Groundwater for Sustainable Development 6 (2018) 227–234

Contents lists available at ScienceDirect

Groundwater for Sustainable Development

journal homepage: www.elsevier.com/locate/gsd

Research paper

Evaluating future stress due to combined effect of climate change and rapid urbanization for Pasig-Marikina River, Manila

Pankaj Kumar[a,*], Yoshifumi Masago[a], Binaya Kumar Mishra[a], Kensuke Fukushi[b]

[a] United Nations University, Institute for the Advanced Study of Sustainability, Tokyo, Japan
[b] Integrated Research System for Sustainability Science, University of Tokyo, Japan

ARTICLE INFO

Keywords:
BOD
DO
River pollution
Wastewater management
Water quality modeling
Manila

ABSTRACT

Considering the finite volume of fresh water resources, managing its quality and quantity sustainably is one of the greatest challenges because of complex global changes. This work strives to predict the combined effect of urbanization and climate change on water quality in Pasig-Marikina River considering its criticalities to develop proactive plan by policy makers working in water sectors. Pasig-Marikina River is an important source of water for different usage viz. domestic, industrial, agriculture and recreation in the National Capital Region (NCR) in Philippines. However, stationarity of this river basin is compromised by global changes and human disturbances viz., climate change, rapid urbanization and weak/non-structured government policies results in severe pollution, makes long section of the river unsuitable for any use in recent past. Therefore, presenting a comprehensive spatio-temporal status of river water quality using transdisciplinary framework will be valuable to guide and implement better management policies within governance structure. In this study, status of water quality of the Pasig-Marikina River was analysed for current and future timescale using population growth, land use change, wastewater production and treatment scenarios. Water Evaluation and Planning (WEAP) model was used to model river pollution scenarios using three indicators for aquatic ecosystem health viz. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD) and Nitrate (NO_3). Comparison of simulated water quality parameters for the year 2015 and 2030 with 2011 (base year) clearly indicates that the water quality at 2030 will rapidly deteriorate and will be not suitable for any aquatic life in terms of major of water quality parameters. Also, even current existing master plan for wastewater treatment plants and policies are not sufficient enough for sustainable water resource management within NCR, Philippines and hence call for immediate and inclusive action.

1. Introduction

Water is the vital natural resource with social and economic value for human being (Hanemann, 2006). Average per capita water availability is sufficient but spatio-temporal asymmetry is great (FAO, 2016). At present around the globe, more than 1.1 billion people have inadequate access to clean drinking water (Pink, 2016). On the other hand, rapid population growth, urbanization, economic development and climate change put constant and tremendous amount of pressure on water resources and their ecosystems results in severe water quality crisis and water scarcity (Alcamo et al., 2007; Saraswat et al., 2016; Mukate et al., 2017). Degradation of the urban water environment is a challenging issue in developing nations despite the adoption of a number of countermeasures (Ismail and Abed, 2013; Purandara et al., 2011). Asian economies have shown impressive growth and rapid urbanization. By 2050, more than half of Asian population (approximately 3 billion) will be living in towns and cities, particularly in secondary cities. This is roughly twice the current population of 1.6 billion. The demands on water, land, and ecosystems as resources pose significant challenges in the delivery of commodities like food, energy, and water for municipal and industrial purposes. Discussion about water in South Asia – in particular the shared rivers of the region – is vociferous, antagonistic and increasingly associated with national security. Renewable water resources in the region have fallen dramatically on a per capita basis since the 1960s and reached water stressed level for countries like India, Pakistan and Afghanistan by year 2015; whereas approaching rapidly to achieve this water stressed level in near future for many countries like Nepal, Bangladesh (Gareth et al., 2014). The expected impacts of climate change will further exacerbate the challenges facing planners and providers of such services. Delivery of sustainable water supply and sanitation services in growing towns and cities remains an issue. Considering the water stress and scarcity,

* Corresponding author.
E-mail address: kumar@unu.edu (P. Kumar).

https://doi.org/10.1016/j.gsd.2018.01.004
Received 16 October 2017; Received in revised form 9 January 2018; Accepted 10 January 2018

United Nations and its associated members unanimously called for sustainable water resource management to achieve water security through availability of sufficient water with good quality for all as the main agenda of the United Nation Sustainable Development Goals by the year 2030 (Bos et al., 2016; Jensen, 2016).

However, the recognition of water management and climate change as multidimensional and multi-scalar concerns (Downing, 2012; Meinke et al., 2009) evidence the need to integrate biophysical and social aspects looking at environmental and human contexts. In line with this, varied types of integrated modeling frameworks have been developed to address the different scales and the different dimensions of climate change, water and agriculture. Trying to better represent socio-economic issues, hydro-economic modeling has been extensively used along the last decades as a prominent tool for guiding and implementing water policy decisions (Blanco-Gutiérrez et al., 2013; Brouwer and Hofkes, 2008; Heinz et al., 2007). Mathematical models are widely used to simulate the pollution of water bodies for likely wastewater production and treatment scenarios (Deksissa et al., 2004; Frija et al., 2015). In case of countries with limited financial resources, for any water quality model to be useful, it should not be data intensive or complex to operate. The Water Evaluation and Planning model (WEAP), a decision support system of the Stockholm Environmental Institute, is widely used for integrated water resource planning and management (Sieber and Purkey, 2011). The WEAP hydrology module enables estimation of rainfall-runoff and pollutant travel from a catchment to water bodies (Ingol-Blanco and McKinney, 2013) using different scenarios. A variety of applications of WEAP for water quality modeling and ecosystem preservation have been reported previously in many studies (Slaughter et al., 2014; Assaf and Saadeh, 2008; Mishra et al., 2017).

Manila, Capital of The Philippines; is the top contributor to the national economy. Metro Manila's population is one of the largest in the Asia Pacific Region and in the world. According to a World Bank Study (World Bank, 2015), Metro Manila is the 3rd largest urban agglomerations in terms of population in East Asia, excluding China. With very high GDP growth at an average rate of 7% and uncoordinated rapid urban expansion, inadequate wastewater treatment facilities and the fragile institutional capability of the concerned agencies; a huge amount of wastewater is generated, causing deterioration of surface water resources. The other problem is the rapid change of land development (from vegetation into built-up areas) around the Pasig-Marikina River Basin area during the last three decades resulting in exaggeration in water quality deterioration and frequency of extreme weathers. So far very few studies have addressed the status of water resources and their management strategies for the near future. Considering the facts stated above, this work intends to assess the current situation and simulated future outlook with regard to pollution in the Pasig-Marikina River Basin area and ultimately aims to help formulate sustainable water resource management options for the area.

2. Study area

The Metropolitan Manila (Metro Manila), otherwise known as the National Capital Region (NCR), is located at 14°40' N and 121°3 E. It is bounded by the Manila Bay in the west, the Laguna de Bay in the southeast, the Sierra Madre Mountain Range in the east and the fertile plains of Central Luzon in the north (Fig. 1a). Located at the mouth of the Pasig River, Metro Manila is generally flat with average elevation of about 10 m on its western part. Five river systems which traverse Metro Manila are Marikina River, San Juan River, Parañaque River, Pasig River and Navotas-Malabon-Tullahan-Tenejeros (NMTT) River. Pasig River, NCR's principal river, extends from the largest freshwater lake in Southeast Asia which is Laguna Lake (Laguna de Bay), located in the south eastern part of Metro Manila. It drains at Manila Bay in the west, virtually bisecting the metropolis horizontally. It has a total length of 25 km and ends ina tidal estuary. Both the Marikina and San Juan Rivers are major tributaries of the Pasig River (Fig. 1b).

Metro Manila has a total land area of 63,600 ha, approximately 0.21% of the country's land area of 30 million hectares. Based on the 2015 census of population, Metro Manila registered a population of 12,877,253 accounts for about 15% of the national population. NCR remains to be the most densely populated region in the country. With 186 persons per hectare, NCR is more than 60 times denser than at the national level. Population density changes during ten years between 2000 and 2010 is shown in Fig. 1c and d. Metro Manila features a tropical wet and dry climate that borders on a tropical monsoon climate. Like the rest of the Philippines, it lies entirely within the tropics. The average temperature during the cold months of December to February is 26.1 °C, while that of during the hot months of March to May is 28.8 °C. It has a distinct, though relatively short dry season from January through April, and relatively lengthy wet season from May through December with an annual average precipitation 2670 mm (PAGASA, 2011).

3. Method

3.1. Basic information about model and data requirements

The WEAP model is used to simulate future total water demand and water quality variables in 2030, which will be useful for assessing alternative management policies in the Pasig-Marikina River Basin. Water quality modeling requires a wide range of input data including: point and non-point pollution sources; past spatio-temporal water quality; detail information about wastewater treatment infrastructures both currently existing and planned by 2030 from master plan (Department of Environment and Natural Resources (DENR)); demographical trend; hydro-meteorological information (Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), 2011); drainage network (Metropolitan Waterworks and Sewerage System (MWSS)); River flow-stage-width relationships; and land-use/land-cover (National Water Resource Board (NWRB)). Different hydro-climatic data (daily rainfall, air temperature, relative humidity and wind velocity) having been collected for the period spanning 1980–2016 and used for model set up. Daily average stream flow data from 1984 to 2016 measured at five stations (namely Napindan, Bambang Bridge, Nagtahan Bridge, Jones Bridge and Manila Bay at Pasig river) was utilized to calibrate and validate the WEAP hydrology module simulation. Data of important water quality indicators (BOD, NO_3 and E.Coli.) were also collected at seven different locations along the Pasig River, used for water quality modeling.

WEAP model application was developed for the Pasig-Marikina-San Juan River Basin, having seven command areas with inter-basin transfers. Hydrologic modeling requires the entire study area to be split into smaller catchments with consideration for confluence points, physiographic and climatic characteristics. The WEAP hydrology module computes catchment surface pollutants generated over time by multiplying runoff volume and concentration or intensity of different types of land use. During simulation, land use information was broadly categorized into three categories viz.: agricultural, forested, and built-up areas. Soil data parameters were identified using previous secondary data and literature (Clemente et al., 2001).

Regarding future climatic variables (rainfall frequency and intensity), statistically downscaled and bias corrected (using quantile method) general circulation model (GCM) output at the local level is used for consistent impact valuation (Elshamy et al., 2009; Sunyer et al., 2015; Kumar et al., 2017). Downscaled output has temporal resolution of 3 h and a spatial resolution of 120 km aptly suited to observed precipitation data on a daily basis. Selection of MRI-CGCM3.2 (Meteorological Research Institute, Japan) GCM precipitation output at the Napindan/C6 Gauging station was made because of its wide use and high temporal resolution compared to other climate models. This study is based on the Representative Concentration Pathway (RCP) 8.5 an

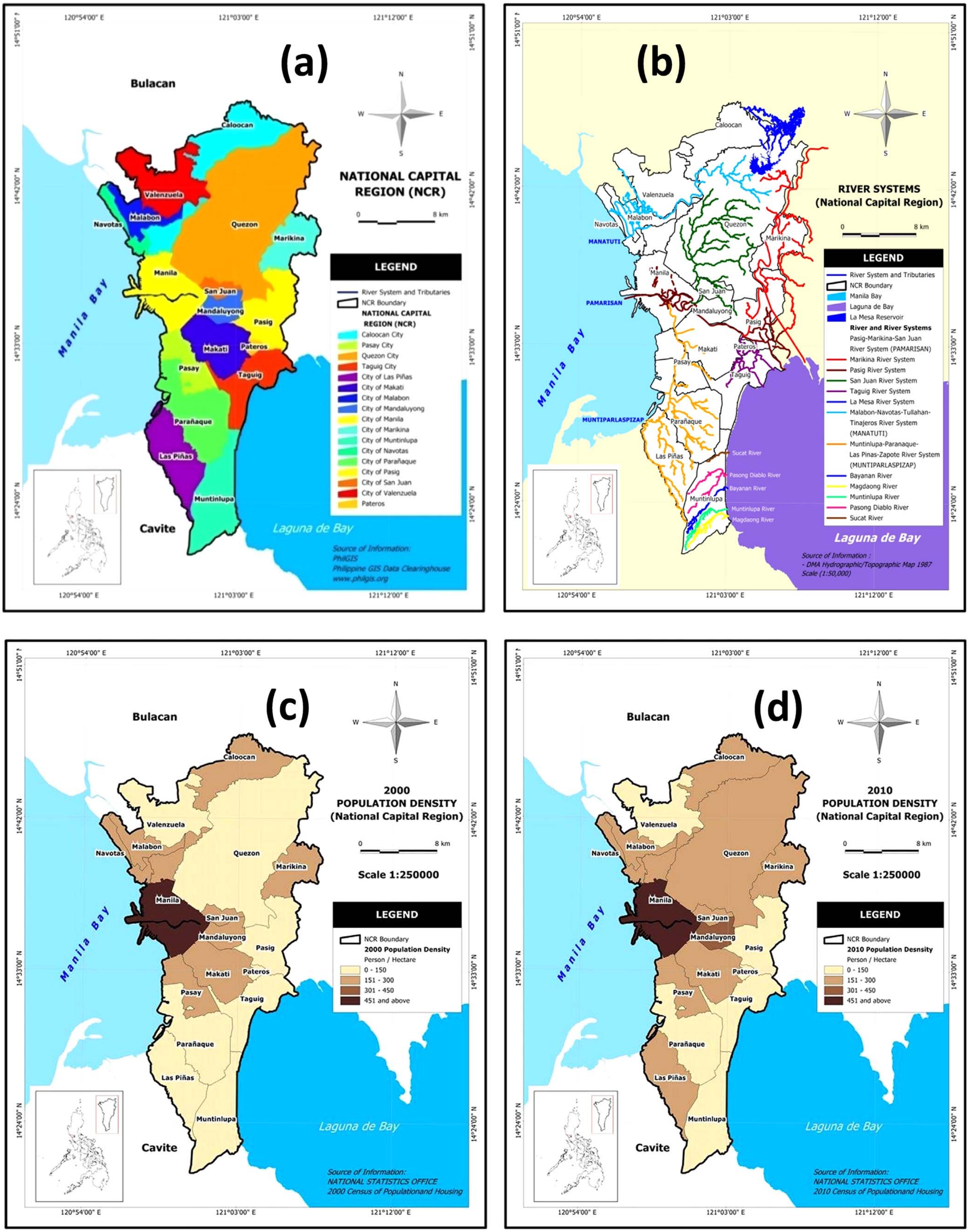

Fig. 1. Maps showing different attributes of Metro Manila (a) administrative boundary, (b) drainage pattern, (c) population in 2000 and (d) population in 2010.

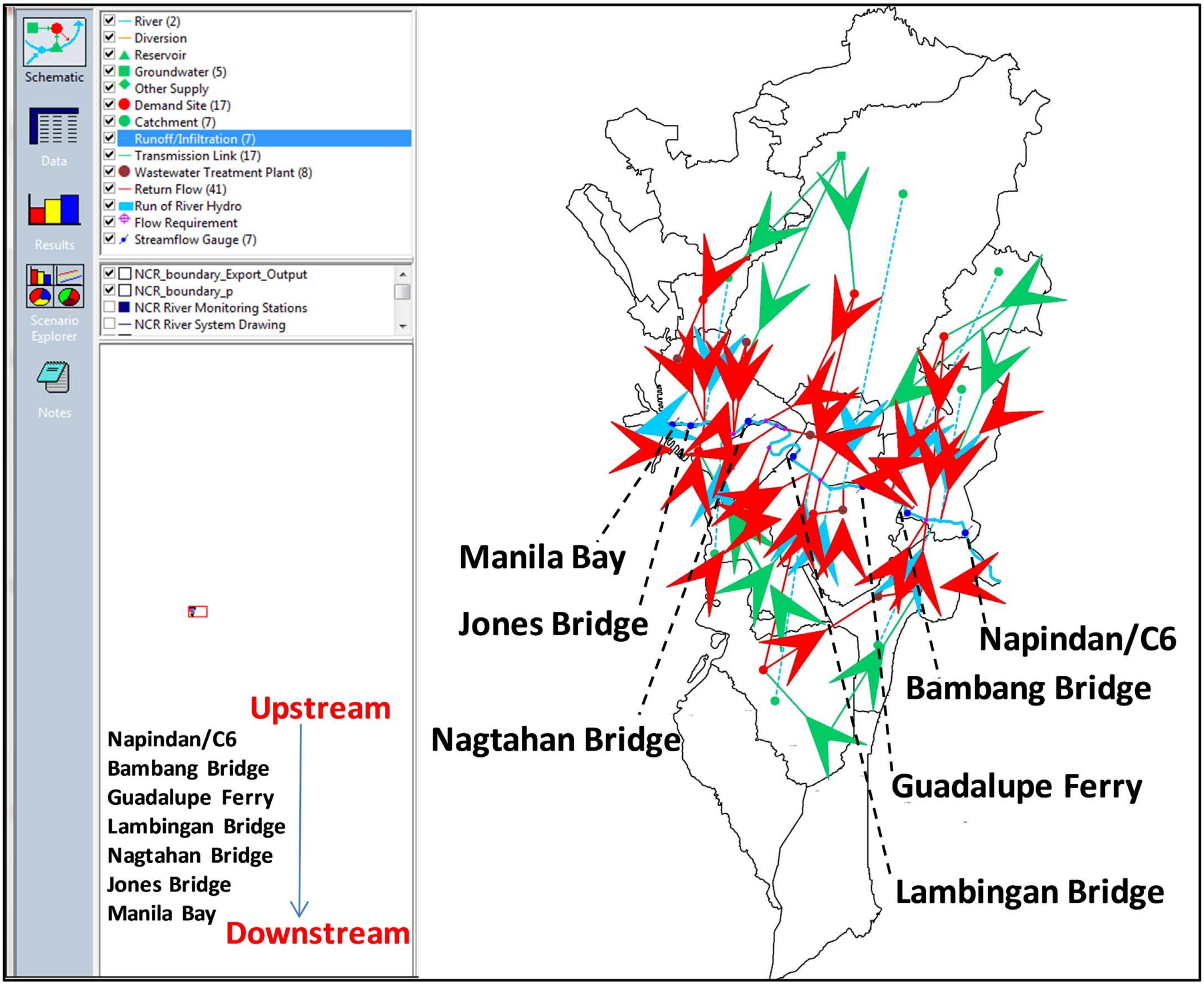

Fig. 2. Schematic diagram showing problem domain for water quality modeling in Metro Manila using WEAP interface.

extreme emission scenario, which assumes that global annual Green House Gas (GHG) emissions (measured in CO_2-equivalents) continue to rise throughout the 21st Century (IPCC. Climate Change, 2014). Here, GCM data from year 1985 to 2004 and 2020–2039 (both 20-year periods) are used for current and future (2030) climatic condition respectively.

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 (ET), 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)).

$$ET = Potentialevapotranspiration\ *(5z_1 - 2z_2^2)/3 \tag{1}$$

$$Surfacerunoff = Precipitation(P) *\ z_1^{Runoffresistancefactor} \tag{2}$$

$$Interflow = (Rootzoneconductivity\ *\ preferredflowdirection)z_1^2 \tag{3}$$

$$Percolation = Rootzoneconductivity * (1 - preferredflowdirection)*z_1^2 \tag{4}$$

$$Baseflow = Deepconductivity\ *\ z_2^2 \tag{5}$$

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 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):

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

where

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

BOD_{init} = BOD concentration at beginning of reach (mg/l), BOD_{final}

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

$$Oxygen \quad saturation \quad or \quad OS = 14.54 - (0.39t) + (0.01t^2) \tag{8}$$

$$O_{final} = OS - \left(\frac{k_d}{k_a - k_r}\right)\left(\exp^{-k_r L/U} - \exp^{-k_a L/U}\right)BOD_{init} - \left[(OS - O_{initial})\exp^{-k_a L/U}\right] \tag{9}$$

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

Similarly, simulation for Chemical Oxygen Demand (COD) and Nitrate (NO_3) is done considering intake by decaying organic and inorganic matter and reaeration induced by oxygen deficit.

3.2. Model set-up

The whole problem domain (and its different components (Fig. 2)) is divided into seven catchments, which have been further subdivided into thirteen sub-basins, to consider influent locations of major tributaries. Other major considerations are fourteen demand sites and one wastewater treatment plant to accurately represent the current situation of the study area. Here, demand sites denote domestic (population) and industrial centres defined with their attributes explaining water consumption and wastewater discharge in Pasig-Marikina River. WWTP are pollution handling facilities with design specifications including total capacity and removal efficiencies of pollutants. In this case, an upflow anaerobic sludge blanket reactor (USAB) type of wastewater treatment plant with its pollutant removal efficiency is considered in the modeling. Because of non-availability of precise data, the daily volume of domestic wastewater generation is based on an estimated 130 litres of average daily consumption per capita.

Scenario analysis is carried out by defining a time horizon for which alternative wastewater generation and management options are explored, which is 2030 in this case. The business as usual condition is represented by a reference scenario with selection of all the existing elements as currently active. Consequently, the new/upgraded WWTPs (information taken from local master plan) are modeled as scenarios representing deviations from the current conditions (reference scenario). The baseline year under the current reference scenario in this study is 2011.

4. Results and discussion

4.1. 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. 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 year of 2011–2014 in case of hydrology module validation (Table 1). Fig. 3(a) compares monthly simulated and observed stream flows at Jones Bridge, showing that they largely match for most months, with an average error of 7%. Whereas, water quality simulation part is validated by comparing simulated and observed BOD concentration at Jones Bridge location. Selection of this location and time i.e. year 2011 was made on the basis of consistent availability of observed water quality data. Results show a strong relation between these two (Fig. 3b) (with error of 8%) confirming suitability of the model performance in this problem domain.

Table 1
Summary of parameters and steps used for calibration.

Parameter	Initial Value	Step
Effective precipitation	100%	± 0.5%
Runoff/infiltration ratio	50/50	± 5/5

4.2. Scenario analyses

Future simulation for both, water quality of selected parameters and total water demand was done for the years 2015 and 2030, while utilising scenarios considering business as usual and involving possible countermeasures to solve water scarcity in future course of time. The results for total water demand are shown in Fig. 4, depicts that yearly water demand for the year 2030 will be around 1.34 billion cubic meters, which is roughly 2.5 times greater than that of the year 2000 i.e. 0.55 billion cubic meters. Sharp deviation of this increasing trend between year 2007 and 2010 might be explained by rapid migration to Metro Manila and relatively more construction activities. Overall, this swift growth in water demand encourage different stakeholders to take suitable measures on immediate basis to provide sustainable water management options for future generations.

For water quality, simulation is done using three possible scenarios as shown in Table 2. Simulation was done for the years 2015 and 2030 using 2011 as reference year with consideration for population increase, land use change, wastewater generation and its treatment at waste water treatment facilities. First, business as usual (denoted hereafter from S1), where effect of population growth and climate change using MIROC5, RCP 8.5 on water quality is observed keeping the capacity of all the existing wastewater treatment plants (65 MLD) constant by year 2030. Second scenario (denoted hereafter from S2), here effect of population growth and climate change using MIROC5, RCP 8.5 on water quality is observed once existing master plan for increasing wastewater treatment plants (625 MLD) is implemented along with sewerage collection rate of 85%. It means 15% of the sewerage is getting lost as non-revenue water because of leakage or other technical issues. While for final and third scenario (denoted hereafter from S3), all conditions were kept same as second scenario except wastewater collection rate increased to 100% considering ideal situation.

Results for simulated water quality using three parameters (namely NO_3, BOD and COD) is shown in Fig. 5. Based on the water quality parameters, a general trend found here is that water quality deteriorates from upstream to downstream because of the cumulative addition of anthropogenic output. Also, when comparing the current water quality situation of Pasig River with desirable water quality standard given by Department of Environment and Natural Resources (DENR) for Class C i.e. Fishable Class (i.e. BOD < 7 mg/L, NO_3- 7 mg/L), it is found that most of the sampling location are not suitable for the use in many sectors. More precisely, most water samples were safe for aquatic systems in terms of NO_3 except those taken from the Manila Bay and Jones Bridge location. The value for BOD varies from 30 to 146 mg/L, clearly indicating that all of the water samples are moderately to extremely polluted with reference BOD required value to safe aquatic system i.e. 7 mg/L (World Health Organization, 2002). The COD value, a commonly used indicator of both organic and inorganic nutrients in water samples, increases with the course of time. In scenario 1, concentration of water quality got even worse compared to current condition. This may be attributed to extreme weather condition coupled with additional amount of wastewater being generated by increasing population and rapid urbanization.

Result from scenario 2 and 3 intends to show the water quality status quo of the river system when current existing master plan for wastewater treatment will be implemented with different collection rate. Result clearly indicates that after implementing master plan for

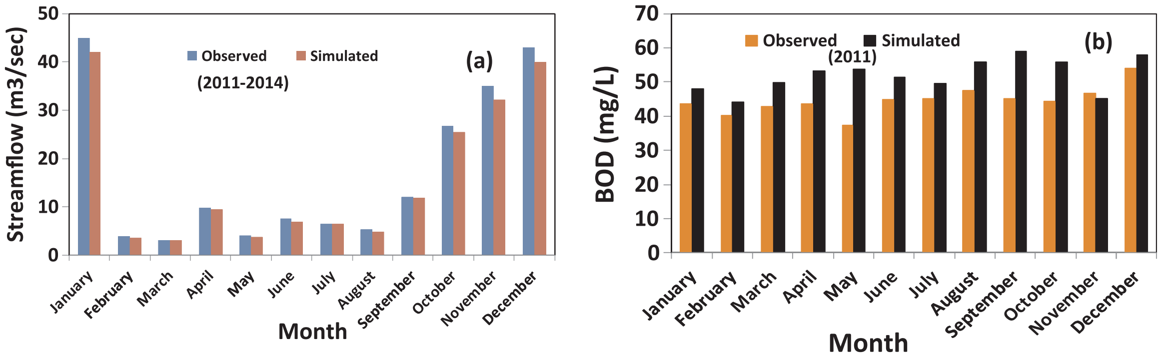

Fig. 3. Validation of the model output by comparing simulated and observed (a) average monthly river discharge for year 2011–2014; (b) BOD values for year 2011 at Jones Bridge.

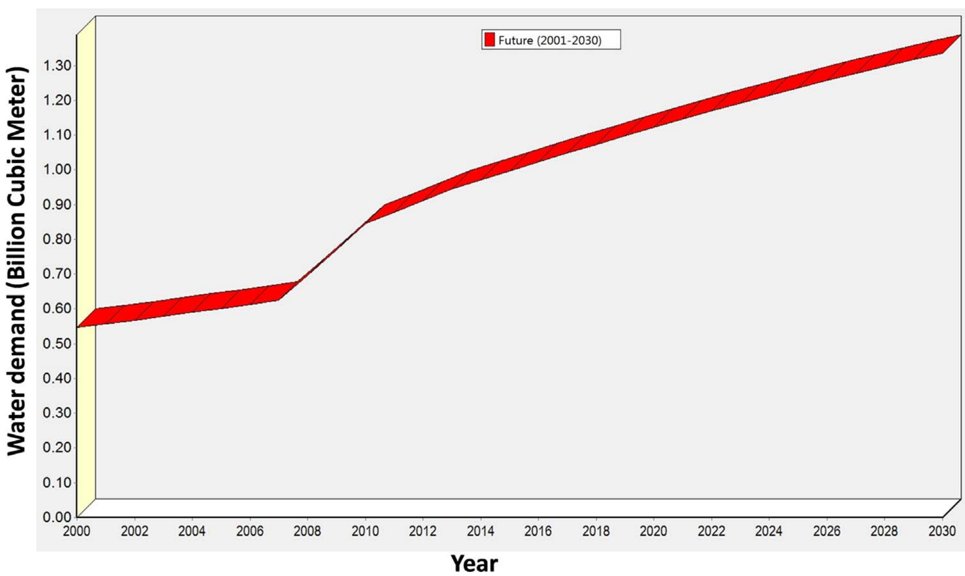

Fig. 4. Simulation results for total water demand in the study area, which clearly indicate rapid increase in water demand because of urbanization and population burst.

Table 2
Summary of all the criteria considered for different scenarios in future water quality simulation.

Scenario	Components
Scenario 1 (2030_S1)	Climate change + population growth + WWTP of 65 MLD
Scenario 2 (2030_S2)	Climate change + population growth + WWTP of 625 MLD (85% collection rate)
Scenario 3 (2030_S3)	Climate change + population growth + WWTP of 625 MLD (100% collection rate)

enhancing the capacity of wastewater treatment facility by 625 MLD, water quality will improve by many folds, which is an encouraging sign. Average removal achieved after this implementation for BOD, NO_3 and COD are 83.7%, 80% and 91.4% respectively. However, looking into water quality guidelines by DENR, many of the location especially along the downstream will not comply with guidelines for Class C (Fishable). Higher concentration of nitrate indicates the influence from high usage of fertilizers in agricultural activities, microbial colonies from faecal matters, untreated sewerage input and animal waste. However, with business as usual, water quality will be deteriorating at other locations as well. This suggests that current management policies are not enough to keep the pollution level in check within a desirable limit and calls for transdisciplinary research for sustainable water resource management.

5. Conclusions

This research work briefly sketches the trend of water quality and quantity of Pasig-Marikina River system in Metro Manila. Strong association between observed and simulated hydrological parameters clearly indicates suitability of WEAP model for the study area. Projection for increased water demand encourages different actors involved in water resources management for switching towards different viable options viz. water reuse, water recycling, technical advancement in supply system for minimizing non-revenue water loss etc. From water quality simulation, it is observed that Pasig-Marikina River is polluted with certain degree throughout the stretch of the River and condition getting worse in future course of time with business as usual scenario. With enhancing wastewater management infrastructure as represented by scenario 2 & 3, water quality will improve at most of the segment of the river except at downstream site which mean existing water management plan is not sufficient and is a matter of concern. Therefore, improved regulation of wastewater treatment and sectoral water usage practice based on water quality should be put in place to preserve precious water resources. The national integrated sewerage and septage management program shall be implemented on priority basis, considering various factors like population density and growth, global changes for both short and long term measures. Policy advocacy with regulators to enforce pre-treatment for non-resident wastewater sources. Regular monitoring for progress of implementation of master plan is highly recommended. Proper roadmap for operation and maintenance for infrastructure built up during 2030 will be highly recommended.

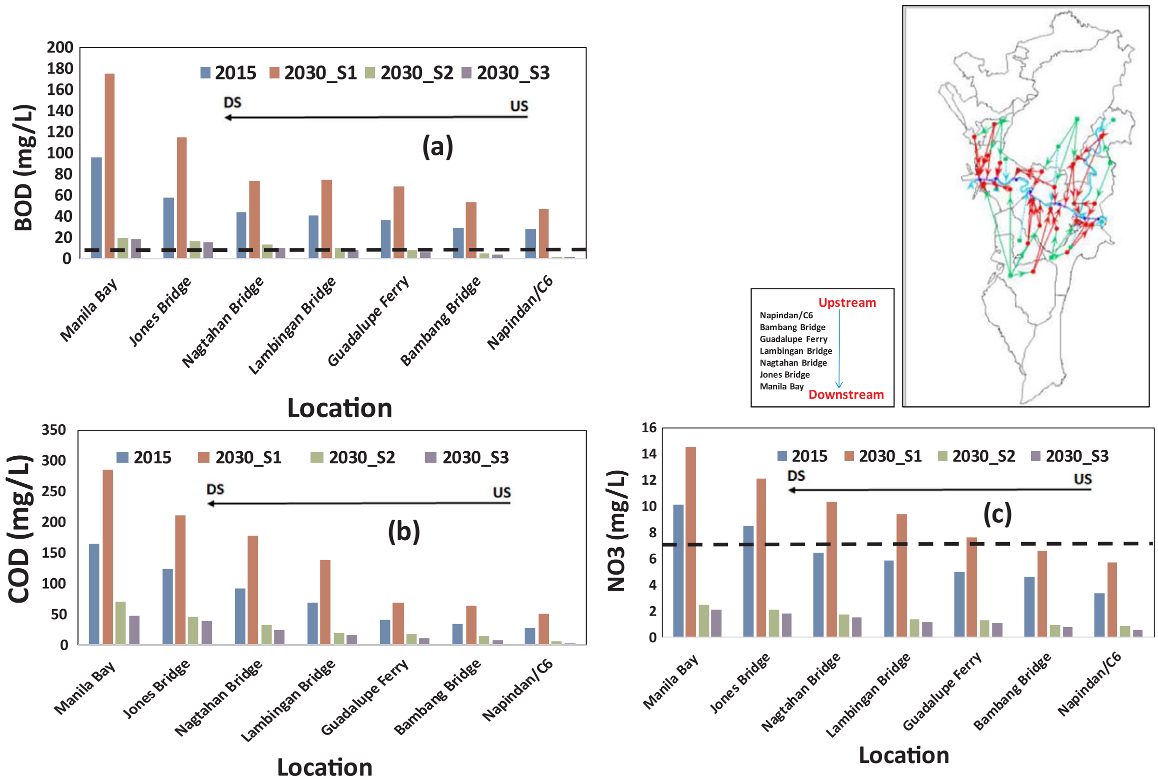

Fig. 5. Simulation results of annual average value for BOD, COD, and NO3 at seven different locations in the study area under three different scenarios. (here, 2015- water quality status for year 2015; 2030_S1- business as usual scenario with observing effect of climate change and population without upgrading wastewater infrastructure as mentioned in master plan; 2030_S2- scenario with upgradation of wastewater infrastructure after implementation of actual master plan on the top of 2030_S1; and 2030_S3- scenario considering ideal situation with upgraded wastewater infrastructure and 100% sewerage collection rate on the top of 2030_S1. Also, DS and US represents downstream and upstream respectively.).

Acknowledgments

The authors would like to acknowledge support by the Water and Urban Initiative (WUI) project of the United Nations University and the Institute for the Advanced Study of Sustainability (UNU-IAS) for financial and other logistic support in conducting this research.

References

Alcamo, J., Flörke, M., Märker, M., 2007. Future long-term changes in global water resources driven by socio-economic and climatic changes. Hydrol. Sci. J. 52 (2), 247–275.

Assaf, H., Saadeh, M., 2008. Assessing water quality management options in the upper Litani Basin, Lebanon, using an integrated GIS-based decision support system. Environ. Model. Softw. 23, 1327–1337.

Blanco-Gutiérrez, I., Varela-Ortega, C., Purkey, D.R., 2013. Integrated assessment of policy interventions for promoting sustainable irrigation in semi-arid environments: a hydro-economic modeling approach. J. Environ. Manag 128, 144–160.

Bos, R., Alves, D., Latorre, C., Macleod, N., Payen, G., Roaf, V., Rouse, M., 2016. Manual on the Human Right to Safe Drinking Water and Sanitation for Practitioners. IWA Publications, pp. 120 (ISBN:9781780407432).

Brouwer, R., Hofkes, M., 2008. Integrated hydro-economic modelling: approaches, key issues and future research directions. Ecol. Econ. 66, 16–22.

Clemente, R., Guillermo, S., Tabios, Q., Ramon, P., Abracosa, C., David, C., Inocencio, A.B., 2001. Groundwater supply in Metro Manila: distribution. Environ. Econ. Assess. Philipp. Inst. Dev. Stud (Discussion Paper Series No. 2001-06).

Deksissa, T., Meirlaen, J., Ashton, P.J., Vanrolleghem, P.A., 2004. Simplifying dynamic river water quality modelling: a case study of inorganic dynamics in the Crocodile River, South Africa. Water Air Soil Pollut. 155, 303–320 (N).

Downing, T.E., 2012. Views of the frontiers in climate change adaptation economics. WIREs Clim. Chang. 3, 161–170.

Elshamy, M.E., Seierstad, I.A., Sorteberg, A., 2009. Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios. Hydrol. Earth Syst. Sci. 13, 551–565.

FAO, 2016. AQUASTAT Main Database. Food and Agriculture Organization of the United Nations, FAO.

Frija, A., Dhehibi, B., Chebil, A., Villholth, K.G., 2015. Performance evaluation of groundwater management instruments: the case of irrigation sector in Tunisia. Groundw. Sustianble Dev. 1,1,2, 23–32.

Gareth, P., et al., 2014. Attitudes to Water in South Asia. Chatham House Report. Chatham House. The Royal Institute of International Affairs, UK. Vinset Advertising, New Delhi, India, pp. 114.

Hanemann, W.M., 2006. The economic conception of water. Water Crisis.: Myth Real. 61–91.

Heinz, I., Pulido-Velazquez, M., Lund, J.R., Andreu, J., 2007. Hydro-economic modeling in river basin management: implications and applications for the European Water Framework Directive. Water Resour. Manag. 21, 1103–1125.

Ingol-Blanco, E., McKinney, D., 2013. Development of a hydrological model for the Rio Conchos Basin. J. Hydrol. Eng. 18 (3), 340–351.

IPCC. Climate Change, 2014. In: Team, Pachauri, R.K., Meyer, L.A. (Eds.), Synthesis Report. In Contribution of Working Groups I; II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change; Core Writing 2014. IPCC, Geneva, Switzerland, pp. 151.

Ismail, A.H., Abed, G.A., 2013. BOD and DO modeling for tigris river at Baghdad city portion using QUAL2K model. J. Kerbala Univ. 11 (3), 257–273.

Jensen, O., 2016. Public–private partnerships for water in Asia: a review of two decades of experience. Int. J. Water Resour. Dev. 1–27.

Kumar, P., Masago, Y., Mishra, B.K., Jalilov, S., Rafiei Emam, A., Kefi, M., Fukushi, K., 2017. Current assessment and future outlook in lieu of climate change and urbanization: a case study of Ciliwung River, Jakarta city, Indonesia. Water 9 (6), 410. http://dx.doi.org/10.3390/w9060410.

Meinke, H., Howden, S.M., Struik, P.C., Nelson, R., Rodriguez, D., Chapman, S.C., 2009. Adaptation science for agriculture and natural resource management—urgency and theoretical basis. Curr. Opin. Environ. Sustain 1, 69–76.

Mishra, B.K., Regmi, R.K., Masago, Y., Fukushi, K., Kumar, P., Saraswat, C., 2017. Assessment of bagmati river pollution in Kathmandu Valley: scenario-based modeling and analysis for sustainable urban development. Sustain. Water Qual. Ecol. http://dx.doi.org/10.1016/j.swaqe.2017.06.01.

Mukate, S., Panaskar, D., Wagh, V., Muley, A., Jangam, C., Pawar, R., 2017. Impact of anthropogenic inputs on water quality in Chincholi Industrial area of Solapur, Maharashtra, India. Groundw. Sustain. Dev. http://dx.doi.org/10.1016/j.gsd.2017.11.001.

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), 2011. Climatological Normals: Rainfall Normal Values (mm) 1981–2010. ⟨http://pagasa.dost.gov.ph/index.php/climate/climatological-normals⟩. Downloaded on December 2014.

Pink, R.M., 2016. Introduction. In Water Rights in Southeast Asia and India. Palgrave Macmillan, US, pp. 1–14.

Purandara, B.K., Varadarajan, N., Venkatesh, B., Choubey, V.K., 2011. Surface water quality evaluation and modeling of Ghataprabha River, Karnataka, India. Environ. Monit. Assess. 184 (3) (1371-8).

Saraswat, C., Kumar, P., Mishra, B.K., 2016. Assessment of stormwater runoff management practices and governance under climate change and urbanization: An analysis of Bangkok, Hanoi and Tokyo. Environ. Sci. Policy 64, 101–117.

Sieber, J., Purkey, D., 2011. Water Evaluation And Planning (WEAP), User Guide. Stockholm Environment Institute, USA (Accessed 01 April 2014).

Slaughter A.R., Mantel S.K., Hughes D.A., 2014. Investigating possible climate change and development effects on water quality within an arid catchment in South Africa: a comparison of two models, In: Ames, D.P., Quinn, N.W.T., Rizzoli, A.E. (Eds.), Proceedings of the 7th International Congress on Environmental Modelling and Software, June 15-19, San Diego, California, USA. ISBN: 978-88-9035-744-2.

Sunyer, M.A., Hundecha, Y., Lawrence, D., Madsen, H., Willems, P., Martinkova, M., Vormoor, K., Bürger, G., Hanel, M., Kriauciuniene, J., et al., 2015. Inter-comparison of statistical downscaling methods for projection of extreme precipitation in Europe. Hydrol. Earth Syst. Sci. 19, 1827–1847.

World Bank, 2015. East Asia's Changing Urban Landscape: Measuring a Decade of Spatial Growth. Urban Development Series. World Bank, Washington, DC. http://dx.doi.org/10.1596/978-1-4648-0363-5. (License: Creative Commons Attribution CC BY 3.0 IGO).

World Health Organization, 2002. Global Water Supply and Sanitation Assessment 2002 Report. WHO and UN Children's Fund, New York.