse impact of climate change by taking countermeasures against water pollution, four types of low carbon technologies were applied to wastewater treatment plants: 1) the introduction of high efficiency pumps, 2) the introduction of high efficiency blowers, 3) utilization of biogas for power generation, and 4) the introduction of solar power systems. By introducing these low carbon technologies, a total of 36,151 tCO_2/year of greenhouse gas (GHG) emissions are reduced in the target area. Of these, utilization of biogas is considered as the most effective item for GHG emission reduction.

Jakarta

Country
Indonesia

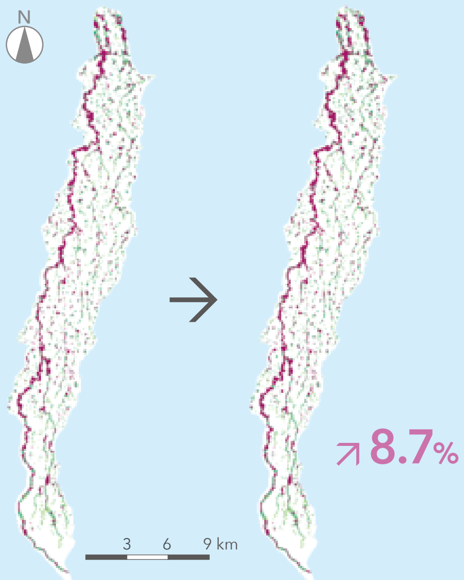
Area
662 km² (DKI)

Location
6°12' S, 106°49' E
Elevation: 15 m

Population
10,135,000 (2014)

Climate
Annual Rainfall: 1,816 mm
Temperature: 22˚C to 32˚C

Urban Flood Risk



Flood Depth (m) No Flood (<0.2) Low (0.2-0.5) Moderate (0.5-1.5) High (>1.5)

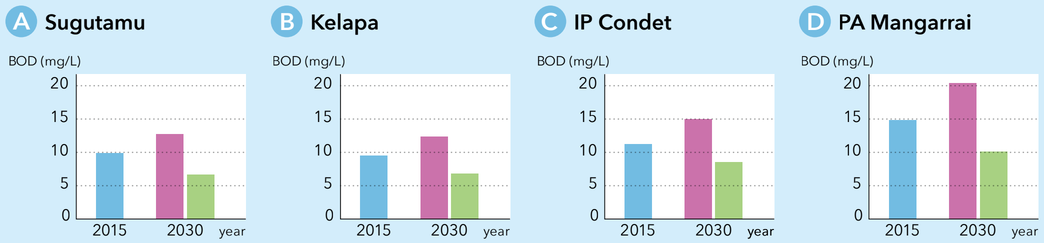
Jakarta city is traversed by several rivers and is therefore highly prone to frequent flooding brought by excessive stormwater from the upper region. The comprehensive flood management plan of Jakarta is largely based on diverting excessive discharge generated in the upper region via east and west flood channels and protecting the lowland areas from inundation. Ciliwung River between Katulampa and Manggarai sections were investigated to assess future flood risk. Comparison of flood hydrographs at Katulampa for the combined effects of climate and landuse change revealed an increase of 130% in peak discharge in 2030. An increase of 8.7% was projected in flood inundation areas with a flood depth of more than 0.5m in the future across the study area. Preliminary simulations for increased river sections (flow area) were found to be highly effective in reducing the depth of flood inundation.

Flood Damage

Flood Damage (USD) Per Grid
No Damage <5,000 5,000-15,000 15,000-25,000 >25,000

The evaluation of direct tangible damage in the Ciliwung river basin revealed that predicted future flood damage will increase due to, in particular, the impact of climate and land use change. The comparison between current and future situations showed that the flood damage is expected to be much higher. It will rise by approximatively 83% in the situation of average climate. In the current situation, damage is significant in Jakarta province (east and south). However, in the future, all regions will be more affected and the increase of flood loss will be more significant in Bogor (Regency and City). This might be a result of predicted urbanization in Bogor. In fact, significant urban growth was estimated for the area, with a projected expansion of 85% by 2030. Mapping flood damage can motivate and encourage local policy makers to adopt appropriate urban resilience strategies to avoid the risk of flooding and to reduce exposure to floods. Additionally, the prediction of spatial distribution of flood damage will be useful for planning structural and non-structural measures.

Water Quality

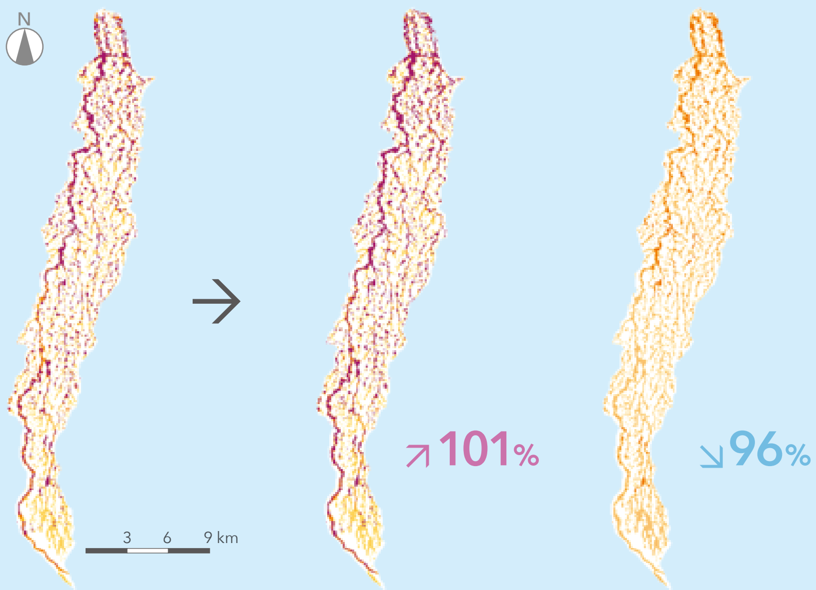


2015: Current 2030: Business-as-Usual 2030: With Mitigation

Two scenarios (business-as-usual and with mitigation plan) were developed to project the water quality of the Ciliwung River in 2030. Due to climate change and population changes, the water quality (expressed as BOD) will have deteriorated by a further 35.5% on average in 2030 when compared to the current situation. According to their master plan, all domestic wastewater currently flowing into the rivers will be transferred to expanded and newly built wastewater treatment plants of a 520 MLD capacity, in comparison to the 22 MLD used at present. The sewerage collection rate will also be increased from 4 % in 2015 to 100% in 2030. Based on the scenario where all wastewater generated in the area is treated (2030: with mitigation), the projected water quality will be much better throughout the stream (47.1% reduction compared to the business-as-usual scenario), which is an encouraging sign. However, the quality of water is still a matter of concern, especially in the downstream area. This is due to the continued inflow of the untreated wastewater from the upstream region. It would be better to focus on and treat wastewater in the upstream of the Katulampa region as well as in the Bogor region.

Health Risk

2015: Current **2030: Business-as-Usual** **2030: With Mitigation**



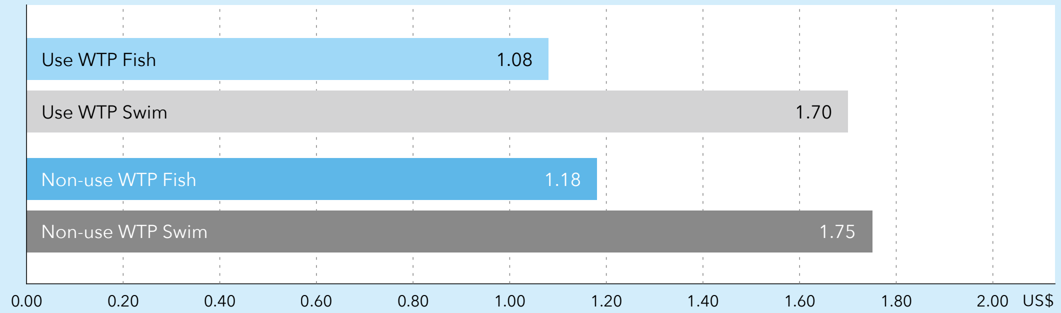
Number of Gastroenteritis Cases Per Grid

No risk | Low risk (< 0.01) | Medium risk (0.01-0.1) | High risk (> 0.1)

The number of floodwater-borne infectious gastroenteritis cases by Norovirus will increase by 101% (972 under the current scenario to 1,956 cases under the business-as-usual scenario) due to changes in flood pattern, river water quality, and population. By improving the wastewater management system to achieve complete coverage of wastewater treatment in the target area, the number of gastroenteritis cases will decrease by 96% and 98% compared to the current scenario and the business-as-usual scenario, respectively.

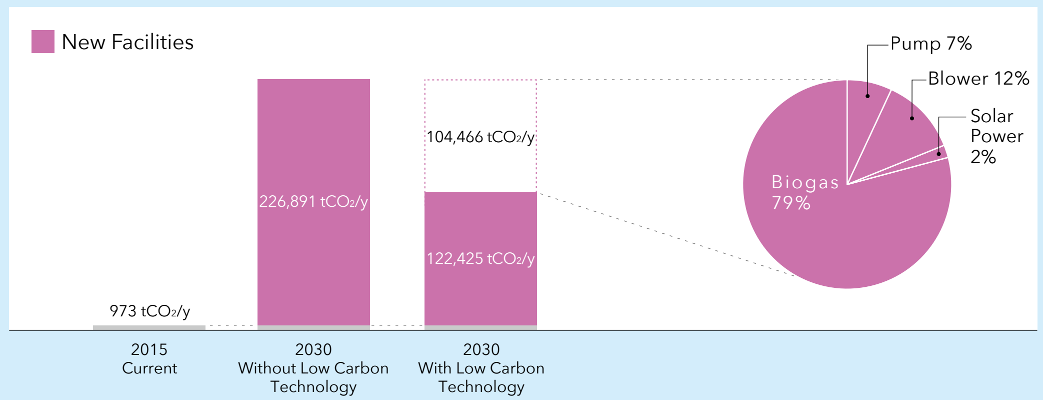
Willingness to Contribute for Improved Water Quality

Use and non-use WTP estimates for swimmable and fishable water quality standards, Jakarta, Indonesia (Use WTP in US$/month, non-use - one time payment)



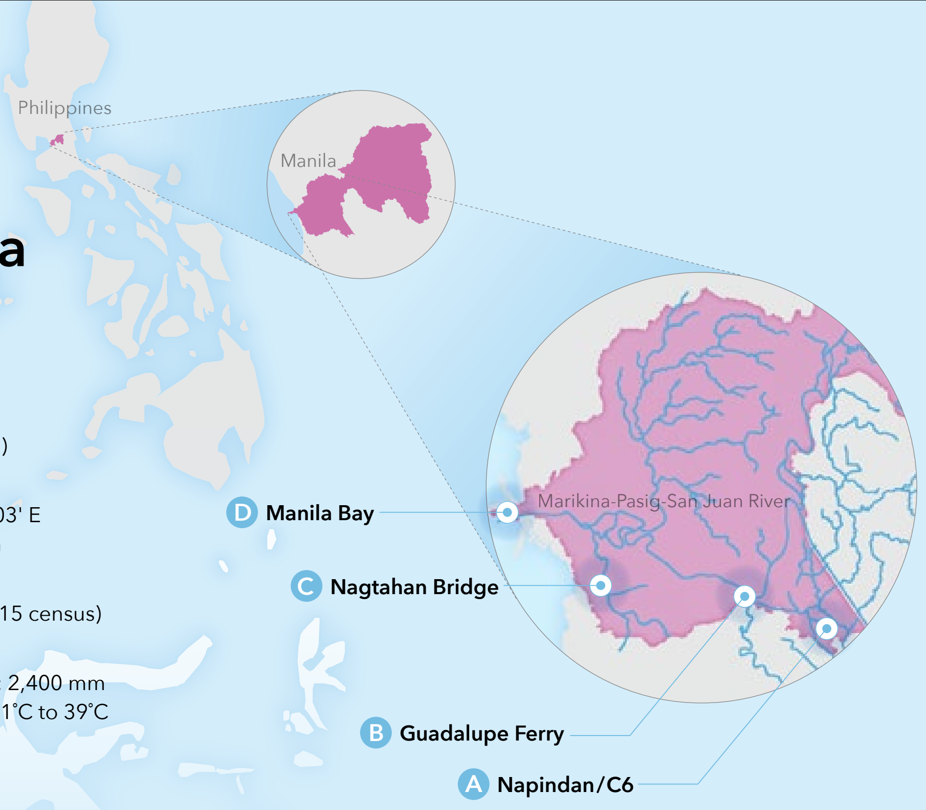
Based on our sampling, 47% of Jakarta residents are willing to contribute to the measures, which could improve existing surface water quality in the city. After aggregation of the obtained WTP from across the whole population of the megacity, the total economic value of water quality improvements is estimated equal to approximately US$89 million per year. The estimated benefits of a clean water environment in Jakarta are not enough to sufficiently cover either losses due to poor sanitation or the costs of new WWTPs construction and operation (i.e., losses and costs are higher than the benefits.).

Low Carbon Technology



With the aim of mitigating the possible adverse impact of climate change by taking countermeasures against water pollution, four types of low carbon technologies were applied to wastewater treatment plants: 1) the introduction of high efficiency pumps, 2) the introduction of high efficiency blowers, 3) utilization of biogas for power generation, and 4) the introduction of solar power systems. By introducing the aforementioned low carbon technologies in the wastewater treatment plants, 104,466 tCO_2/year of greenhouse gas (GHG) emissions can be altogether reduced in the target area. Of these, utilization of biogas is considered as the most effective item for GHG emission reduction.

Manila



Country
Philippines

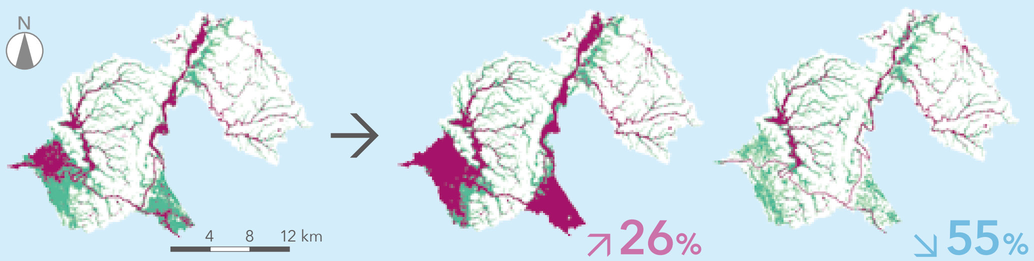
Area
636 km² (Metro)

Location
14°40' N, 121°03' E
Elevation: 24 m

Population
12,877,253 (2015 census)

Climate
Annual Rainfall: 2,400 mm
Temperature: 21˚C to 39˚C

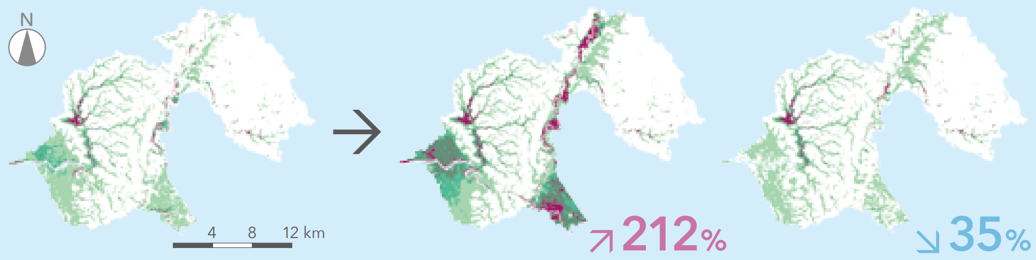
Urban Flood Risk



Flood Depth (m) No Flood (<0.2) Low (0.2-0.5) Moderate (0.5–1.5) High (>1.5)

Inundation modeling was carried out downstream of the Montalban area of Marikina-Pasig-San Juan river system, which covers most of Metro Manila, to assess future flood risk and adaptation strategies. The Ondoy flood event of 2009, with an approximate 100 years return period, was considered for comparing future flood risk under climate change and urban expansion. Structural and non-structural countermeasures available for a flood management master plan/vision (JICA, 2014) were tested. Analysis of climate change projections revealed an increase of 25% and 40% in 100-yrs daily maximum precipitation for moderate and extreme conditions, respectively. Moderate climate change projections also indicated that there would be an increase of 30% peak discharge at Montalban from 4000 m^3/s to 5300 m^3/s for 100-years return period. Structural flood control measures, such as river flow capacity improvement, improved diversion channel regulation and dam construction (u/s of Montalban region) were found to be highly effective in reducing the flood inundation.

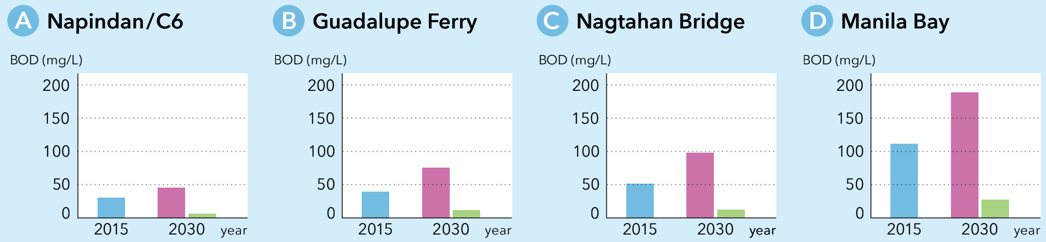
Flood Damage



Flood Damage (USD) Per Grid
No Damage <10,000 10,000-25,000 25,000-50,000 >50,000

The comparison between current and future situations with and without mitigations pointed to the state level of flood damage. Due to the impact of change in climate and land use, flood damage increased by approximately 212%. Nevertheless, the implementation of flood risk reduction will decrease flood damage by approximatively 35% when compared to the current situation. Mapping of flood damage shows that Manila, Pasig, Taytay, Cainta, and some parts of Rodriguez and San Mateo are the most susceptible cities within the study areas. Additionally, serious damage was also detected in cities located along the Marikina Pasig and San Juan River system, such as Marikina. The damage is attributed to the magnitude of hazard (water depth), the level of exposure (assets located in threated areas), and vulnerability parameters. These results can be useful for decision-makers to adopt suitable strategies on flood control and to enhance urban infrastructures.

Water Quality

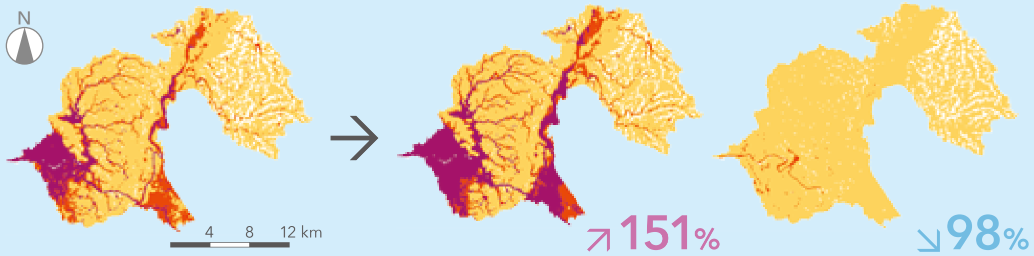


2015: Current 2030: Business-as-Usual 2030: With Mitigation

Two scenarios (business-as-usual and with mitigation plan) were developed to project the water quality of the Pasig-Marikina River in 2030. Due to climate and population changes, the water quality (expressed as BOD) will have deteriorated by a further 83.4% on average in 2030 when compared to the current situation. According to their master plan, all domestic wastewater currently flowing into the rivers will be transferred to expanded and newly built wastewater treatment plants of a 612 MLD capacity, compared to the 42.5 MLD used at present. The sewerage collection rate will also be increased from 22 % in 2015 to 100% in 2030. Based on the scenario where all wastewater generated in the area is treated (2030: with mitigation), the projected water quality will be much better throughout the stream (89.6% reduction compared to the business-as-usual scenario), which is an encouraging sign. However, water quality is still a matter of concern, especially in the downstream area. This may be a result of non-consideration of factors like climate change and differences between contaminant removal efficiency of the WWTPs at the current stage (reality vs assumed during simulation). Another possible reason for this deviation is non-consideration of untreated waste being generated before Napindan.

Health Risk

2015: Current **2030: Business-as-Usual** **2030: With Mitigation**



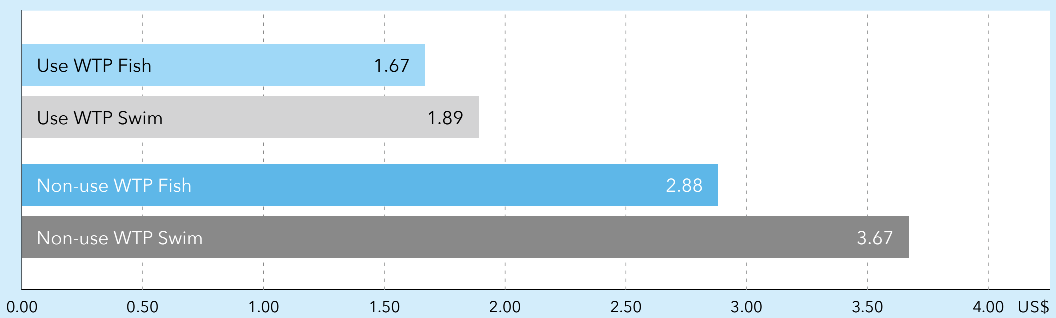
Number of Gastroenteritis Cases Per Grid

No risk · Low risk (< 0.01) · Medium risk (0.01-0.1) · High risk (> 0.1)

The number of floodwater-borne infectious gastroenteritis cases by Norovirus will increase by 151% (1,007 under the current scenario to 2,528 cases under the business-as-usual scenario) due to changes in flood pattern, river water quality and population. By implementing the master plan to reduce urban flooding and to achieve complete wastewater treatment in the target area, the number of gastroenteritis cases will decrease by 98% and 99% compared to the current scenario and the business-as-usual scenario, respectively.

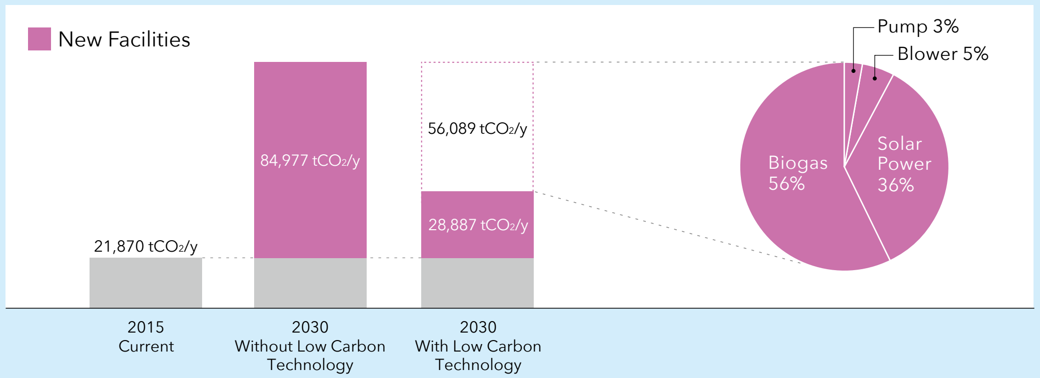
Willingness to Contribute for Improved Water Quality

Use and non-use WTP estimates for swimmable and fishable water quality standards, Metro Manila, Philippines (Use WTP in US$/month, non-use - one time payment)



Based on our sampling, 74% of Metro Manila residents are willing to contribute to the measures, which could improve existing surface water quality in the city. After aggregation of the WTP from across the whole population of the megacity, the total economic value of water quality improvements is estimated as equal to approximately US$190 million per year. The estimated benefits of a clean water environment in Metro Manila are not sufficient enough to cover either losses due to poor sanitation or the costs of new WWTPs construction and operation (i.e., losses and costs are higher than the benefits.).

Low Carbon Technology



With the aim of mitigating the possible adverse impact of climate change by taking countermeasures against water pollution, four types of low carbon technologies were applied to wastewater treatment plants: 1) the introduction of high efficiency pumps, 2) the introduction of high efficiency blowers, 3) utilization of biogas for power generation, and 4) the introduction of solar power systems. By introducing the aforementioned low carbon technologies in the wastewater treatment plants, 56,089 tCO_2/year of greenhouse gas (GHG) emissions are altogether reduced in the target area. Of these, utilization of biogas is considered as the most effective item for GHG emission reduction.

Chennai

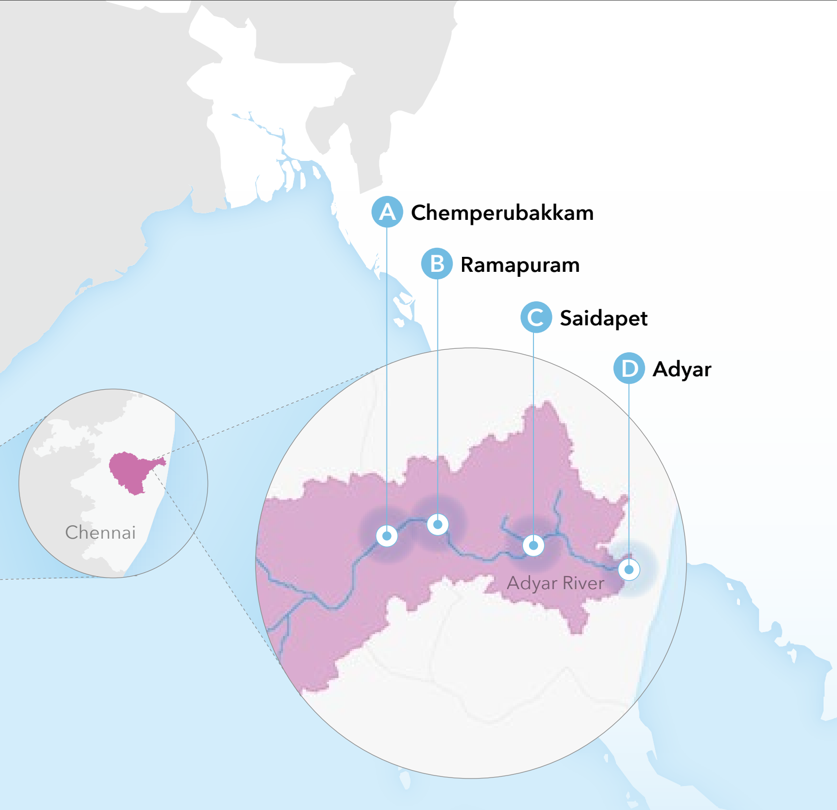
Country
India

Area
426 km² (Municipal Corporation)

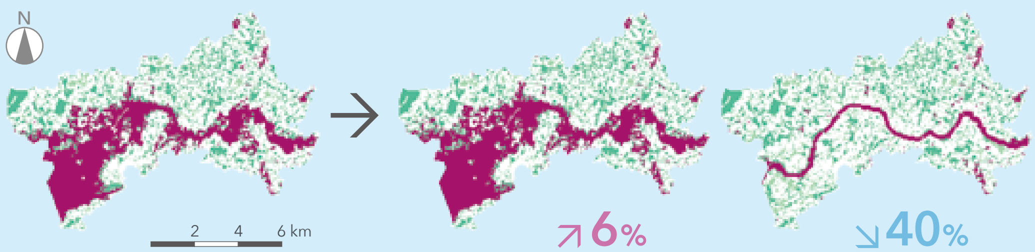
Location
13°05' N, 80°16' E
Elevation: 0 to 25 m

Population
7,088,000 (2011)

Climate
Annual Rainfall: 1,400 mm
Temperature: 18˚C to 42 ˚C



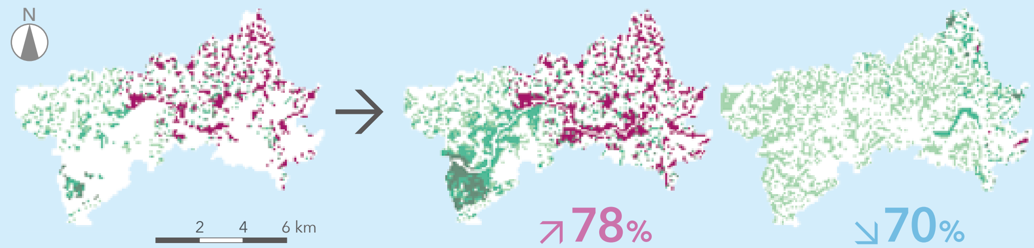
Urban Flood Risk



Flood Depth (m) No Flood (<0.2) Low (0.2-0.5) Moderate (0.5–1.5) High (>1.5)

The Adyar river basin, with an area of 65 km² inside Chennai Municipal Corporation, was considered in the analysis of flood risk under changes to climate and landuse and various structural/non-structural countermeasures. The catastrophic flood event of December 2015 was used as baseline for projecting future flood risk and exploring potential countermeasures towards improving the urban water environment in the Chennai Metropolitan area. Climate change projections revealed an increase of 10% to 16% in 100-yrs daily maximum precipitation for moderate and extreme conditions, respectively. Also, projected climate change (moderate) in 2030 could increase peak discharge by 15% from 2800 m³/s to 3200 m³/s for the 100-years return period. In order to urgently realize the flood mitigation effect, promotion of non-structural measures (runoff control measures), such as the installation of rainwater storage and infiltration facilities, and conservation and rehabilitation of ponds (Situ) is recommended.

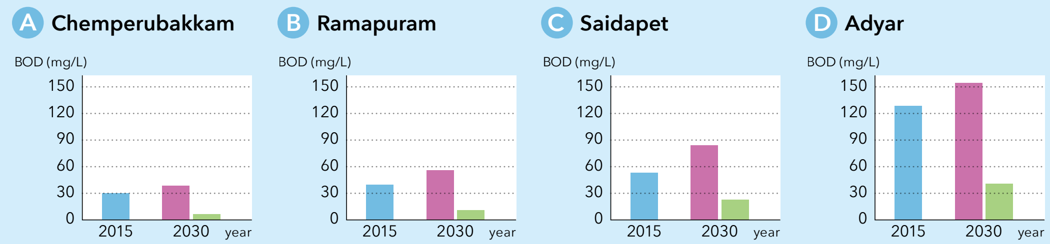
Flood Damage



Flood Damage (USD) Per Grid
No Damage < 10,000 10,000-25,000 25,000-50,000 >50,000

Flood damage has been evaluated for the urban portion of the Adyar river basin. The comparison between the current and 2030 situations shows that approximately 78% of flood damage will increase with the effects of climate change and expansion of built-up areas. The tendency of flood loss is mainly related to water depth. It was also determined that high flood damage will be detected in some cities located along the Adyar River, such as Saidapet and cities with potentially high rates of future urban growth, such as some portions of the Thiruvallur and Kancheepuram districts. However, through the implementation of combined flood mitigation based on hard and soft measures, flood loss will be drastically reduced by an approximate 70% when compared to the current situation. This finding can lead to enhancing awareness of local decision makers, prompting them to adopt suitable mitigation measures for sustainable urban development.

Water Quality

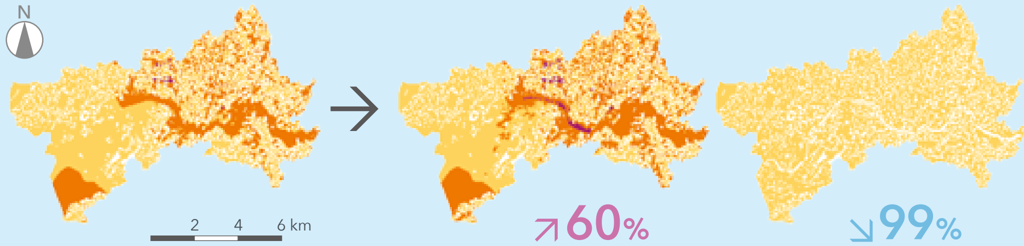


2015: Current 2030: Business-as-Usual 2030: With Mitigation

Two scenarios (business-as-usual and with mitigation plan) were developed to project the water quality of the Adyar River in 2030. Due to both climate change and population changes, the water quality (expressed as BOD) will have deteriorated by a further 26.7% on average in 2030 when compared to the current situation. According to their master plan, all domestic wastewater currently flowing into the rivers will be transferred to expanded and newly built wastewater treatment plants of an 886 MLD capacity, compared to the 180 MLD used at present. The sewerage collection rate will also be increased from 25% in 2015 to 100% in 2030. Based on the scenario where all wastewater generated in the area is treated (2030: with mitigation), the projected water quality will be much better throughout the stream (74.2% reduction compared to the business-as-usual scenario), which is an encouraging sign. However, water quality is still a matter of concern, especially in the downstream area. Even after implementing the master plan, water quality still deviated from the desired quality standard. This may be the result of non-consideration of factors like climate change and differences between contaminant removal efficiency of the WWTPs at the current stage (reality vs assumed during simulation).

Health Risk

2015: Current | 2030: Business-as-Usual | 2030: With Mitigation



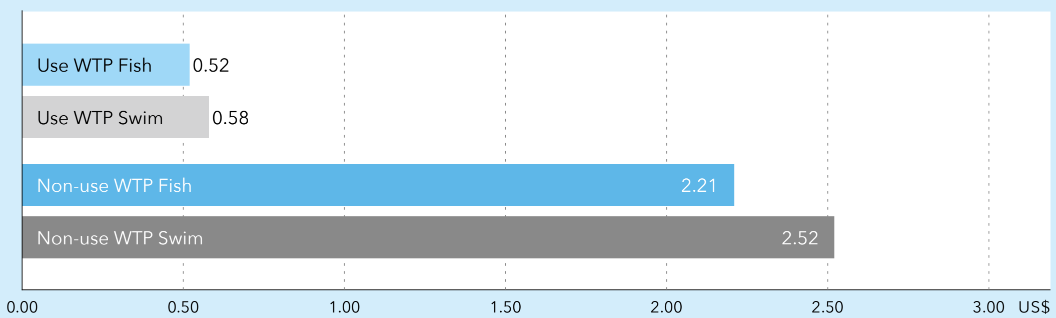
Number of Gastroenteritis Cases Per Grid

No risk | Low risk (< 0.01) | Medium risk (0.01-0.1) | High risk (> 0.1)

The number of floodwater-borne infectious gastroenteritis cases by Norovirus will increase by 60% (183 under the current scenario to 293 cases under the business-as-usual scenario) due to changes in flood pattern, river water quality and population. By implementing the master plan to reduce urban flooding and to enhance wastewater treatment in the target area, the number of gastroenteritis cases will decrease by 99% and 99% compared to the current scenario and the business-as-usual scenario, respectively.

Willingness to Contribute for Improved Water Quality

Use and non-use WTP estimates for swimmable and fishable water quality standards, Chennai, India (Use WTP in US$/month, non-use - one time payment)



Based on our sampling, 56% of Chennai residents are willing to contribute to the measures, which could improve existing surface water quality in the city. After aggregation of the obtained WTP from across the whole population of the city, the total economic value of water quality improvements is estimated equal to approximately US$64 million per year. The estimated benefits of a clean water environment in Chennai are not enough to sufficiently cover either losses due to poor sanitation or the costs of new WWTPs construction and operation (i.e., losses and costs are higher than the benefits.).

Lucknow

Country
India

Area
349 km² (Municipal Corporation)

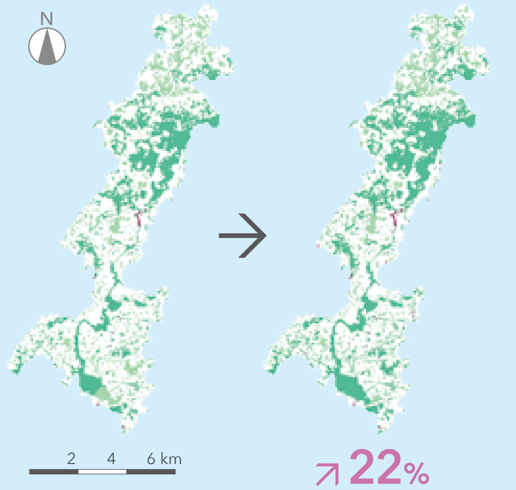
Location
26°08' N, 80°09' E
Elevation: 100 to 130 m

Population
2,902,920 (2011)

Climate
Annual Rainfall: 900 mm
Temperature: 5˚C to 45˚C

Urban Flood Risk

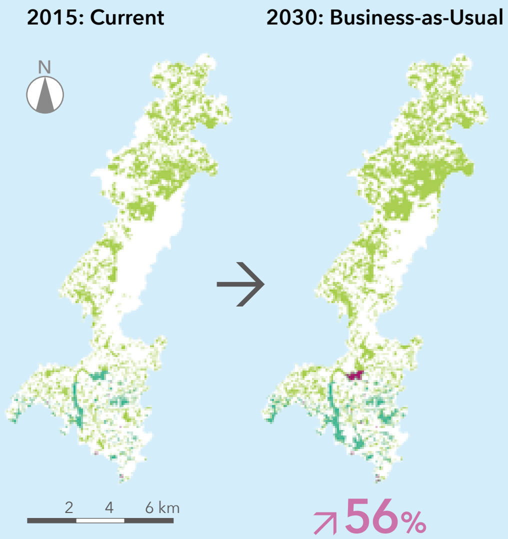
2015: Current | 2030: Business-as-Usual



In general, the Lucknow City was found to have small-scale inundation events with local pockets of water logging every year. Lucknow city was found to have lost 46% of its water bodies, which is of great importance in regulating urban flooding. The 2031 Lucknow Master plan was taken into account while investigating urban flood risk in the city. The master plan was found to be completely missing the impacts of climate change consideration. The climate change projections revealed an increase of 30% and 50 % in 100-yrs daily maximum precipitation for moderate and extreme conditions, respectively. The effect of the projected climate change (moderate) in 2030 might increase the urban flooding area with a flood depth of more than 0.5m by 22 % for the 100-years return period. In order to realize the effects of urban flood mitigation, promotion of non-structural measures (runoff control measures), such as the installation of rainwater storage and infiltration facilities, and the conservation and rehabilitation of ponds, needs to be further explored.

Flood Depth (m) No Flood (< 0.2) | Low (0.2-0.5) | Moderate (0.5–1.5) | High (> 1.5)

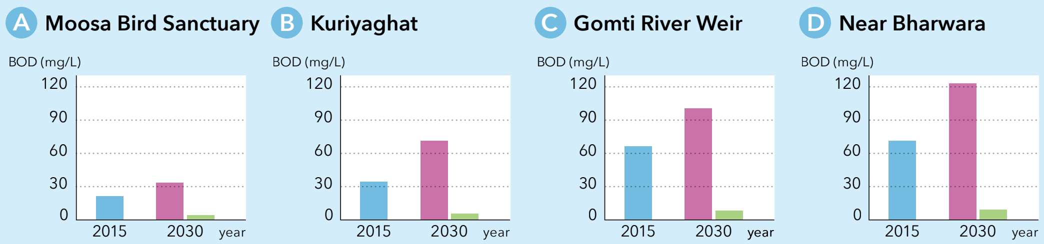
Flood Damage



The assessment of flood damage in the Kukrail river basin in Lucknow revealed that the impact of climate change and rapid urbanization would be significant in 2030. It was estimated that flood damage will increase by 56% and that more attention should be paid to the Bakshi Ka Talab region. The spatial distribution of flood loss was correlated with the depth of flood water and exposure of assets to flooding. In fact, flood depth and land use change are considered as the main factors to determine the level of loss. The identification of priority areas for flood risk reduction using damage maps will be helpful to decision-makers for adopting strategies at local and regional scales.

Flood Damage (USD) Per Grid No Damage <5,000 5,000-10,000 >10,000

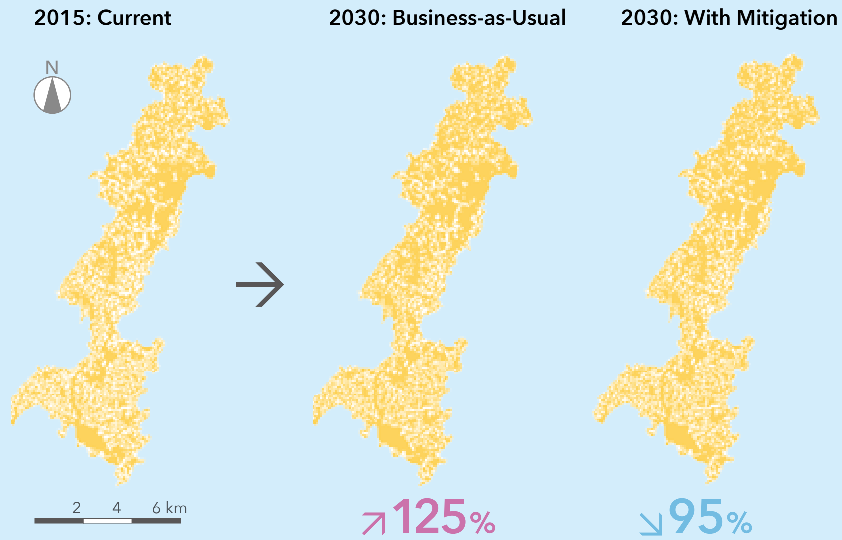
Water Quality



2015: Current 2030: Business-as-Usual 2030: With Mitigation

Two scenarios (business-as-usual and with mitigation plan) were developed to project the water quality of the Gomti River in 2030. Due to climate change and population changes, the water quality (expressed as BOD) will have deteriorated by a further 70.8% on average in 2030 when compared to the current situation. According to their master plan, all domestic wastewater currently flowing into the rivers will be transferred to expanded and newly built wastewater treatment plants of a 1119 MLD capacity, in comparison to the 145 MLD used at present. The sewerage collection rate will also be increased from 19% in 2015 to 100% in 2030. Based on the scenario where all wastewater generated in the area is treated (2030: with mitigation), the projected water quality will be much better throughout the stream (91.7% reduction compared to the business-as-usual scenario), which is an encouraging sign. However, water quality is still a matter of concern, especially in the downstream area. Even after implementing the master plan, water quality still deviated from the desired quality standard. This may be the result of non-consideration of factors like climate change and differences between water quality in the river head (BOD-4 mg/L) and a desirable water quality of class B (BOD-3 mg/L).

Health Risk



Number of Gastroenteritis Cases Per Grid

No risk Low risk (< 0.01) Medium risk (0.01-0.1) High risk (> 0.1)

The risk of floodwater-borne infectious gastroenteritis by Norovirus was low because flood inundation is less severe and water pollution is mild compared to other cities. All scenarios projected less than one case of gastroenteritis, although they showed a significant increase of 125% due to changes in flood pattern, river water quality and population. Improving the quality of river water by enhancing wastewater treatment coverage reduced the risk by a further 95% and 98% compared to the current scenario and the business-as-usual scenario, respectively.

Medan

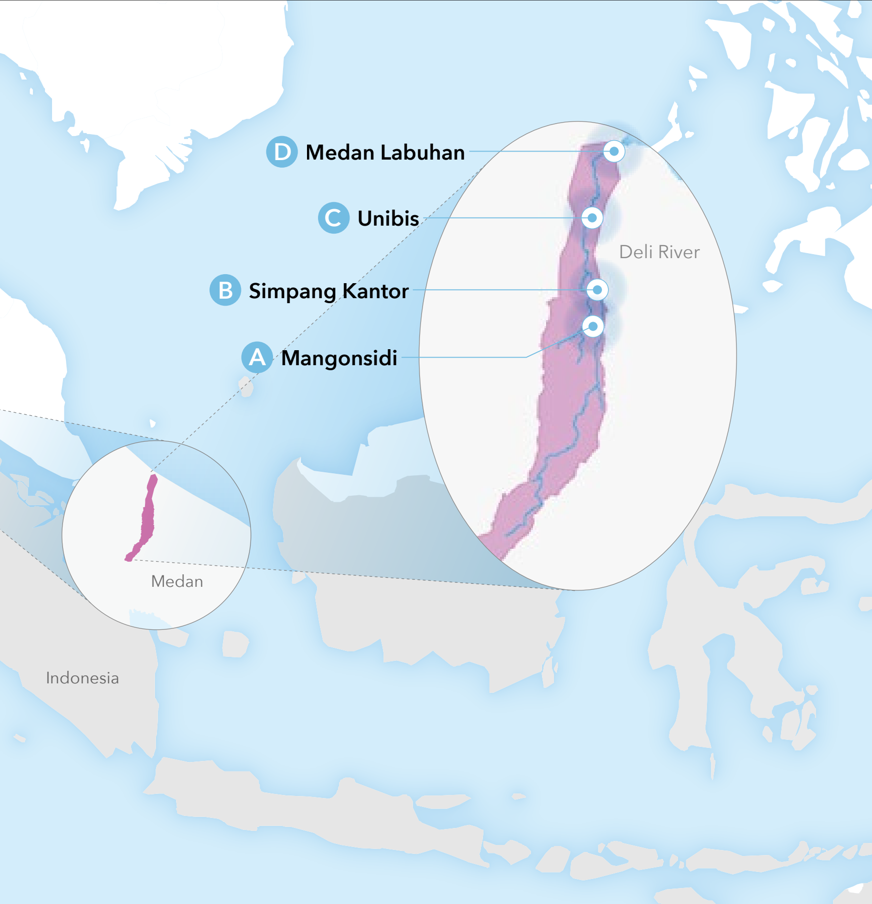
Country
Indonesia

Area
265 km²

Location
3°35' N, 98°40' E
Elevation: 2.5 to 37.5 m

Population
2,191,140 (2014)

Climate
Annual Rainfall: 2,263 mm
Temperature: 24˚C to 32 ˚C



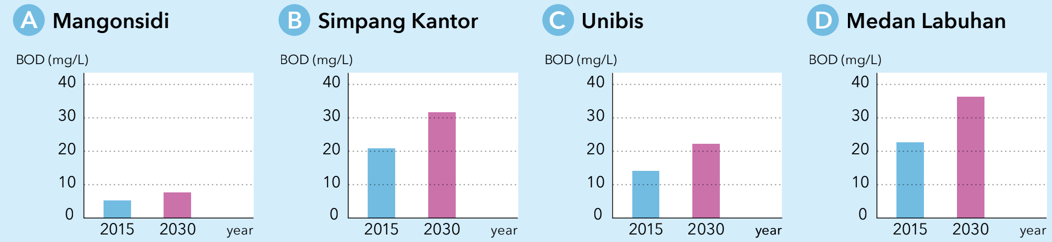
Urban Flood Risk

2015: Current **2030: Business-as-Usual**

The Deli river system, the main river passing through the centre of Medan city, was studied in the analysis of comparative flood inundation conditions. Hydrologic analysis enabled the estimation of peak discharge at Titi Kuning where a flood diversion channel sends excessive stormwater from Deli River to Percut River. Flood inundation simulation was carried out over an area of approximately 160 km² downstream of the diversion point. A design discharge of 70 (current) to 120 (future) m³/s available in the flood disaster plan report was considered for current and future conditions. Comparison of the 50-year return period daily maximum rainfall values indicated that climate change would increase the risk of extreme events by 17 to 42%.

Flood Depth (m) No Flood (< 0.2) Low (0.2-0.5) Moderate (0.5–1.5) High (>1.5)

Water Quality

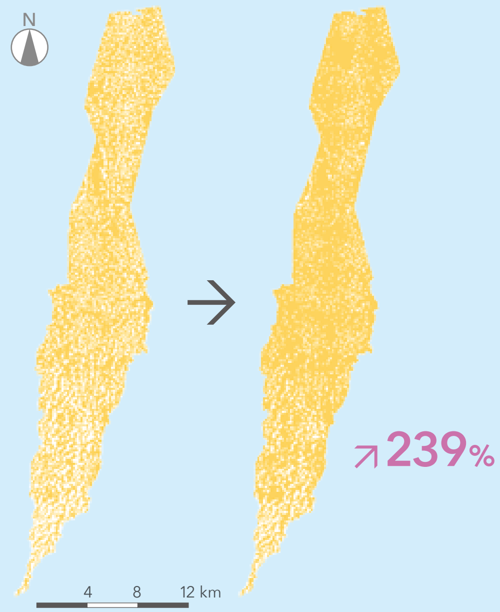


2015: Current 2030: Business-as-Usual

Future projections were made in order to estimate the water quality of the Deli River by 2030. Due to climate change and population changes, the water quality (expressed as BOD) will have deteriorated by 54.2% on average in 2030 when compared to the current situation. Whereas the individual contributions from population and climate change to water quality were 86% and 14%, respectively. Taking into account this rapid deterioration of water quality, an integrated approach for the national sewerage and septage management program will be implemented on a priority basis, considering various factors, such as population density and growth, and global changes, to more precisely account for both short and long term measures.

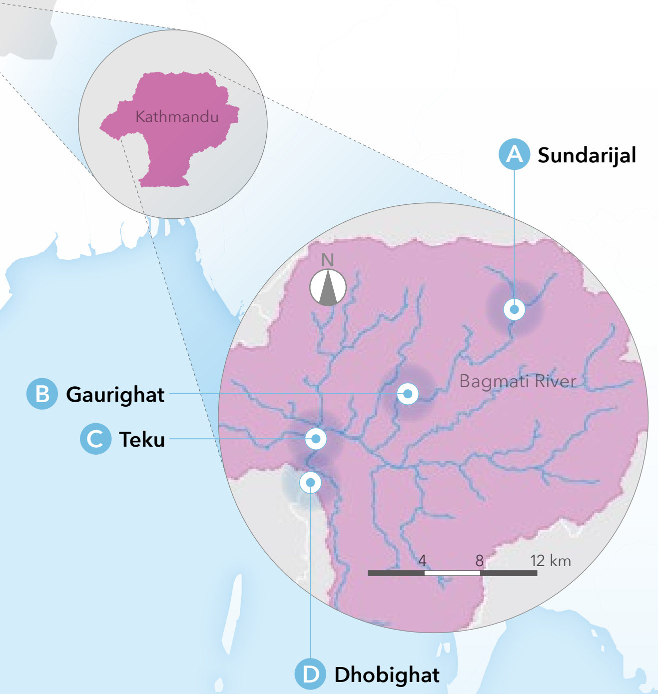
Health Risk

2015: Current **2030: Business-as-Usual**



The risk of floodwater-borne infectious gastroenteritis by Norovirus was low because water pollution was mild compared to other cities. However, the number of cases showed a significant increase of 239% (1.5 under the current scenario to 5.0 cases under the business-as-usual scenario) due to changes in flood pattern, river water quality, and population.

Number of Gastroenteritis Cases Per Grid
No risk Low risk (< 0.01) Medium risk (0.01-0.1) High risk (> 0.1)



Kathmandu

Country
Nepal

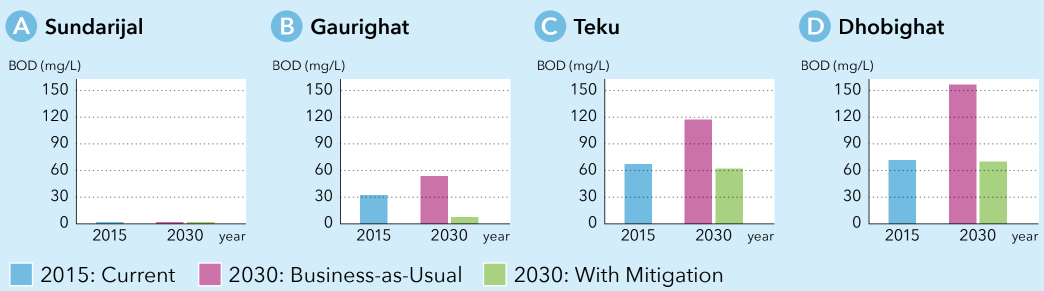
Area
595 km² (Valley)

Location
27°42' N, 85°20' E
Elevation: 1975 m

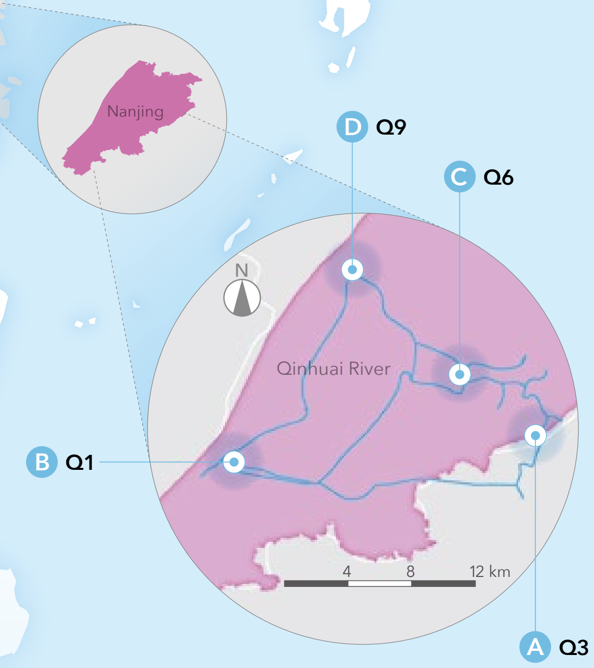
Population
2,383,698 (2011)

Climate
Annual Rainfall: 1,400 mm
Temperature: 2˚C to 27˚C

Water Quality



The water environment in Kathmandu was assessed by analyzing its river pollution scenarios. At Bagmati River, the main river in the valley, pollution was analyzed for current and future wastewater production and treatment scenarios using two important indicators of aquatic health. The DO and BOD were simulated to assess river pollution along a 25km stretch of water between Sundarijal and Chovar. Comparison of the simulated DO and BOD values for 2030 with those of 2014 indicated that the water quality of the Bagmati River within Kathmandu Valley would not significantly improve as a result of the planned wastewater treatment plants and would require additional countermeasures. For example, for BOD in 2030, an overall increase of 79% is projected for 'business-as-usual (population growth) and decrease of 23%' with implementation of master plan (completion of planned wastewater treatment plants) scenarios. The study highlighted the inefficiencies of the current practice of discharging untreated sewage into the surface water, which has resulted in the river water flowing from the Gaurighat area to the Chovar area becoming polluted and unsuitable.



Nanjing

Country
People's Republic of China

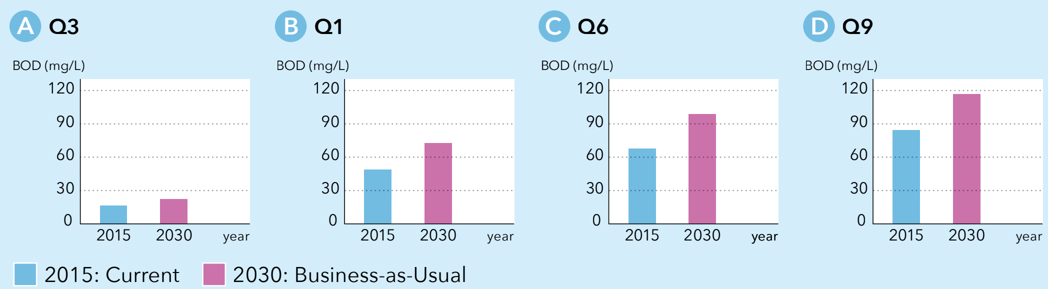
Area
6,598 km²

Location
31°14' N, 118°22' E
Elevation: 20 m

Population
8,200,000 (2013)

Climate
Annual Rainfall: 1,090 mm
Temperature: 3˚C to 29˚C

Water Quality



The water environment of Nanjing was assessed by analyzing its river pollution scenarios. At Qinhuai River, the main river in Nanjing, pollution was analyzed for current and future scenarios based on two important indicators of aquatic health (BOD and *E. coli*). Future projections were made to estimate the water quality of the Qinhuai River in 2030. Due to population changes, the water quality (expressed as BOD) will have deteriorated by a further 40.1% on average in 2030 compared to the current situation of the year 2015. Considering this rapid deterioration of water quality, an integrated approach for the national integrated sewerage and septage management program will be implemented on a priority basis, considering various factors, such as population density and growth, and global changes, to more precisely account for both short and long term measures.

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