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Numerical quantification of current status quo and future prediction of water quality in eight Asian megacities: challenges and opportunities for sustainable water management

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Abstract Finite freshwater sources are facing huge threats both for quality and quantity from uncertain global changes, namely population growth, rapid urbanization, and climate change. These threats are even more prominent in developing countries where institutional capacity of decision-makers in the field of water resources is not sufficient. Attention of scientific communities to work on adaptation barriers is increasing as the need for global change adaptation becomes apparent. This paper presents a comparative study of assessing the current water quality as well as predicting its future situation using different scenarios in eight different cities of South and Southeast Asia. The idea behind this transdisciplinary work (integrated use of hydrological science, climate science, social science, and local policies) is to provide scientific evidence to decision-makers to help them to implement right management policies at timely manner. Water Evaluation and Planning (WEAP), a numerical simulation tool, was used to model river water quality using two scenarios, namely business as usual (BAU) and scenario with measures. Water quality simulation was done along one representative river from all eight cities. Simulated results for BAU scenario shows that water quality in all the study sites will further deteriorate by year 2030 compared to the current situation and will be not suitable for fishing category as desired by the local governments. Also, simulation outcome for scenario with measures advocating improvement of water quality compared to current situation signifies the importance of existing master plans. However, different measures (suggested upgradation of wastewater handling infrastructure) and policies will not be sufficient enough to achieve desirable river water quality as evident from the gap between concentration of simulated water quality and desirable water quality concentrations. This work can prove vital as it provides timely information to the decision-makers involved in keeping inventory for attaining SDG 6.0 in their regions and it also calls for immediate and inclusive action for better water resource management.

Keywords Water quality · Asia · Hydrological simulation · Wastewater management · WEAP

Introduction

Freshwater resources are necessary for the human well-being in terms of different usages, namely industrial activities, agriculture, drinking, hygiene, and recreation. Around the globe, approximately 500 million people live in areas where water consumption exceeds the locally renewable water resources by a factor of two (Mekonnen and Hoekstra 2016). The increasing demand for water by population and industrial growth is creating chronic water shortages throughout the world. Added to this is the poor balance between global changes and water resource development jeopardizing water security to a critical level (Pittock et al. 2013). Extreme

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weather conditions (heavy rainfalls and draughts) and changes in air temperature because of climate change alone cause lot of negative impacts on freshwater resources quality and quantity (Delpla et al. 2009; USGCRP 2014; Whitehead et al. 2015; Hosseini et al. 2017). It is found that renewable water resources at individual scale has drastically dropped down since the last four decades and reached to the water-stressed level by year 2015 in different Asian countries, namely India, Pakistan, and Afghanistan, while also reaching this status rapidly in the near future in other countries like Nepal and Bangladesh (Gareth et al. 2014).

With this exploding rate of population growth and urbanization, it is predicted that approximately 60% of the world population will live in urban areas (UNDESA 2015). It is projected that cities with population more than 10 million will increase from 28 (at present) to 41 in 2030, and most of these (24 out of 41) will be in Asia alone. Due to the rapid urbanization combined with a high rate of economic development, cities are experiencing degradation and depletion of natural resources including water quality deterioration, with detrimental impacts on human health and ecosystems. The exponential growth of urban areas together with inadequate wastewater treatment infrastructure development and the fragile capability of the decision-makers in the field of water resources results in the discharge of 80% of untreated wastewater directly into water bodies in many Asian countries, leading to deterioration of the water environment (Azhoni et al. 2017; UN Water 2017; UN WWAP 2017).

Considering the above facts, the United Nations and its associated members univocally recognized that access of good quality water together with an adequate quantity is necessary for achieving Sustainable Development Goals (SDGs) for water security (SDG 6), food security (SDG 2), health (SDG 3), and ecosystem (SDGs 14 and 15) (UN 2015; UN-HABITAT 2015; Jensen 2016). In order to provide the practical solution for sustainable management of water resources in these Asian countries, decision-makers need scientific evidence about the status quo and predicted future of water resources in their countries. The baseline assessment with scenario analysis will also help to explore possible mitigation measures (technical and management measures) as well as adaptive measures (governmental/institutional policies to protect and restore water quality) (UNEP 2016).

Research framework and target cities

This research strives to do hydrological simulation to provide scientific evidence to decision-makers for developing policies to manage urban water environment in different megacities of Asia. Here, scenario-based hydrological simulation is done to predict current and future water quality and thus helps to answer “what if” questions and their respective possible adaptive measures. Water quality status is projected for future with spatio-temporal trend analysis under different possible interventions/countermeasures mentioned in existing local master plans for sustainable water management. Chief interventions considered for doing different trend analysis by year 2030 were population growth, land use/land cover changes, climate change, and wastewater infrastructure as mentioned by the local master plan. The research findings generated through this transdisciplinary approach fill an important gap in global understanding of water-related changes in urban water environments and contribute to improved policymaking in this key area.

River water quality were simulated through three different scenarios viz current scenario (composed of existing situation), business as usual scenario (future situation without any mitigation measures for the year 2030), and with measures scenario (future situation with mitigation measures targeting year 2030). The system 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 as shown in Fig. 1.

Predictive models for surface water quality in urban areas were developed using Water Evaluation and Planning System (WEAP), a numerical modeling software (Sieber and Purkey 2011). In simulation, existing water environment were mimicked using different drivers (urbanization, climate change, and population growth along with currently existing master plan) to predict future water quality. Through simulated water quality result, this work depicts the policy gaps between planned provisions to manage wastewater generation in year 2030 and their real need.

The work is focused in eight cities in Asian countries (Fig. 2), which are facing rapid population growth, urbanization, and rapid water quality deterioration. Data and information necessary to develop simulation models and to conduct analysis were collected in collaboration with research institutes and agencies in the target areas.

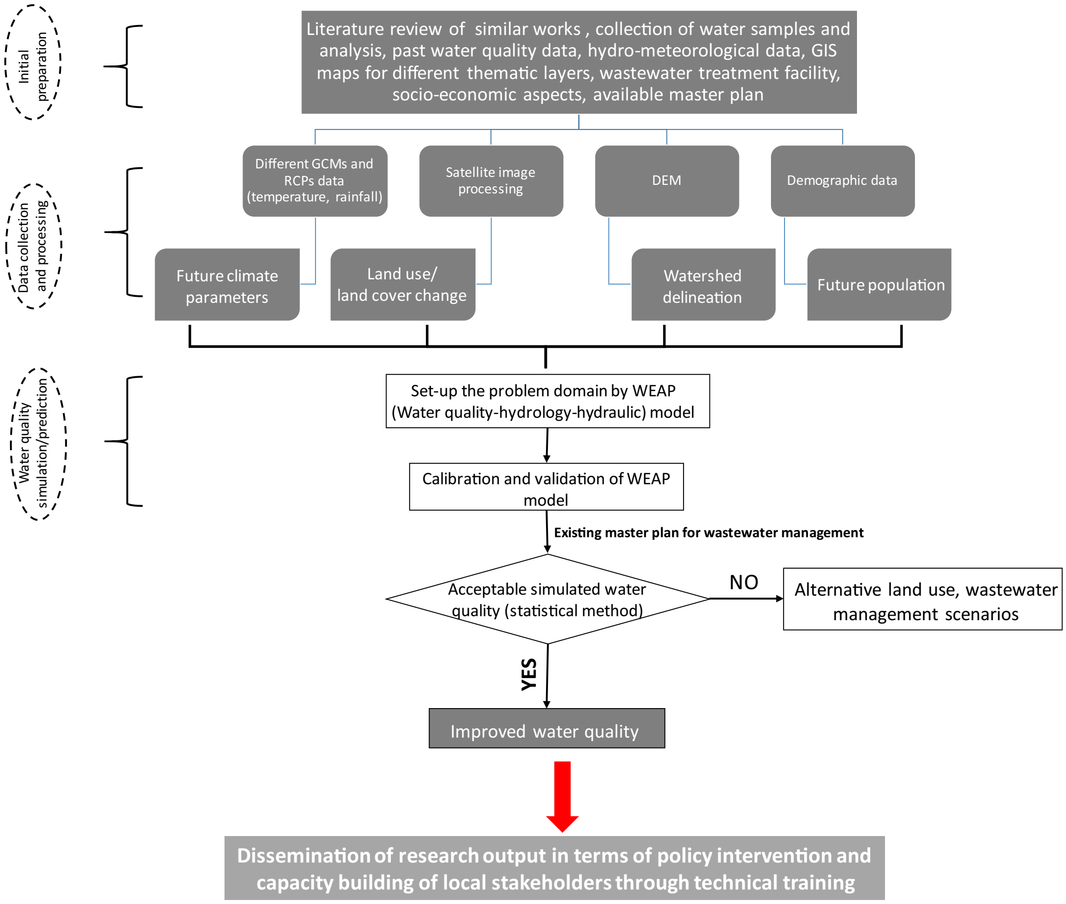


Fig. 1 Flowchart of the research framework

Methodology (data required and model setup)

The WEAP model is used to simulate future water quality variables in the year 2030 to assess alternative management policies in the eight river basins. WEAP can simulate concentration different water quality parameters by using two key driving mechanisms, namely simple mixing and first-order decay (Pelletier et al. 2006). In order to simulate water quality, various data set ranging from past observed river water quality data at different monitoring stations, hydro-meteorological data (rainfall, evaporation, temperatures, etc.), river characteristics (river discharge, river cross section, drainage network), demographic attributes (population, income), information about significant point loading about sewerage effluents to the different sections of the river, wastewater management infrastructure, and strategies to manage wastewater by year 2030 as recorded in the local master plan. Basic information about all target river bodies along with its water quality for two key parameters is given in Table 1.

Under the WEAP hydrology module, the soil moisture method is used to estimate the different hydrological parameters for this study. This method can simulate different components of the hydrologic cycle, including evapotranspiration, surface runoff, interflow, base flow, and deep percolation (Sieber and Purkey 2011). Here, each catchment is divided into two soil layers: an upper soil layer and a lower soil layer, which represent shallow water and deep water capacities, respectively. The upper soil layer is targeted for spatial variation in different types of land use and soil types, whereas the lower soil layer is considered to represent groundwater recharge and baseflow processes, and its parameters remain the same for the entire catchment. Different hydrological components are estimated, with z_1 and z_2 as the initial relative storage (%) for the upper (root zone) and lower (deep) water capacity, respectively (Eqs. 1–5).

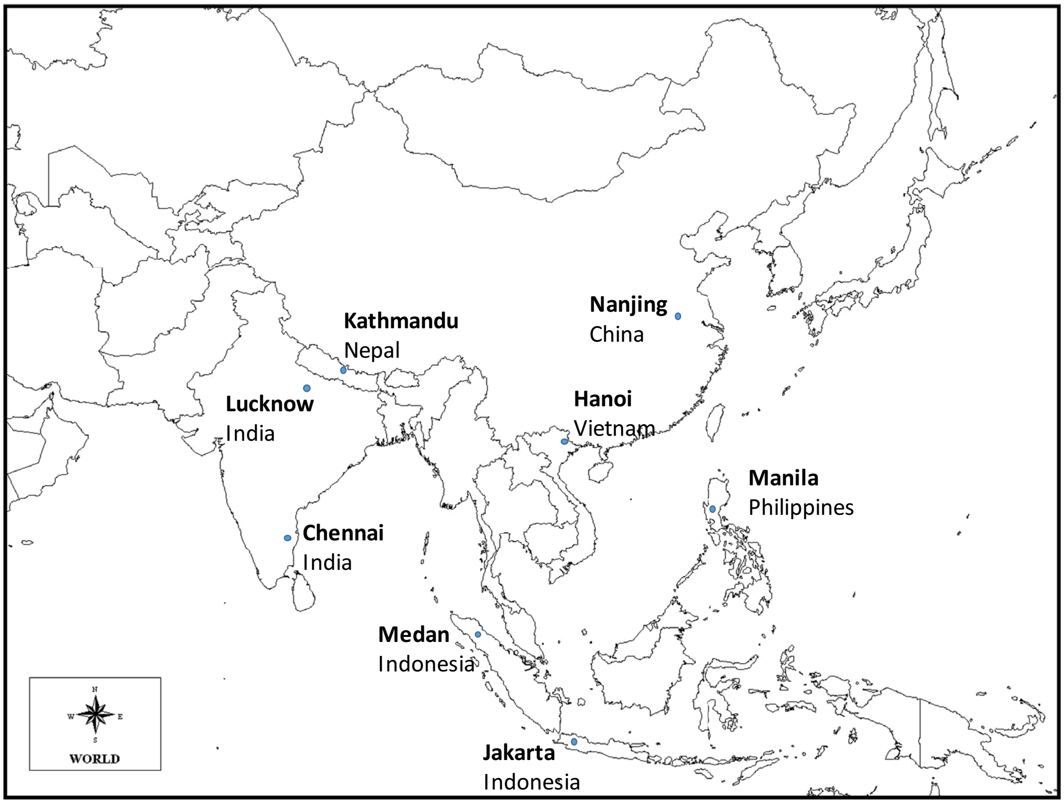


Fig. 2 Target cities of this research work

$$ET = Potential\ evapotranspiration \times \left(5z_1 - 2z_2^2\right)/3 \quad (1)$$

$$Surface\ runoff = Precipitation\ (P) \times z_1^{Runoff\ resistance\ factor} \quad (2)$$

$$Interflow = (Root\ zone\ conductivity \times preferred\ flow\ direction) z_1^2 \quad (3)$$

$$Percolation = Root\ zone\ conductivity \times (1 - preferred\ flow\ direction) \times z_1^2 \quad (4)$$

$$Baseflow = Deep\ conductivity \times z_2^2 \quad (5)$$

z_1 and z_2 = upper soil layer and lower soil layer (m), which represent shallow water and deep water capacities, respectively.

The water quality module of the WEAP tool makes it possible to estimate pollution concentrations in water bodies and is based on the Streeter–Phelps model. In this model, two processes govern the simulation of oxygen

Table 1 Summary of different attributes for target study area and river bodies along with their water quality in this research work

Target city	Target river	BOD (mg/L)	*E. coli* (CFU/100 ml)	Population targeted (million)
Hanoi	To-Lich	79.6	60,940,000.0	6.35
Jakarta	Ciliwung	11.0	32,265,125.6	4.17
Manila	Pasig	47.3	17,165,870.3	8.42
Chennai	Adyar	66.2	7,568,333.3	5.45
Lucknow	Gomti	46.2	483,333.3	5.05
Medan	Deli	15.7	113,640.0	2.31
Kathmandu	Bagmati	63.1	NA	2.85
Nanjing	Qinhuai	54.3	1,402,102.0	6.95

balance in a river: consumption by decaying organic matter and reaeration induced by an oxygen deficit (Sieber and Purkey 2011). BOD removal from water is a function of water temperature, settling velocity, and water depth (Eqs. 6–9):

$$BOD_{final} = BOD_{init} exp^{\frac{-k_{rBOD}L}{U}} \tag{6}$$

$$k_{rBOD} = k_{d20}{}^{1.047(t-20)} + \frac{\upsilon_s}{H} \tag{7}$$

where

$\mathrm{BOD_{init}}$ = BOD concentration at beginning of reach (mg/l); $\mathrm{BOD_{final}}$ = BOD concentration at end of reach (mg/l); t = water temperature (in degree Celsius); H = water depth (m); L = reach length (m); U = water velocity in the reach; υ_s = settling velocity (m/s); k_r, k_d, and k_a = total removal, decomposition, and aeration rate constants (1/time); and k_{d20} = decomposition rate at reference temperature (20 °C). Oxygen concentration in the water is a function of water temperature and BOD:

$$\begin{aligned} &Oxygen \quad saturation\ or\ OS \\ &\quad = 14.54-(0.39t) + \left(0.01t^2\right) \end{aligned} \tag{8}$$

$$\begin{aligned} O_{final} = OS-&\left(\frac{k_d}{k_a-k_r}\right)\left(\exp^{-k_rL/U}-\exp^{-k_aL/U}\right)\mathrm{BOD}_{init} \\ &-\left[(OS-O_{initial})\exp^{-k_aL/U}\right] \end{aligned} \tag{9}$$

O_{final} = oxygen concentration at end of reach (mg/l), and O_{initial} = oxygen concentration at beginning of reach (mg/l).

The schematic for different river systems in all eight cities using different nodes and transmission links mainly demand sites, catchment areas, WWTPs, return flow, etc., were developed using the WEAP numerical tool in such a way that it can mimic the real field situation. Here, catchment areas were decided after considering the convergence points of different major tributaries of the river concerned along with physiographic and climatic characteristics. Demand sites, another major components of the model schematic, were created to represent the population of different cities/cluster of administrative units lying on both side of the river within our study as well as to estimate the effect of population growth on river water quality status by discharging their domestic sewerage water. Other major considerations are demand sites and currently existing wastewater treatment plant (WWTP). Wastewater treatment plants are pollution-handling facilities with design specifications that include total capacity and removal rates of pollutants. In this study, flow of wastewater into the different rivers and its tributaries mainly feeds through domestic runoff routes. Here, upflow anaerobic sludge blanket reactor coupled with sequencing batch reactor (UASB-SBR) type of wastewater treatment plant is considered in the modeling and its treatment efficiency is assumed as 97% for BOD and 99.69% for fecal coliform (Elshamy et al. 2009).

The hydrology module within the WEAP tool enables modeling of the catchment runoff and pollutant transport processes into the river, whereas the water quality component deals with concentration of water quality parameters well controlled by various processes, namely decay rate and simple mixing. Contaminant transport from catchment coupled by rainfall-runoff is enabled by ticking the water quality modeling option during model setup. The WEAP hydrology module computes catchment surface pollutants generated over time by multiplying the runoff volume and concentration or intensity for different types of land use. During simulation, the land use information was broadly categorized into three categories, namely agricultural, forest, and built-up areas as reported by Kumar et al. (2018).

In order to calculate the effect of climate change on water quality, change in monthly average precipitation was estimated. Understanding the potential impacts of climate change is essential for informing both adaptation strategies and actions to avoid dangerous levels of climate change. Regarding future precipitation data, different Global Climate Models (GCMs) and Representative Concentration Pathway (RCP) outputs were used after downscaling and bias correction (Goyal and Ojha 2011). Statistical downscaling followed by trend analysis, a less computation demanding technique which enables reduction of biases in the precipitation frequency and intensity (Mishra and Herath 2015; Dahm et al. 2016), is used here to get climate variables at monthly scale. Historical rainfall analysis using the monthly precipitation data of past 20–25 years depend on the consistent data availability for different study sites was done. This study carried a comprehensive assessment of the possible climate change over different sites by using MRI-CGCM3.2 and MIROC5 as the most reliable GCMs with RCP4.5 and RCP8.5 emission scenarios. In this work, future climate corresponds to the period of 2020–2044.

Effect of population growth on water quality is visualized by future trend of population growth and their corresponding sewerage discharge. Future population for all cities were estimated by ratio method using UNDESA projected growth rate (Beven and Alcock 2012).

Once model setup is done, calibration followed by validation was performed before making it ready for future simulation. For calibration part, different hydrological/hydraulic parameters, namely effective precipitation, runoff/infiltration ratio, and river head water quality concentration were adjusted using stepwise trial and error method in such a way that model results mimics closely the observed values at field. After calibration, validation was performed by doing correlation analysis between simulated and observed result of water quality (BOD) and river discharge for certain period of time depending on consistent availability of observed data. Once satisfied statistically, numerical simulation for target year, i.e., 2030 was conducted using different scenarios called business as usual (BAU) scenario and scenario with mitigation measures with capacities of WWTPs as mentioned in their local master plan as shown in Table 2.

Model performance evaluation

Before doing future scenario analysis, performance of the WEAP simulation is justified with significant association between observed and simulated values of hydrological and water quality parameters using trial and error method. Hydrology module parameters (mainly effective precipitation and runoff/infiltration) were adjusted during simulation in order to reproduce the observed monthly stream flows for the period of certain year for hydrology module validation (Table 3), whereas water quality simulation part is validated by comparing simulated and observed concentration of water quality concentrations at some observation points. Selection of this location and time was made on the basis of consistent availability of observed water quality data. Main parameters adjusted here at step by step basis are household discharged water quality parameters concentrations both at the observation site and river head. Once correlation is made between observed and simulated values statistically satisfied to confirm suitability of the model performance in this problem domain, future simulation for both water quality and hydrological parameters were initiated.

Result and discussion

Precipitation and population change

Summary for future population projected by UNDESA and projected average annual precipitation from two different GCMs (MRICGCM3.2 and MIROC5) along with two different RCPs (4.5 and 8.5) in year 2030 for

Table 2 Summary of WWTP capacities considered for different scenarios for different target areas during numerical simulation

	Business as usual	With measures
Hanoi (To-Lich)	WWTP Cap. (200 MLD) for To-Lich River + CC + Pop. growth	Diversion of treated waste water from Ho Tay Plant to To-Lich River
Jakarta (Ciliwung)	WWTP Cap. (22 MLD), Sew. Col. rate (4%) + CC + Pop. growth	WWTP Cap. (520 MLD), Sew. Col. rate (100%) + CC + Pop. growth
Manila (Pasig)	WWTP Cap. (65 MLD), Sew. Col. rate (22%) + CC + Pop. growth	WWTP Cap. (625 MLD), Sew. Col. rate (100%) + CC + Pop. growth
Chennai (Adyar)	WWTP Cap. (180 MLD), Sew. Col. rate (25%) + CC + Pop. growth	WWTP Cap. (886 MLD), Sew. Col. rate (100%) + CC + Pop. growth
Lucknow (Gomti)	WWTP Cap. (145 MLD), Sew. Col. rate (19%) + CC + Pop. growth	WWTP cap. (1119 MLD), Sew. Col. rate (100%) + CC + Pop. growth
Medan (Deli)	CC + Pop. growth	NA
Kathmandu (Bagmati)	WWTP Cap. (8.5 MLD) + CC + Pop. growth	WWTP Cap. (480 MLD), Sew. Col. rate (100%) + CC + Pop. growth
Nanjing (Qinhuai)	CC + Pop. growth	NA

WWTP wastewater treatment plant, *MLD* million liters per day, *CC* climate change, *Pop growth* population growth

Table 3 Value of hydraulic parameters used for calibration for different study sites

			Final calibrated value							
Parameter	Initial value	Step	Hanoi (To-Lich)	Jakarta (Ciliwung)	Manila (Pasig)	Chennai (Adyar)	Lucknow (Gomti)	Medan (Deli)	Kathmandu (Bagmati)	Nanjing (Qinhuai)
Effective precipitation	100%	± 0.5%	92%	97%	96.50%	95%	93%	94%	95%	93.50%
Runoff/infiltration ratio	50/50	± 5/5	55/45	50/50	55/45	50/50	60/40	60/40	50/50	55/45

all areas (except Kathmandu and Nanjing) are presented in Table 4. Comparative result of monthly precipitation pattern clearly indicates that simulated average annual precipitation from different GCM outputs is not much different from the current observed precipitation. Looking into the projected population in year 2030, it is found that values will be increasing by manyfold for all areas except Hanoi where in Central Hanoi, the future population will shrink because of their local urban planning.

Water quality simulation

Result for validation of water quality for all cities is shown in Fig. 3. Significant correlation (with error percentage ranging from 8 to 18%) was found between observed and simulated value of BOD in all the study sites confirming that model is working well. For most of the cities, observed past water quality data is very limited and normally ranging from 4 to 5 years. Henceforth, base year for all models is kept very close to that of the current year (2015 in most of the cases). Post-validation, future simulation is made for two key indicators of water quality, namely BOD and *Escherichia coli* and the result is shown in Fig. 4 (edited from Masago et al. 2018). For *E. coli*, past observed data from Kathmandu and Nanjing was not available; therefore, simulation for these cities was not carried out. There was no monitoring data of *E. coli*, because it is too expensive for a regular basis monitoring. From the simulated result, it is observed that with currently existing wastewater infrastructure (treatment plant capacity, sewerage collection rate, removal efficiency); the present status of water quality throughout the river is very poor as compared with local guideline for class B, i.e., swimmable category (BOD < 3 to 5 mg/L and *E. coli* < 1000 CFU/100 mL). To further answer "what if" questions, different scenarios without and with mitigation measures also called business as usual and scenario with measure respectively were considered.

Looking into simulated water quality from business as usual scenario, it is found that effect of both climate

Table 4 Comparative summary for observed and simulated population and average annual rainfall

Target city	Target river	Population (million) (2015)	Population (million) (2030)	Annual precipitation in mm (observed)	Annual precipitation in mm (simulated) (2030)			
				2015	MRICGCM3.2		MIROC5	
					RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Hanoi	To-Lich	6.35	6.07	1644.5	1637.4	1647.8	1638.9	1641.1
Jakarta	Ciliwung	4.17	5.76	2679.9	2656.9	2653.6	2622.8	2612.1
Manila	Pasig	8.42	10.89	2803.1	2806.8	2814.6	2568.1	2649.2
Chennai	Adyar	5.45	7.67	1652.6	1669.8	1676.3	1675.5	1678.4
Lucknow	Gomti	5.05	7.02	844.8	831.8	883.1	802	822.1
Medan	Deli	2.31	3.09	2061.6	2114.7	2139.1	2156.9	2187.1
Kathmandu	Bagmati	2.85	4.49	1454	–	–	–	–
Nanjing	Qinhuai	6.95	9.41	1106.3	–	–	–	–

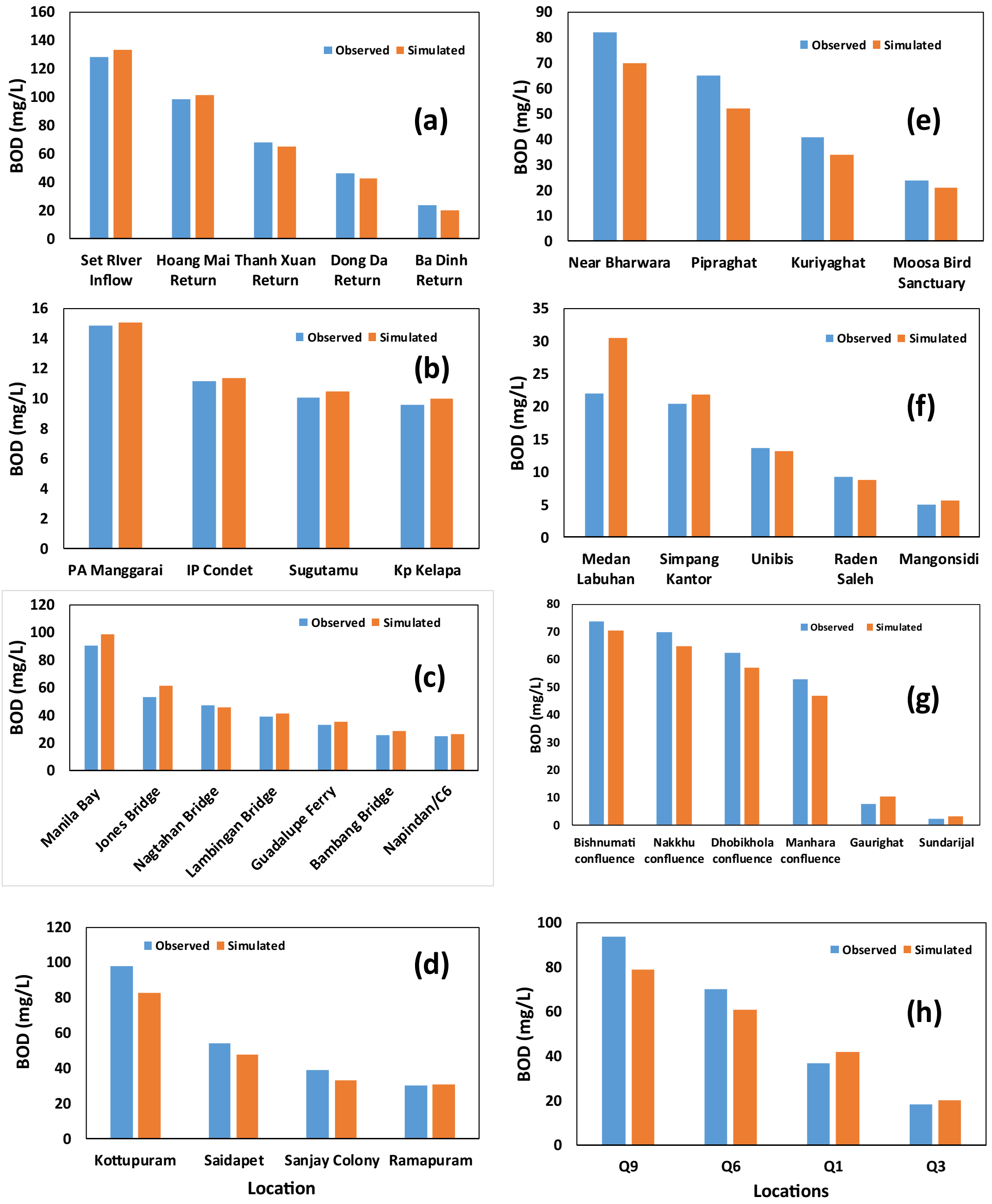
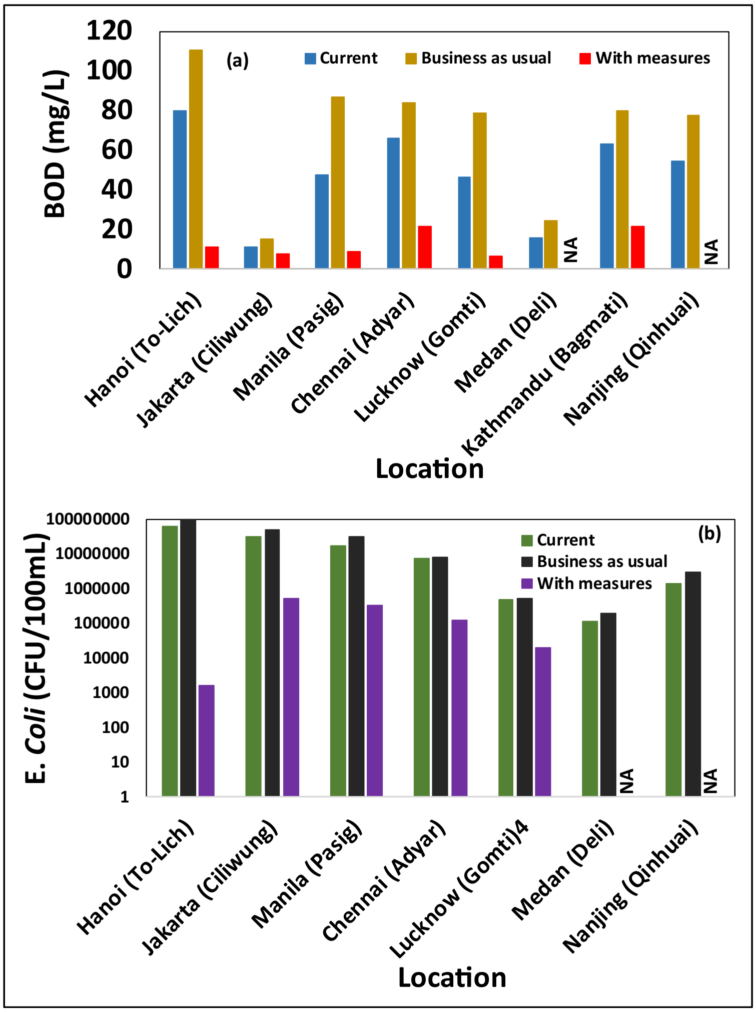


Fig. 3 Result of validation for BOD in all eight cities. **a** Hanoi, **b** Jakarta, **c** Manila, **d** Chennai, **e** Lucknow, **f** Medan, **g** Kathmandu, and **h** Nanjing

change and population changes were prominent and negative on water quality status. The quality will worsen further to extremely polluted level in 2030 when compared to the current situation. However, based on scenario with measures, two different mitigation measures as mentioned in their local master plan were considered. Firstly, whole wastewater generated locally will be collected through 100% sewerage collection rate. Second, the capacity of WWTP will be increased significantly assuming it will be enough for treating above collected wastewater as mentioned in their local master plan. It is found that with mitigation measures as suggested by the local planners and decision-makers, river water quality will improve significantly as compared to the business as usual and current situation and it almost approached the water quality class B in most of the segment of the river. These improved values of both BOD and *E. coli* in the river water for scenario with measures is an encouraging sign for both scientific communities and decision-makers involved in sustainable management of water resources in these cities. However, looking in to the simulated water quality result at spatial scale, it is observed that quality is still a matter of concern especially in the downstream area when compared with class B. The above result suggests that current management policies and near future water resources management plan are not enough to check the pollution level within the desirable limit and calls for more inclusive research considering both human and physical science together.

Finally, to get a clear picture about necessary mitigation and adaptive measures needed, effect of each individual parameter, i.e., population growth and climate change on the water quality deterioration, was investigated. It is analyzed by keeping one parameter functional, while the other parameter as constant. For example, when calculating individual effect of population growth, the value of rainfall as a representative of climate change in this case by year 2030 kept constant and vice versa. The obtained result is shown in Fig. 5, where it is very clear that population growth has way bigger contribution in water quality deterioration (with average of 83.8%) compared to climate change (with average of 16.2%). Effect of rapid population growth can be simply linked with increased release of wastewater or sewerage generation. Climate change can affect water quality

Fig. 4 **a**, **b** Simulation result for BOD and *E. coli* by year 2030 for different scenarios (edited from Masago et al. 2018)



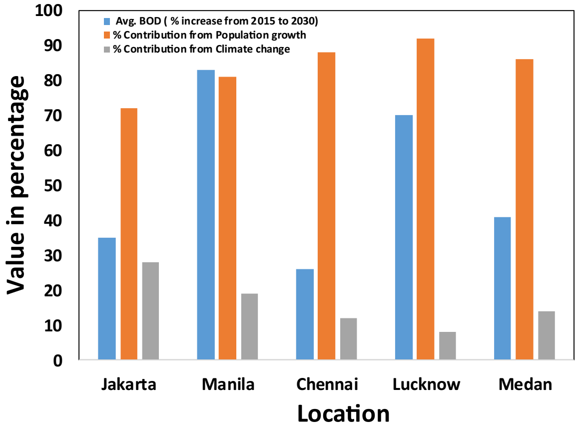


Fig. 5 Result showing individual effect of both climate change and rapid population growth on water quality deterioration

because of both kinds of extreme weather conditions, namely extended dry periods or concentrated rainy periods. Because of extended dry seasons, concentrations of pollutants in the water bodies tend to increase because of relatively higher evapotranspiration and reduction in the river discharge. On contrary, concentrated wet periods generally tend to dilute pollutant concentration and may add additional pollutants from combined sewer overflow and increased surface runoff well supported by the previous scientific findings (Alam et al. 2013; Akomeah et al. 2015).

Conclusion and recommendation

The above work tried to draw a comparative picture of water environment for current (2015) and future (2030) in eight different cities of South and Southeast Asia. The main idea behind this research work was to see how different Asian megacities are faring to achieve Sustainable Development Goals (SDGs) especially goals directly related to SDG 6 (water quality), SDG 11 (climate change adaptation), and SDG 13 (sustainable cities). Hydrological simulation result in this work has shown that water quality of the entire monitored stretch of all eight river bodies is significantly polluted when compared with swimmable class as a desirable limit recommended by the local government. Furthermore, for business as usual scenario, where no additional mitigation measures were considered for water quality improvement, the simulated water quality worsens further by the year 2030. Finally, after considering scenario with mitigation measures as mentioned in local master plan for water resources management, simulated water quality has shown much improved results, clearly indicating significance of their master plan as well as an encouraging news for the local governments. However looking carefully into the simulated water quality results especially at downstream areas of targeted river bodies, it was seen that they still does not comply with desirable water quality of class B, which means they need further attention. Some of the potential reasons behind this failure are (a) at current stage, despite the considerable capacity of existing WWTPs, the wastewater coming to these plants are not sufficient because of poor sewerage collection rate or poor connection between each household and main sewerage line. The reason behind this ranges from non-willingness to pay the connection fee by the local residents because of its expensive nature and even once it gets connected they have to pay more money in terms of water or sewerage treatment bills. (b) Lack of proper coordination between different actors/stakeholders involved in water management to implement the master plan (water infrastructure) at timely manner. The result of this study will also be helpful to guide different decision-makers/stakeholders in the target cities to develop strategies to achieving Target 6.3 (improving water quality by reducing pollution halving the proportion of untreated wastewater) and reducing water-borne diseases (Target 3.3), deaths, and illnesses from water pollution (Target 3.9).

Based on the above conclusions, the following recommendations should be taken into consideration at priority basis to address the issues of water scarcity:

1. Make urbanization and land use climate sensitive for better participatory management: Providing results and information about effect of different drivers and pressures on water quality from this kind of transdisciplinary research activities for most of the major river systems to the local people and stakeholders will be vital to taking timely decision at individual scale for rejuvenating the water bodies. These activities may include minimizing the encroachment of the river banks in your own locality, squatter settling, and illegal dumping of waste in water bodies.
2. Revising the master plan to make it more inclusive in nature: Our simulated water quality clearly has shown the effect of mitigation measures considered in local master plan which is motivating itself. However, for making this master plan more

effective in order to achieve water quality for the entire river body within the desirable range, the following measures are suggested:

- i. Consideration of all major drivers (like climate change) and pressure (like population growth and land use/land cover change) before finalizing the mitigation and adaptation measures for sustainable water management. As of now, many targeted city master plans do not consider the factor of climate change in designing mitigation measures.
- ii. Master plan should consider socio-cultural attitude and organizational normative behavior for its better operation and efficiency.
- iii. In terms of technical aspects, master plan should give a consideration to combined system of decentralized and centralized wastewater treatment because they are resource efficient and only feasible option for congested megacities where spatial setup/expansion of large wastewater treatment is nearly impossible because of scarcity of space.
- iv. Master plan should have a provision for making local people aware about sewage generation and its impact on environment as well as to provide subsidy in term of monetary help for people willing to connect their house to the main sewerage pipelines

3. Transdisciplinary working approach is the need of the hour for solving the complex issue of wastewater management: Although many factors that play a crucial role in wastewater management are intricate in nature, responsible stakeholders and institutions especially in developing Asian countries are still working in silos. This leads to inefficient use of resources (human, finance, and time) as well as delay in project completion. Henceforth, it is highly advisable to promote transdisciplinary planning including different aspects hydrological science, climate science, and human science along with governance and institution to achieve sustainable urban water environment.
4. Further refinement/improvement of the model output: In order to improve the significance of modeling out for real-world implementation, it is imperative to keep updating the model input data with every progress in the status quo of ongoing projects on wastewater infrastructure more precisely about (i) building any new wastewater plants or changing technical specification about contaminant removal efficiency of the existing plants, (ii) changing pattern in per capita water consumption, (iii) policies related to reuse and reclaim the wastewater, etc.

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