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Sustainable Urban Water Management: Application for Integrated Assessment in Southeast Asia

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Abstract: The design, development, and operation of current and future urban water infrastructure in many parts of the world increasingly rely on and apply the principles of sustainable development. However, this approach suffers from a lack of the necessary knowledge, skills, and practice of how sustainable development can be attained and promoted in a given city. This paper presents the framework of an integrated systems approach analysis that deals with the abovementioned issues. The "Water and Urban Initiative" project, which was implemented by the United Nations University's Institute for the Advanced Study of Sustainability, focused on urban water and wastewater systems, floods, and their related health risk assessment, and the economics of water quality improvements. A team of researchers has investigated issues confronting cities in the developing countries of Southeast Asia, in relation to sustainable urban water management in the face of such ongoing changes as rapid population growth, economic development, and climate change; they have also run future scenarios and proposed policy recommendations for decision-makers in selected countries in Southeast Asia. The results, lessons, and practical recommendations of this project could contribute to the ongoing policy debates and decision-making processes in these countries.

Keywords: urban water management; sustainable development; water quality assessment; Manila; Jakarta; Hanoi

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1. Introduction

1.1. Water and Urban Initiative

The vast share of the world's freshwater resources, 27%, is located in Southeast Asia [1]. However, the region is experiencing issues with the availability of clean water as an estimated 90% of all wastewater is discharged directly into waterbodies with no proper treatment [2]. Moreover, fast economic developments have resulted in negative consequences for many river systems, resulting in changes in their hydrology, ecology, and environment. This happened partly because of lack of a solid waste and wastewater treatment infrastructure.

Starting with the Brundtland Report of 1987, and finishing with the New Urban Agenda of 2016, "sustainable development" has been established as one of the major concepts of our times. Within the concept of "sustainable development", special attention is deserved for the issue of "sustainable urban development", and more specifically, "sustainable urban water management". Urban water management involves the sectors of water supply, urban drainage, wastewater treatment, flood protection, and preservation of a city's surface and underwater resources. However, difficulties arose with the understanding of this term, and the lack of appropriate and accepted methodology that could be applied to analyze such complex issues. In this context, integrated systems analysis approach could be that tool and mechanism that could address the complexity of natural and human-made systems with the help of state-of-art computer technologies. As Tad Soroczynski stated:

> Integrated systems analysis (ISA) can be defined as application of the scientific method for examination of complex problems impacted by interdisciplinary component systems. ISA, therefore, is a combination of theories and techniques for studying, describing and making predictions, on the basis of inputs → transformations → outputs of 'component systems' or 'components', which may be presented in the format of differing scenarios. Such analyses of component systems may need to be conducted individually, or may need to be integrated, and may also need to consider classification of systems, adopted time horizons, and uncertain conditions, where applicable [3].

To enhance the capacities of local governments in Southeast Asia and to improve and increase their knowledge, as well as to increase technical preparation in the application of the latest techniques to managing urban water management, the United Nations University Institute for the Advanced Study of Sustainability initiated a research project called the "Water and Urban Initiative (WUI)" in 2014. WUI aims to contribute to sustainable urban development by creating scientific tools to forecast the future state of urban water environments. This project also seeks to help develop the capacity to improve urban water environments in developing countries in Asia, by focusing on climate change, urbanization and low-carbon measures. 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 improved policy-making 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 and management, including the economic assessment of physical damages caused by urban flooding; (b) water quality assessment; (c) floodwater-related health risk assessment; and (d) the economic evaluation of water quality improvement (Figure 1). The systems analysis is the core of the research framework, which aims to integrate outcomes from the one study into another, and analyze results with respect to a series of comprehensive goals and objectives. The procedure used in studies that utilize systems analysis includes studies of different selected cities, technical models, and future scenarios affecting the water infrastructure in a city.

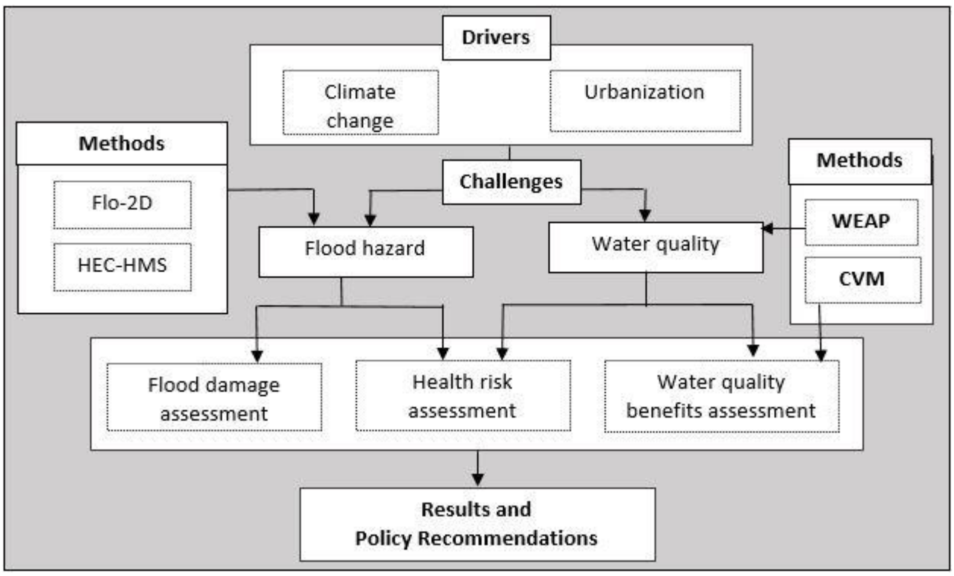

Figure 1. Systems analysis approach undertaken by the UNU-IAS research group in the current study (Flo-2D—Hydrologic and Hydraulic Modelling System; HEC-HMS—Hydrologic Modelling System; WEAP—Water Evaluation and Planning System; CVM—Contingent Valuation Method).

Although some cities still pursue an "old-style", linear, traditional approach, many others are shifting to use an integrated, adaptive, coordinated, and participatory approach that is required by sustainable urban water management [4]. The goal is to try to manage urban water resources as a "total water cycle" to reflect the complexities and interconnections between the different sectors and aspects of urban water management. Traditional, linear approaches in city management were mainly characterized by an uncoordinated institutional framework while each sector was managing its area of responsibility in a "silo" technocratic approach, which often resulted in unclear and fragmented responsibilities; there was no or limited community engagement, and an overall absence of long-term development strategy.

The main objective of this paper is to present the framework for an integrated systems analysis approach to address and promote sustainable urban water management. The paper begins with the main dimensions of the research areas, which are described as follows. The second part contains the methodology and analysis. Finally, the results are discussed, and practical recommendations are proposed in the concluding third part of the manuscript.

1.2. Climate Change and Urban Flood Risk

In recent decades, the increasing frequency of disaster events, particularly hydro-meteorological disasters, has threatened human lives and infrastructure. The Sendai Framework for Disaster Risk Reduction 2015–2030, which was adopted at the Third UN World Conference in Sendai, Japan on 18 March 2015, greatly emphasized the need for an improved understanding of disaster risk to ensure a sustainable future [5]. Flooding has been identified as the most frequent type of natural disaster that affects lives and property in vulnerable areas [6].

Several studies have indicated that climate and land use changes are the major drivers of the increasing numbers of flood events [7–10]. Changes in climate and land use patterns affect water availability and runoff, which alter the flood regimes of rivers. In developing countries, urbanization is occurring at a high rate. Already, more than half of the world population lives in cities, and this number is expected to increase to 70% by the middle of century. According to the World Factbook published by CIA, the average world rate of urbanization for 2015–2020 estimated as 1.84%, with the highest rate of 5.59% in Rwanda, and the negative of −0.83% in Trinidad and Tobago [11].

The IPCC (2014) report indicated that a greater number of regions are likely to experience extreme heavy precipitation and flood events in the future. Urbanization leads to increased impervious areas and the construction of stormwater drainage networks that shorten the time needed for the concentration and increase of direct runoff, thereby resulting in more rapid rises in streamflow and the depletion of the water table [12]. Additionally, natural water bodies, such as lakes, wetlands, and waterways, which can hold a considerable amount of floodwater, have been largely reduced or filled, thus increasing the incidence of flooding. The increasing frequency of urban flood disaster events has threatened human lives and infrastructure, leading to greater economic losses. Actually, in 2016, the occurrence of hydrological disasters, such as flood and landslides, increased in comparison to average of the period between 2006 and 2015. It was estimated that the occurrence of hydrological disasters represents 51.7% of total natural disasters that occurred in 2016. However, it was 50.5% for the period 2006–2015. Additionally, the total cost due to hydrological disasters in 2016 rose by 74% above annual average [13]. It has been shown that the impact of a natural disaster will alter the GDP of a country, not only during the year of a given event, but also in successive years [14]. Indeed, the negative impact on GDP is correlated with the probability of occurrence of the disaster [14]. Furthermore, flooding results in economic and social damages that can be classified in direct and indirect categories, i.e., as tangible and intangible damages [15]. It is important to quantify and assess flood damage to implement appropriate strategies of flood risk reduction. The increases in the cost of damages and human vulnerability have made it necessary for local decision-makers and governments to invest in short- and long-term flood controls. Accordingly, they have adopted appropriate strategies based on structural and non-structural measures to reduce the effects of natural disasters.

Hydrological disasters are the most frequent catastrophe in all Asian regions [13]. Furthermore, Flooding is considered to be one of the greatest problems in Southeast Asian cities, including Jakarta [16], Hanoi [17], and Metro Manila [18]. Compounded by poor drainage systems, flooding occurs frequently in these cities. Because of the high flood risk in these regions, a comprehensive flood risk evaluation that encompasses flood forecasting and flood damage should be performed. Flood risk assessment is essential to mitigate or circumvent disaster risks in these flood-prone areas. The effectiveness of adaptation measures will depend on the role of water managers, and the implementation of a suitable water management system to both minimize the effects of floods and to optimize access to potable water and the treatment of wastewater.

1.3. Urbanization and Urban Water Quality

Water is a vital natural resource that has social and economic value for human beings [19]. At present, around the globe, more than 1.1 billion people have inadequate access to clean drinking water [20]. Furthermore, population growth, urbanization, economic development, and rapid urbanization have placed a constant and tremendous amount of pressure on water resources and their ecosystems [21]. Despite the adoption of a number of countermeasures, the degradation of the urban water environment remains a challenging issue in developing nations [22,23]. According to the Asian Development Bank (ADB), 17 out of 25 most densely populated cities in the world are located in Asia, and the main reason is the mass migration from the rural into urban areas, which is "unprecedented in human history", and has led to significant environmental consequences [24].

Access to good quality fresh water resources is heavily skewed by rapidly increasing population, urbanization, or land use/land cover changes, climate change, poor institutional capacity, poor governance, and a lack of awareness. While the challenges facing water resources (both in terms of their quality and quantity) vary across countries, population growth in terms of their demand with change in lifestyle is the biggest challenge for water management, and the factor that has most clearly threatened water (although agriculture, industrialization and urbanization are also changing water usage patterns) [25].

However, for integrated water resource management (IWRM), transdisciplinary research is currently necessary, and it is worth exploring the possible hazards generated by the deterioration of water quality and quantity, and their associated health risks. Additionally, it is necessary to perform the economic evaluation of water quality to determine what local economic help can feasibly be generated for possible countermeasures to improve water quality.

1.4. Health Risk of Waterborne Infectious Diseases Related to Urban Flooding

Extreme water-related events are often followed by outbreaks of waterborne infectious diseases [26]. Human pathogens in rivers, lakes, and sometimes sewage, have the potential to infect humans when they overflow during flooding events, as people are exposed to floodwater. For example, a massive outbreak of leptospirosis, an infectious disease caused by the pathogenic bacteria *Leptospira* spp., occurred following the historical flood caused by Typhoon Ondoy in 2009, in Manila and its surrounding cities, which resulted in 3389 cases and 249 deaths [27]. An epidemiological study showed that urban flooding events increased cases of gastroenteritis in Taiwan [28].

The predictive estimation of such health risks during flooding events is difficult, because necessary information, such as the concentrations of pathogens in floodwater and people's behavior during flooding, is rarely reported. Recently, a few attempts have been made in developed countries to estimate the health risks of waterborne infectious diseases spread via floodwater [29,30] using the quantitative microbial risk assessment (QMRA) framework. This approach is potentially useful for understanding the effects of urban flooding on waterborne infectious diseases and simulating the disease burden in hypothetical scenarios.

1.5. Benefits of Improving Water Quality

Most of the values associated with surface urban waters are non-priced environmental benefits, including aesthetic values, such as pleasant landscape and clean air, the preservation and enhancement of urban fishery and biodiversity, potential recreation opportunities for urban residents, improved health conditions (i.e., lower risks of contracting waterborne diseases), and reduced flood impact. The benefits and costs of the development and management of water use-related infrastructural projects are often assessed in monetary terms. However, the quantitative valuation of a clean urban water environment is difficult to integrate into the assessment procedure of policy decisions in a city. At present, authorities and policy-makers in many cities in developing countries are challenged by the explicit valuation of these clean water-related benefits that are supposed to be embedded into policy decisions and result in more effective city decision-making processes. The low appreciation of clean urban water environments is also reflected in the limited budget allocations of many cities.

2. Methods and Assessment

The growing recognition of complexity requires the need for systems approaches to solve issues in urban water management. Integrated systems approaches involve interdisciplinarity, as complex city infrastructures comprise intersecting diverse natural, technical, and institutional dimensions [31]. Therefore, properly understanding these issues and the ways to solve them requires researchers and professionals from different academic and professional disciplines to provide input, exchange opinions, and learn from each other to discover new, creative solutions. In this work, an integrated approach is applied to interrelate the abovementioned four services of urban water management (Figure 1). Here, this approach is applied to three focus cities in Southeast Asian countries: Metro Manila, Philippines; Hanoi, Vietnam; and Jakarta, Indonesia (Figure 2).

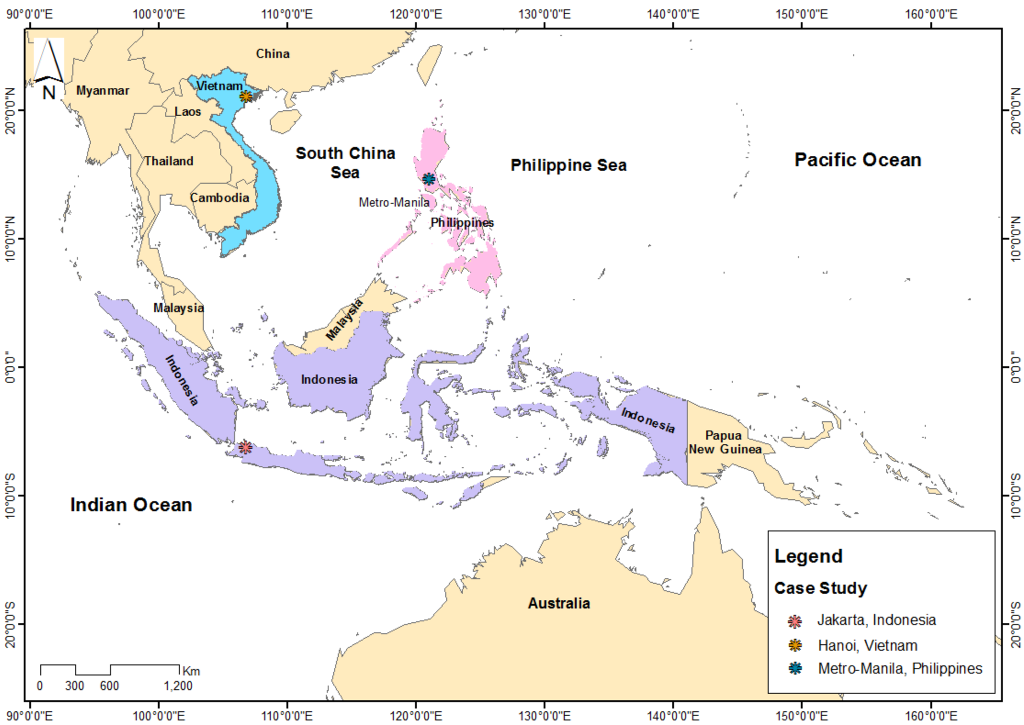

Figure 2. Location of case study area.

2.1. Climate Scenarios and Flood Damage Assessment

Computer models are widely used to simulate the characteristics of flood events, including the peak discharge and flood inundation occurring under various conditions. Hydrologic models are generally used for river discharge estimations, and hydraulic models are often used for inundation simulations. Computer models such as HEC-HMS, SWMM, FLO-2D, and MIKE are widely used for urban river basins [32,33]. Such models provide a good representation of the physical phenomena that occur during floods. These models predict the flood risk generated by extreme events with different return periods, or multiple land use and climate change scenarios [34–36]. The outputs of these models can be integrated in Geographic Information Systems (GIS) to provide comprehensive information about spatial flood risk and flood damages [17,37,38].

General Circulation Models (GCM) are used to project future climatic variables to predict the likelihood of increased flood risk due to global warming. There are a number of GCM and emission scenarios providing predictions of future changes in climate. Due to great amount of uncertainty associated with the scenarios and projections (for example, 50 year daily maximum rainfall was estimated as 416 mm, 297 mm, 411 mm for RCP4.5, and 412 mm, 593 mm, and 411 mm for RCP85, for MRI, MIROC5, and HadGEM GCMs, respectively, over Hanoi region); use of multiple GCMs are recommended to provide the range of recommendations for addressing various climate change impacts.

Mishra and Herath [8] used the MRI-GCM precipitation output to investigate the impact of climate change on peak discharge in the Bagmati River in Nepal. Dahm et al. [39] used HadGEM2-ES and MIROC-ESM and GFDL-CM3 of the CMIP5 to assess the Brahmani–Baitarani River Basin in India, and focused on changes in the four selected indices of precipitation extremes. In the climate modelling community, projections are available in terms of four emission scenarios: one mitigation scenario (RCP2.6), two medium stabilization scenarios (RCP4.5/RCP6), and one very high baseline emission scenario (RCP8.5). The RCP2.6 scenario is considered largely idealistic, due to lack of consensus on emission mitigation among the countries. The best choice among these scenarios include RCP4.5 and RCP8.5, considering one medium stabilization scenario and the high emission scenario covering the entire range of radiative forcing. McSweeney [40] illustrated a methodology for selecting GCM from the available CMIP5 models, in order to identify a set of 8–10 GCMs for use in regional climate change assessments. The selection focused on their suitability across multiple regions: Southeast Asia, Europe, and Africa. Considering plausible and satisfactory annual cycle performance of rainfall, as well availability periods and scenarios, three GCM outputs available for RCP4.5 and RCP8.5 were selected for this study.

The use of the GIS technique is very popular and effective in disaster risk management [37,41]. The field of disaster reduction has greatly benefited from the use of the GIS technique in risk map preparation, damage assessment, and modeling for forecasting and planning. While it is difficult to estimate intangible damage, such as injuries or anxiety, in a purely deterministic manner [42], the GIS technique is widely used to estimate physical damage. In the case of floods, hazard information is represented as water height, velocity, and the distribution of the flood duration over the catchment. Combining this information with population distribution helps identify people at risk. The daily precipitation outputs of three GCMs (MRI-CGCM3.2, MIROC5, and HadGEM2-ES), with spatial resolutions ranging from 100 to 150 km, were used for the climate change impact assessment. Multiple GCMs and scenarios were used to reflect the uncertainties associated with climate change. Quantile–quantile bias correction technique was applied to downscale or minimize the biases in the GCM data. This method consists of two steps: (1) truncating GCM rainfall below a threshold value corresponding to empirical non-exceedance probability of zero observational rainfall value (Figure 3); and (2) matching the CDF of truncated GCM data series and observation data series by taking the inverse CDF of the GCM data with observational shape and scale parameters. Calculation of threshold value and matching of truncated daily CDF was carried out monthly scale. Later, Gumbel frequency analyses were conducted to estimate the 1-day maximum precipitation for the current and future flood assessments. Moderate climate was defined by an average of 6 extreme rainfall events for each of the return periods (50 and 100 years), and extreme climate was defined considering the maximum among 6 extreme values. Finally, flood inundation simulation for the moderate and extreme climate conditions for each of the return periods. The most recent land use data and projected land use data for 2030, representing the future urban growth scenario, were employed to understand the impact of urbanization. To generate the future land use/land cover map of 2030 in the study area, remote sensing products and the Land Change Modeler (LCM) for ArcGIS were applied to predict land use patterns based on past changes. The HEC-HMS model provided estimates of the peak discharge values at the inlet of the inundation study area. The hydrologic modelling was primarily performed to generate flood hydrographs at the inlet location of the inundation modelling area. Use of HEC-HMS was limited to the Manila and Jakarta, to accommodate flood hydrographs from the upper region. However, in case of Hanoi, there was no need to consider inflow hydrographs. FLO-2D is a two-dimensional flood routing model that was used to simulate flood inundations for the current and future climate conditions. FLO-2D, which simulates runoff over a system of square grid elements, was used to map inundation areas [43]. This model is capable of numerically routing a flood hydrograph while predicting the area of inundation and simulating flood wave attenuation. This model simulates the progression of the flood hydrograph, while conserving the flow volume over a system of square grid elements representing topography and flow roughness.

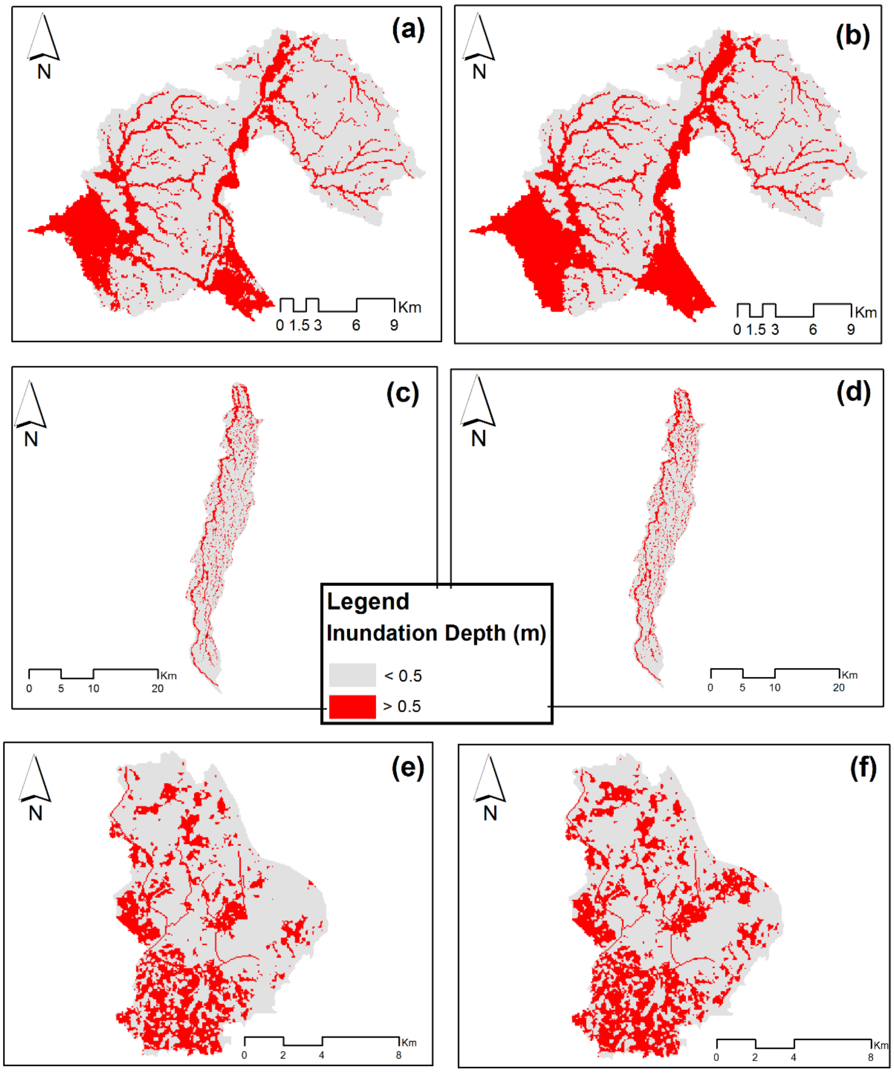

Figure 3. Spatial distribution of inundation depth. (**a**) Current situation without the effect of climate change in Metro Manila; (**b**) Future situation with the effect of climate change in Metro Manila; (**c**) Current situation without the effect of climate change in Jakarta; (**d**) Future situation with the effect of climate change in Jakarta; (**e**) Current situation without the effect of climate change in Hanoi; (**f**) Future situation with the effect of climate change in Hanoi.

The flood damage methodology followed here is a spatial approach based on the integration of various factors, such as types of property and flood characteristics, into a GIS. A flood depth function was established for the damage evaluation. It expresses potential damage as a percentage of cost under a particular type of hazard; in the case of floods, this is given by the depth of the water height [44,45]. Then, the map of flood inundation depth obtained from FLO-2D is overlain onto the property distribution map generated from Landsat satellite image products. The damage estimation was carried out within GIS, depending on the complexity of the damage depth function, and the flood rate at each grid in the expected scenario. In this study, the assessment of urban flood is analyzed by the establishment of the flood damage depth function based on surveys. The data collection survey was conducted with local people in affected urban areas using an appropriate questionnaire. The survey was carried out at local level in Barangays in Manila, District or Kecamatan in Jakarta, and wards in Hanoi. There are many flood characteristics such as velocity, duration, depth [46], but in this study, water depth is used for flood damage modeling. Therefore, flood depth damage function was generated as an indicator of vulnerability. In order to establish flood function, flood hazard map, which is characterized by depth, was used to identify a location for interviews, and potential classes of interviewees. Then, respondents were selected randomly in the delimited area, and were interviewed based on a face-to-face technique. The data collected was mainly related to a past flood event. For Metro Manila, questions were about tropical Storm Ondoy 2009, Jakarta was about the flood in 2007, and Hanoi was about the flood in 2008 which occurred in the city. The questionnaire used in the survey is composed of three parts. 1—household characteristics; 2—flood risk/damage and 3—flood risk management measures. Data collected from the survey were useful to derive the relationship between flood damage and flood depth in a past flood event. The flood damage depth function is an important component of direct flood estimation, and can be used to predict flood losses. Once the flood height and land use (i.e., property distribution) were obtained, the total damage in each grid was estimated using a damage function constructed from the collected data.

2.2. Water Quality

Water Evaluation and Planning (WEAP), a decision support system tool, is widely used for the planning and management of integrated water resources. The WEAP model supports extensive environmental master planning functionalities to represent wastewater generation and treatment. Additionally, WEAP includes a catchment module for rainfall-runoff simulation, which removes the need to find another hydrologic model for streamflow simulation, which is an essential input parameter for water quality modeling. The WEAP hydrology module enables the estimation of rainfall runoff and pollutant travel from a catchment to water bodies.

The WEAP model greatly supports scenario formation functionalities where policy alternatives can be considered for current and future conditions well supported by several scientific findings. The WEAP hydrology module enables estimation of rainfall runoff and pollutant travel from a catchment to water bodies. Scenarios can be developed based on key drivers affecting water quality and quantity viz. population growth, industrial and commercial activities, land use/land cover, the capacity and status of treatment plants, climate change, and several other factors. WEAP also provides a geographical information system (GIS)-based interface to graphically represent wastewater generation and treatment systems. WEAP can simulate several conservative water quality variables (which follow exponential decays) and non-conservative water quality variables, in addition to pollution generation and removal at different sites.

Building on the above background, the WEAP model was used to simulate current and future water quality variables (i.e., biochemical oxygen demand (BOD) and *Escherichia coli*) in the years 2015 and 2030, to assess the deterioration trends compared to their current status in the target river basin. The master plan in our target areas intends to give a solution for better water environment by year 2030. Therefore, this study also selected 2030 as future target year for numerical simulation in order to give an adaptive solution to the policy makers for making the currently existing master plan more robust. A wide range of input data (both observed and secondary data), including the amount and quality of domestic discharge, past spatiotemporal water quality, existing wastewater treatment plants, population, historical rainfall, evaporation, temperature, drainage networks, river flow-stage-width relationships, river length, groundwater, surface water inflows and land use/land cover, are provided.

Simulation scenarios are developed based on population growth, land use/land cover change, and climate change, while keeping the capacity and treatment technology of current wastewater treatment plants same for both scenarios that can significantly influence ambient water quality. The current population distribution and its future trends were estimated using the ratio method based on the UN DESA population projection for Jakarta [47]; the Vietnam Water, Sanitation and Environment [48] report projection for Hanoi; and the Philippines Statistics Authority (PSA) projection for Manila [49]. To evaluate the effect of climate change, change in the monthly precipitation is considered in this study. Regarding future precipitation, the bias-corrected GCM outputs used in the flood simulation were adopted for calculating the average monthly precipitation. Under the WEAP hydrology module, the soil moisture method, which is the most sophisticated and widely accepted method, was used to estimate the different hydrological parameters in this study. The water quality module of the WEAP tool was used to estimate the quality of river water. Oxidation–reduction and first order decay processes were selected to govern the value of BOD and *E. coli*, respectively. Different parameters viz. effective precipitation, runoff/infiltration ratio, and head water quality, were used to calibrate different components of the model. A detailed description of the calibration and validation required before obtaining future simulations for different scenarios was provided by Kumar et al. [50].

2.3. Health Risk Assessment

The human health risk posed by pathogens in floodwater was evaluated following the approach of Masago et al. [51]. Noroviruses are selected as a reference pathogen; they are the major cause of viral gastroenteritis worldwide, with an estimated 698.8 million cases and 218,800 deaths annually [52]. The distribution of norovirus concentrations in floodwater was estimated based on the *Escherichia coli* concentrations simulated using the WEAP model, and the relationship between *E. coli* concentrations and norovirus concentrations observed in the Nhue River, which flows through Hanoi city [53,54] (this relationship was used in other cities as well). The volume of the unintentional ingestion of floodwater was estimated using the hourly inundation depths in each grid from the inundation model using Flo-2D. The hourly probability of infection by noroviruses in floodwater was calculated using the dose–response model for the *Norovirus* GI.1 8fIIa strain, without considering the effect of aggregation [55]. A previously developed Python-based program code [51] was used to calculate the cumulative probability of norovirus infection for each grid during 24 h (Manila) or 48 h (Hanoi and Jakarta) of flooding events in each scenario (current/future precipitation and population). Finally, the number of infected people in each Flo-2D grid was calculated by multiplying the probability of infection by the current/future population per grid.

2.4. Contingent Valuation Method

The most widely used economic methods for the monetary estimation of these benefits are the contingent valuation method (CVM) and the hedonic pricing method. The assessment of recreation benefits is widely done through the use of the travel cost method; however, it is challenging to apply this method in an urban context, because there are often no travel expenses involved in assessing those areas.

The CVM is the most frequently applied method in the valuation of environmental assets [56–58]. The CVM represents a stated preference technique, which is used by economists to assess the monetary value of nonmarket goods, such as water quality. The CVM or conjoint analysis has an advantage over other stated preference techniques because it allows us to measure both the use values and non-use values of environmental goods. This method bypasses the need to refer to market prices by explicitly asking individuals to place monetary values upon environmental goods. The CVM provides a broader way of assessing large numbers of amenities than other methods do, e.g., estimating the willingness to pay (WTP) for improved water quality that might be planned, but not yet provided. The CVM involves creating a hypothetical market to a sample of respondents and asking their opinions on the values of public environmental goods or services (e.g., WTP for a change in the supply of an environmental resource) under specified contingencies [59].

Mail surveys and phone or face-to-face interviews are usually used to administer these surveys. The respondents are asked what the maximum amount they are willing to pay toward the preservation or improvement of an environmental good/asset. The researcher then estimates the monetary value of the asset by calculating the average WTP of the respondents and multiplying this by the total number of users of the environmental good. As the questionnaire is the principal tool in the CVM, designing a good questionnaire is critically important.

Generally, the CVM survey consists of three parts: (1) an explanation of the good being valued, and the hypothetical situation which the respondent has to confront/imagine; (2) the question of their willingness to pay for the environmental good; and (3) follow-up questions related to their general attitudes toward the good under consideration and the socioeconomic characteristics of the respondent. The issues concerning the survey's design, administration, and implementation have been widely discussed and described in the literature [60–65].

We conducted two workshops in Metro Manila to identify the hypothetical scenario of water quality improvement for this particular survey. This is one of the key tasks in preparation for the CVM, because in the absence of actual market for such an environmental good, researchers need to create a hypothetical market and request respondents to put the value on the proposed change in the environmental service. Such a hypothetical scenario was selected as the Surface Water Quality Improvement Program in Metro Manila. There are two components in the program: (1) constructing new wastewater treatment facilities; and (2) expansion of the existing sewerage system. The questionnaire has been translated into Tagalog language, the most commonly spoken language in the megacity.

Some 40 respondents in the two cities of Quezon and Manila were selected for a pilot study, where a developed questionnaire was pretested. The objective was to check whether the survey was logical, and if the WTP questions were understood correctly by residents. The main survey was conducted in June 2016 in Metro Manila, and involved a total of 240 respondents. The random stratified sampling method has been used because we could not secure a voters list from the local government, and did not want to use telephone book to compile sampling for the survey, because it does not cover the entire area of the megacity. The selection techniques were based on two classes: (1) walking distance to the river, which assumes that within 30 min, one can reach the nearest waterbody; and (2) need to drive or take public transportation to the nearest waterbody. SAS statistical package was used for the analysis. The WTP was estimated by a tobit model. Theoretically, the tobit (censored regression) model better to use to analyze the data as the OLS estimates could be biased (because the range of dependent variable is limited, WTP ≥ 0).

3. Results and Discussion

The results in this section are presented through a series of case studies representing situations where one or more categories of integrated approaches, as highlighted above, were applied. We did not intend to introduce a full, comprehensive application of systems approaches, but rather intended to demonstrate their applicability in the water management strategies of particular cities in Southeast Asia. These case studies have been selected to illustrate the diverse contexts of socioeconomic, geographic and urban conditions in selected cities.

3.1. Urban Flood Risk

The flood modeling approach is an effective option that can produce realistic reproductions of the characteristics of urban floods. Under specific rainfall forecasts and land uses, flood inundation maps can be created using model outputs, and the results can be used to issue early warnings and predict required evacuations to minimize flood damage. Flood height and damage were identified at the grid cell scale in Southeast Asian cities. The flood risk assessment was carried out in urban watersheds, namely, those of the Lich River in Hanoi, the Marikina–Pasig–San Juan River system in Metro Manila, and the Ciliwung River in Jakarta. The impacts of urbanization and climate change on urban flood risk were investigated to understand flood occurrence in a changing environment. The comparison between recent and 2030 land use maps noted significant urban growth, with expansions of 10% in Metro Manila, 42% in Jakarta, and 7% in Hanoi. Additionally, the climate projection analysis revealed the enhancement of rainfall in 2030, with increases of approximately 25% in Metro Manila for a 100 year return period, 9% in Jakarta for a 100 year return period and 23% in Hanoi for a 50 year return period. Similarly, flood inundation areas of more than 0.5 m in depth in these cities are expected to increase by 26% in Metro Manila, 8% in Jakarta, and 19% in Hanoi. These findings show that the extent and depths of flood inundation under future conditions are significantly higher than those under the current conditions. A spatial comparison between the current situation and the situation with the effects of climate change in Metro Manila, Jakarta, and Hanoi is presented in Figure 3. Later, impacts of several structural and non-structural countermeasures were tested on reduction of flood inundation and economic losses. For illustration, Figure 4 provides a comparison of increasing/decreasing flood inundation under current, future moderate/extreme climate change conditions, and combinations of countermeasures, like upper storage dam (75 MCM), larger channel flow (600 m^3/s to 1200 m^3/s), flood diversion (1600 m^3/s to 2400 m^3/s), and additional infiltration (by 10% with implementation of WSUD—water sensitive urban design). These measures were found to be greatly effective in reducing flood inundation.

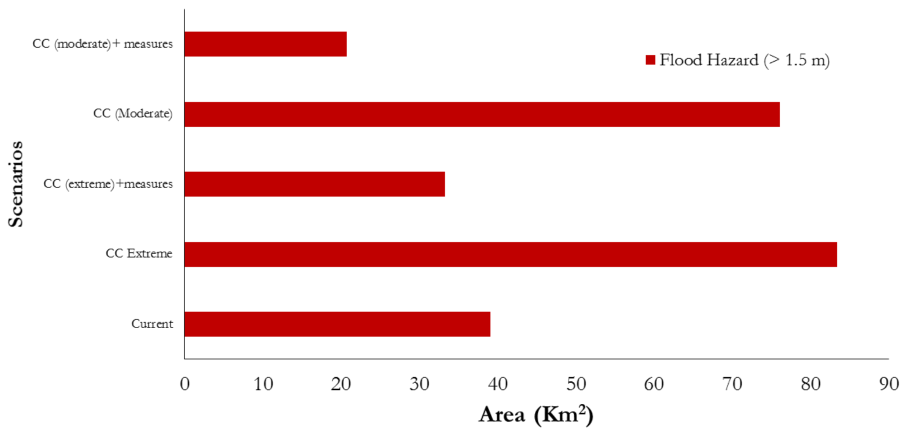

Figure 4. Comparison of inundation (flood hazard) under climate change (moderate and extreme) and combination of countermeasures in the Marikina–Pasig–San Juan River basin, Manila.

In Metro Manila, Jakarta, and Hanoi, significant increases in loss will occur due to the impact of global changes in the future. In Metro Manila, climate change and rapid urbanization will lead to increased inundated areas and an increased risk of flood and damage. The results showed that damage may increase by approximately 212%, 26%, and 83% in Metro Manila, Hanoi, and Jakarta, respectively. This corresponds to higher inundation depths and higher degrees of flood damage. Figure 5 indicated the spatial distribution of flood damage in Metro Manila to support the flood damage analysis.

The flood volumes and damage are predicted to increase with rapid urbanization and climate change. These findings clearly emphasize the need for further flood adaptations and mitigation measures for sustainable urban development. The identification of high-priority areas for flood risk reduction countermeasures using flood hazard and damage assessments will be helpful for decision-makers.

These increases in precipitation and flood patterns will have major implications for the design, operation, and maintenance of municipal wastewater management infrastructure. The impacts of changes in climate and land use indicate that the design standards and guidelines that are currently employed must be revised. Increased peak flows and flood inundation should be considered in future flood management systems, and flexible adaptive measures should be adopted, due to the uncertainty in future climate and land use changes.

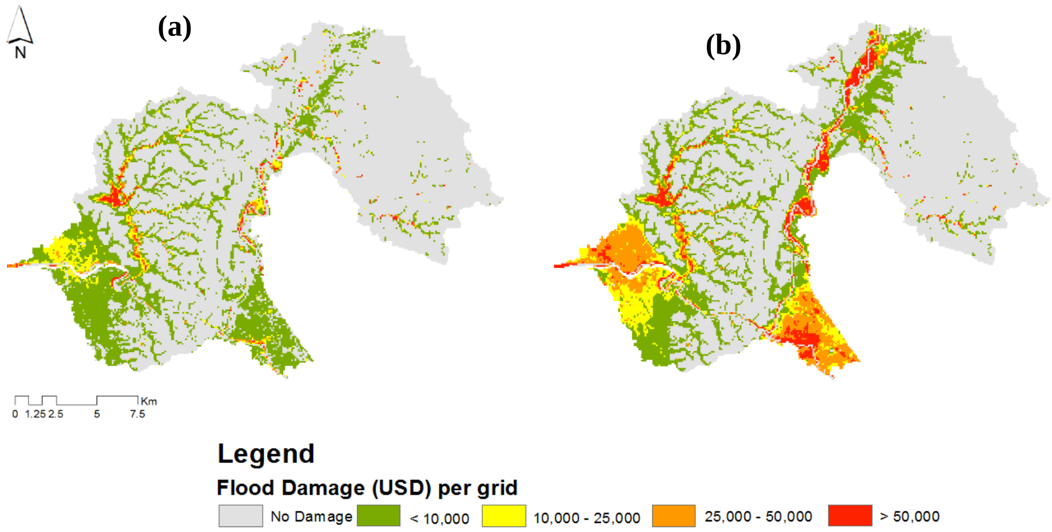

Figure 5. Spatial distribution of flood damage (Marikina–Pasig–San Juan River, Metro Manila). (**a**) Current situation without the effect of climate change; (**b**) Future situation with the effect of climate change.

3.2. Water Quality

Once the calibration and validation of the model output is done, the simulation of future water quality using BOD and *E. coli* as indicators is done for the years 2015 and 2030, to depict the effects of population growth, climate change, and urbanization/land use changes. The effect of climate change is shown through changes in rainfall, while that of urbanization is observed through changes in population and land cover/land use patterns. Table 1 summarizes the current status of wastewater infrastructure and sewage collection rates in all three study areas. The resulting comparison between current and simulated future water quality is presented in Figure 6.

Table 1. Summary of current status of water infrastructure in different study areas.

Target Area	Water Quality Simulation for Year 2030 (to Evaluate the Effect of Climate Change + Population Growth)
Manila	Present Waste Water Treatment Plants capacity—65 MLD
Jakarta	Present Waste Water Treatment Plants capacity—22 MLD
Hanoi	Present Waste Water Treatment Plants capacity

The goal of this simulation is to obtain deep insight into future water environments, and to recommend possible policy interventions or countermeasures that may provide potential solutions for water-related problems. Based on the simulated results for the two water quality parameters, the water quality in 2030 is worse than that in 2015, due to the addition of sewage discharge caused by population increase. Furthermore, the combined effect of all the driving factors, viz. climate change, population growth, and urbanization, has a negative impact on water quality. The reason for this may be extended dry periods and concentrated wet periods due to climate change, which add additional amounts of wastewater discharge and increased surface runoff, respectively.

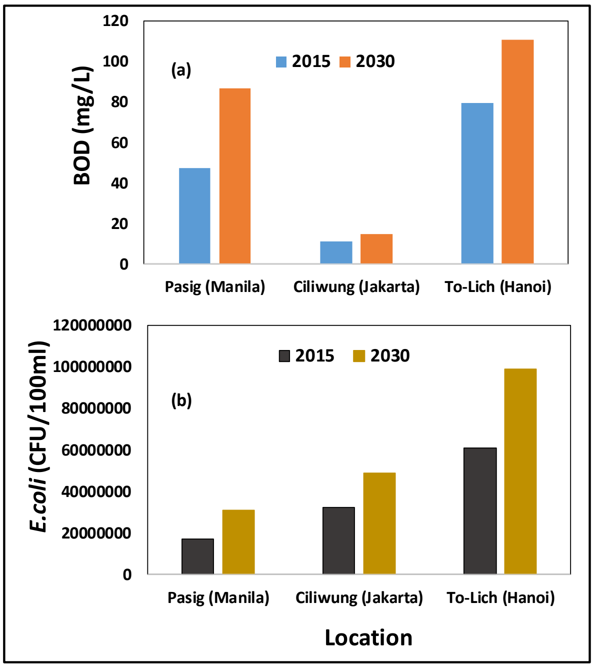

Figure 6. The simulation results of the average values of (**a**) biochemical oxygen demand (BOD) and (**b**) *E. coli* for the entire stretch of each river investigated at the annual scale for the years 2015 and 2030 including the effect of population growth and climate change considering MRI-CGCM with RCP8.5.

3.3. Health Risk Assessment

The effects of urban flooding and water quality deterioration, which are affected by both climate change and urbanization (population increase and land use change), on public health were examined by using the risk of infectious gastroenteritis by noroviruses in floodwater as a reference. Our health risk assessment model simulated the probability of infection, as well as the number of infected people among residents in flooded areas, using the results of the flood simulation model and the water quality simulation model. Figure 6 shows the distribution of norovirus infections in flooded areas in Manila under current and future scenarios. High-risk areas (red areas in Figure 7a,b) are more clustered in the southwestern area of the simulated region, compared to the highly inundated areas (red areas in Figure 6), which are also spread in the upstream region, because the southwestern region of Metro Manila has a much larger population than other areas. The high risk areas in Jakarta (Figure 7c,d) and Hanoi (Figure 7e,f) also clustered in populated regions, both in the northern part. Our simulation results also highlighted high-risk areas in terms of waterborne infectious diseases following flooding events, which are located in populated areas, and where severe inundation is expected.

The estimated numbers of infected people in the three target cities (Hanoi, Jakarta, and Manila) under the current and future scenarios are summarized in Table 2. The simulation results clearly show that both the number of infected people and the probability of infection will increase substantially (with increases of 54–134% in infected people and 64–102% in the probability of infection) in all target cities in the near future. This increase is due to the combination of the increased severity of flooding, more deteriorated quality of river water, and increased population. Because these factors each independently affect the health risk, the total increase in health risk was larger than that of each of the input parameters. For example, in the case of Manila, the number of infected people increased by 134%, which was larger than the 26% increase in flooded areas (>50 cm) and 87% increase in *E. coli* concentrations. Although we simulated the risk under extreme precipitation events corresponding to 50 or 100 year return periods, the high probability of infection (mostly on the order of 10^{-2} infections/24 or 48 h) indicated that flood-related infectious gastroenteritis has a significant impact on public health. These results warrant immediate measures to prevent infectious diseases following flooding events, in addition to those to prevent direct damage (e.g., drowning) to residents.

Table 2. Estimated total number of infected people and arithmetic mean probability of infection by noroviruses in floodwater using current and future (average) precipitation scenarios corresponding to 50 year return period and current/future population.

City	Total Infected People in the Area			Probability of Infection		
	2015	**2030**	**2030/2015**	**2015**	**2030**	**2030/2015**
Manila	59,472	139,446	234%	0.0062	0.012	202%
Jakarta	40,768	72,123	177%	0.014	0.023	164%
Hanoi	38,363	59,088	154%	0.033	0.059	179%

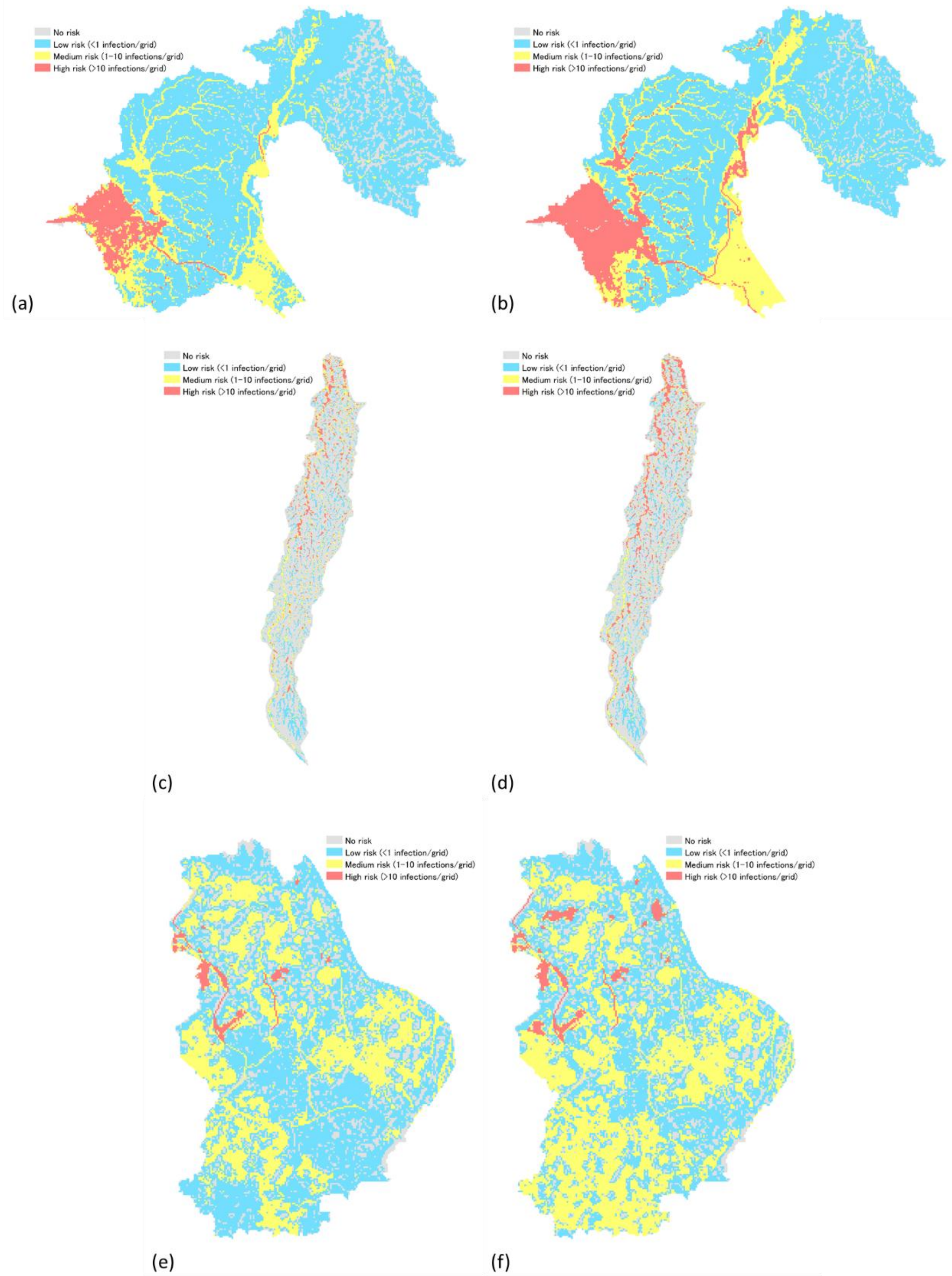

Figure 7. Risk maps of floodwater-borne norovirus infections for Manila ((**a**) for 2015 and (**b**) for 2030), Jakarta ((**c**) for 2015 and (**d**) for 2030), and Hanoi ((**e**) for 2015 and (**f**) for 2030).

3.4. Economic Assessment in Manila, Philippines

There is clear interest in improving the surface water quality of Manila waterbodies by those who placed monetary value on this improvement, as 71% of the respondents (n = 170) indicated their willingness to support the proposed Surface Water Quality Improvement Program in Metro Manila. Among the 29% of the participants (n = 70) who voted against the proposed action plan, the most common answers were "Do not want to place monetary value" and "Objected to way question was presented". These were considered to be protest (zero) answers, in addition to true WTP = 0 answers, and were excluded from further analysis. The maximum threshold of 5% of the income level was selected to accept the stated WTP.

The vast majority of survey participants (84%) had visited or seen a river/lake/canal in the city in the last month. Among them, 45% went regularly, 34% went a few times, 6% went once, and 15% preferred not to answer this question. The majority of respondents (86%) answered that the water quality of the city's waterbodies was not sufficiently acceptable for recreational activities; 12% stated otherwise (that the water quality was sufficient); and 2% did not know whether or not the water quality was sufficient.

The socioeconomic data of the respondents are given in Table 3. As seen from the table, the socioeconomic backgrounds of the respondents are representative. The employment status data show that most of the survey participants are occupied with a full-time job (29%) or are self-employed (28%). Only 9% of them are unemployed, and 17% are non-working students. Most of the interviewed individuals are educated people; only one person had not attended any form of school.

Male respondents formed the majority in our survey (51%), followed by female (43%) and unspecified (6%) respondents. Middle-aged people dominated the survey (40%), while 36% were represented by the younger generation (less than 25 years old), and only 5% were elderly people (61 and over). More than half of all respondents were married, one-third were single, and only 6% were divorced or separated.

Income levels varied widely among the survey participants. In fact, the Philippines has the highest Gini coefficient (inequality ratio) among all countries in this region, which means that it has a greater rate of inequality compared to other Southeast Asian countries. While 11% of respondents belonged to the poorest sector of the population, who live on USD 2 a day (USD 1 = PHP 47.03), 14% receive a monthly income of USD 850 or higher.

The representativeness of the data was tested, and they were found to be statistically representative of the whole population, i.e., the residents of Metro Manila. As our data were based on random sampling, it was necessary to validate the obtained demographic data using the available demographic data on the Philippines population. This was done by comparing three demographic parameters, namely, gender, age distribution, and household size. The comparison of demographic data from the 2011 Philippine Demographic Yearbook [66] revealed minor differences: (1) household size—ours is higher than the average value in the country (5.3 vs. 4.6); (2) gender ratio—our survey comprised 46% females and 54% males relative to 49% and 51% in the country, respectively; and (3) population structure—the Philippines has a relatively young population, and the median age of the country's population is 23.4 years, which means that half of the household population was younger than 23.4 years. The ages of the majority of our respondents fell in the interval of 26–40.

Again, the majority of the respondents were willing to pay for the improvement of the water quality in the city's waterbodies. The number of positive bids reached 71%, which is a relatively high number. A small share of the respondents (7%) stated that their true value was zero. The amount of protest responses was close to 20%. The main motives for true zero WTP were either that they lived far from the closest waterbody or economic reasons.

Table 3. Socioeconomic data of 170 respondents (%).

Employment Status		Schooling		Gender		Age		Marital Status		Income (PHP)	
Part-time	14	No school	1	Female	43	16–25	36	Married	59	Under 3000	11
Full-time	29	Grade school 1–8	7	Male	51	26–40	40	Single	35	3001–5000	14
Self-employed	28	Grade school 9–11	29	Unspecified	6	41–60	19	Divorced/Separated	6	5001–10,000	21
Not employed	9	Some school	29			61 and over	5			10,001–20,000	27
Student (not working)	17	College graduate	32							20,001–40,000	14
Retired	3	Postgraduate	2							40,001 and above	13
Total	100		100		100		100		100		100

The willingness to pay for swimmable water quality (which is a higher water quality) ranged between zero and PHP 1200 (USD 25.52) per person per month, and the average rate for implementing the proposed program was PHP 102.44 (USD 2.17). The WTP for fishable water quality ranged from zero to PHP 1000 (USD 21.27) per month, with an average value of PHP 102.39 (USD 2.17). Indeed, these are very close estimates, and there is almost no difference between these two WTP values. There are two reasons that may explain this phenomenon. First, the city's residents do not see any difference between these water qualities, because the current water quality in urban waterbodies is very bad. People simply do not believe that the water quality could be significantly improved, and pollution could be prevented. Second, people see more benefits from fishing than from swimming. For example, swimming is prohibited in the city's waterbodies, but people can still enjoy open waters. Residents simply prioritize their income (to catch and sell fish) over the condition of their health.

Within the overarching question of how much people are willing to pay to improve the water quality in their city, it has been explored whether their willingness to pay varies with characteristics such as employment, schooling, gender, age, marital status, household size and income, perceptions of the impact of water quality on people's health, and people's concerns about water quality in the city's waterbodies. Two major factors influenced the use- and non-use WTP for both water quality scenarios, namely, income and marital status (Table 4). As expected, a resident's WTP increases with increasing income; surprisingly, married people were willing to pay more than single or divorced/separated people. Actually, this is not very surprising, as married couples would likely be bringing two incomes into a house; therefore, one household would have a higher net income than one person living alone, and divorced and single people may face more economic pressure for residence costs unless they cohabitate. This was obvious from the workshops that preceded the actual survey, when married people were more active in discussions and debates, and expressed concern about the direct and indirect effects of water pollution on their families. Another discovery was that while many people who lived relatively far from the nearest waterbody were skeptical about their WTP ("why I should pay if I live far and don't pollute water"), the results do not show any significant impacts of the "distance to waterbody" variable. Table 3 shows only the variables that had a significant impact on the two WTP estimates.

Table 4. Estimated regression coefficients for four willingness to pay (WTP) estimates.

Variable	WTP Swimmable	WTP Fishable
Intercept	14.58 *	15.12 *
Marital status	7.91 *	8.03 *
Income	23.68 **	23.91 **
R^2	0.18	0.19

* and ** denote statistical significance at the 5% and 1% levels, respectively.

The total benefits for Metro Manila can be estimated from the average WTP of the two categories of water quality (PHP 102.44 and PHP 102.39). The total population of Metro Manila aged 15–60 in 2011 was 7.685 million [66], which implies that the value of the potential total benefits received from the improved water quality implied by a given scenario may be within the limits of PHP 9443 billion to PHP 9447 billion (USD 190 million) per year.

4. Conclusions

Today's society faces far more interconnected environmental, social and economic challenges than ever before. These challenges require an interconnected, integrated analysis and solution. Continuous economic development, population growth, and urbanization in Southeast Asia have propelled the greater consumption of many resources, such as energy, water, land, and materials, and wide-ranging changes in land use. These changes have greatly influenced the surrounding environment; in many cases, this impact was negative.

Although this research has not incorporated a high level of detail, its preliminary results can help local policy-makers and water planners better manage floods by 2030. Increases in precipitation and flood patterns will have major implications on the design, operation, and maintenance of municipal wastewater management infrastructure. The resulting impacts of climate and land use changes indicate that the design standards and guidelines that are currently employed must be revised. Increased peak flows and flood inundation should be considered in future flood management systems, and flexible, adaptive measures should be adopted, due to the uncertainty of future climate and land use changes. Because urban rivers flow through densely populated areas, there is little room for channel widening or large centralized structures, which necessitates a comprehensive approach and distributed facilities for flood risk control in urban areas. Non-structural measures, such as flood hazard and risk mapping, can be highly effective for land use planning and flood damage mitigation [67], and these measures are also important tools for building flood-resilient communities. Flood hazard and risk mapping require a detailed understanding of the flood inundation characteristics at various locations within the target area. Thus, it is important to understand the likely impacts of climate and land use changes on floods in rapidly growing cities to craft sustainable urban water environment strategies.

Specific countermeasures, like storage capacity and regulation dams in the upper region, could be highly effectively in reducing increased peak flows (entering the city). Inside the city (lower region), pumping of floodwater, especially in low land region inundation, structural flood control measures, such as river flow capacity improvement, diversion, and non-structural (infiltration, forecast) measures could be more effective, and require greater attention. Additionally, the identification of high-priority areas for flood risk reduction using flood hazard and damage maps will help decision-makers adopt strategies at both a local and regional scale. Indeed, the detection of flood prone areas will let planners adopt appropriate strategies on urban planning and flood risk reduction. Moreover, these strategies can lead to reduced vulnerability of people and buildings. Furthermore, the uncertain and unpredictable occurrences of flooding have caused local governments to pay attention to these disasters. In conclusion, because floods are a global issue, they require the cooperation and collaboration of all stakeholders. Moreover, the prediction of future flood situations will be useful for planning and designing structural and non-structural measures. The implementation of blue-green infrastructure can help minimize the effects of floods and protect the environment.

Mitigation and adaptation measures, that aim to prevent the further deterioration of these water resources and their improvement in a sustainable way, must focus on the diligent monitoring and assessment of water resources, and the development and proper management of water infrastructure to cope with the adverse effect of uncertainties stemming from population growth and climate change.

The results of simulated water quality in the year 2015 clearly indicate that the rivers in all three cities are moderately to extensively polluted relative to the recommended limit defined by the WHO. However, with the addition of climate change, population growth and urbanization, this quality further deteriorated. By giving more a precise prediction of wastewater to be generated considering different aspects of global changes by year 2030, this study will help all stakeholders and policy makers involved in water resource management to think about all possible countermeasures for minimizing the generation and treating all generated wastewater. Based on the exponential increase in the total demand for water resources, promoting the reuse and recycling of water in industries can also contribute to restoring and reclaiming water resources, and can thus reduce the urban water demand. More attention should be paid to prevent the spread of infectious diseases in such areas, given that this risk will increase significantly in the near future.

Recent years have been marked by growing concerns about water pollution in the urban waterbodies of fast-growing Southeastern Asian countries, in particular, Philippines, Indonesia, and Vietnam. Many countries have adopted water quality standards for surface waterbodies, and have strengthened pollution control and upgraded their enforcement mechanisms. However, the implementation of these measures imposes a real cost on society and the government in terms of the cost of treatment, mitigation, and compensation. We focused on exploring the economics of improved water quality, specifically in Metro Manila, Philippines. The evidence presented here suggests that the WTP for swimmable water quality is PHP 102.44, and the WTP for fishable water quality is PHP 102.39. Based on these numbers, improving the water quality in Metro Manila has potential total benefits of PHP 9443 billion to PHP 9447 billion per year, which translates to USD 190 million per year. This estimation could help policy-makers plan and promote new and/or upgraded existing wastewater treatment plants in megacities. To prevent the further deterioration of Metro Manila's waterbodies, and improve the overall environmental situation in the city, policy-makers should raise people's understanding and awareness of the environmental issues facing the area through school programs and public information campaigns. There are two ways to use the results of the CVM surveys in policy-making: they could be used to contribute to and stimulate public awareness of the potential monetary benefits of the improvement of surface water quality, and they could be used to influence and develop new policies through cost-benefit analysis or by justifying existing decisions in urban water management and decision-making. However, the extent, coverage, and goal of the use of the CVM results in urban water management planning and policy-making vary across countries. For instance, monetary valuation is widely used to assess possible ex-ante and ex-post outcomes of environment-related policies in USA, Australia, and the UK, while this is not the case in many developing countries.

The results of the integrated systems analysis approach undertaken by this particular study brought useful insights on current conditions of water-related infrastructure, preparedness to natural hazards, and future development patterns for Metro Manila, Jakarta, and Hanoi. This work could be handy in helping local policy-makers involved in the water sector to formulate strategic and adaptive plans to address sustainable and resilient future development in the cities.

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