Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
e-ISSN: 2395-3454
Vol. 17 | No. 4 | pp. 1219-1225 | 2018

Original Research Paper | Open Access

Evaluation of Urban Water Balance Using Decision Support System of Varanasi City, India

Satya Prakash Maurya†, Anurag Ohri and Prabhat Kumar Singh
Department of Civil Engineering, Indian Institute of Technology, Banaras Hindu University, Varanasi-221 005, India
†Corresponding author: Satya Prakash Maurya

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 07-11-2017
Accepted: 09-04-2018

Key Words:
Wastewater reuse
Wastewater treatment
Urban water balance
Urban sustainability

ABSTRACT

Degradation of freshwater resources has become a major issue of this century in many parts of the world. In order to ensure urban sustainability, decision support system (DSS) is a useful tool to help in water balance and to predict the various scenarios according to the scope of reuse. In the present paper, a framework for decision support system for urban water balance (DSSUWB) has been proposed. A graphical user interface (GUI) has been developed incorporating seven wastewater treatment technologies (WWTT) with six treated wastewater reuse options and two disposal options. The developed system has been validated using available data for Varanasi city (Uttar Pradesh, India). The indicative results suggest that the annual groundwater extraction is 89.1 MCM and annual water balance is estimated as -100.4 MCM which is too low. However, forecasted demand for the next 15 years will be increasing significantly by 37%. The estimated annual storm water of 55.3 MCM and untreated wastewater of 73 MCM requires a proper management which may contribute to help in future water balance. Three scenarios were considered for water reuse, which show that if water reuse capacity increased to 20%, 30% and 50%, then the water balance will improve by 32.9%, 49.27% and 82.12% and water extraction will reduce by 24.1%, 36.14% and 59.10% respectively. Hence, wastewater treatment technology selection has to be made considering the potential of reuse and there is requirement of separate infrastructure for storm water within urban boundary.

INTRODUCTION

Sustainability is a broad term used in society, but its accountability increases when context focuses to natural resource management. The concept of sustainability was introduced in late 80's. However, its implication is still not applicable to society directly due to lack in planning framework. In the continuation of natural resource management, water scarcity has been increasing worldwide and many countries may become absolute water scarce by the year 2025 (Seckler et al. 1999). In India, the available water is already under stress condition and will continue depleting (Table 1). There is different perception about objectives of watershed management in developed and developing countries. Developed countries usually focus on environmental concerns, while developing countries focus on resources generation and their management.

In urban setup, apart from continuous increasing demand of freshwater with increase in population and advancement of infrastructure, wastewater is also becoming the major problem in the urban sustainability, which is also affecting the environment and human health. To solve the problem, several measures for sustainable water resource utilization have been developed, while wastewater reclamation is currently one of the top priorities. Total water cycle management (TWCM) was termed for planned use of water in urban areas including several components, i.e. water demand and supply, storm water management, wastewater generation, treatment and reuse of wastewater (Chanan & Wood 2006). The degree of system centralization, overall balance, potential of rainfall, storm water and wastewater to offset current demand and water cycle rate are the major quantitative performance indicators (Kenway et al. 2011). A linear programming based model is proposed to examine trade-offs among wastewater reuse, supplies and demands as well as the related costs and profits. This model was tried to apply over 342 cities of China, but it could not be validated properly due to unavailability of adequate data (Chu et al. 2004). The challenge of water management at micro level is to make reliable assessment of water demand and its availability with less available data. However, an attempt has been made for wastewater management plan to meet future demands for wastewater treatment maintaining the water quality standards for water bodies within the Jaipur city (Dass et al. 2014).

Sustainable and optimal allocation of water maximizes the net economic benefit over term planning horizon (Bouguerra 2007). A comprehensive, complete and quantitatively defined problem analysis including alternative strategies for solving problems can be evaluated (Kumar & Singh

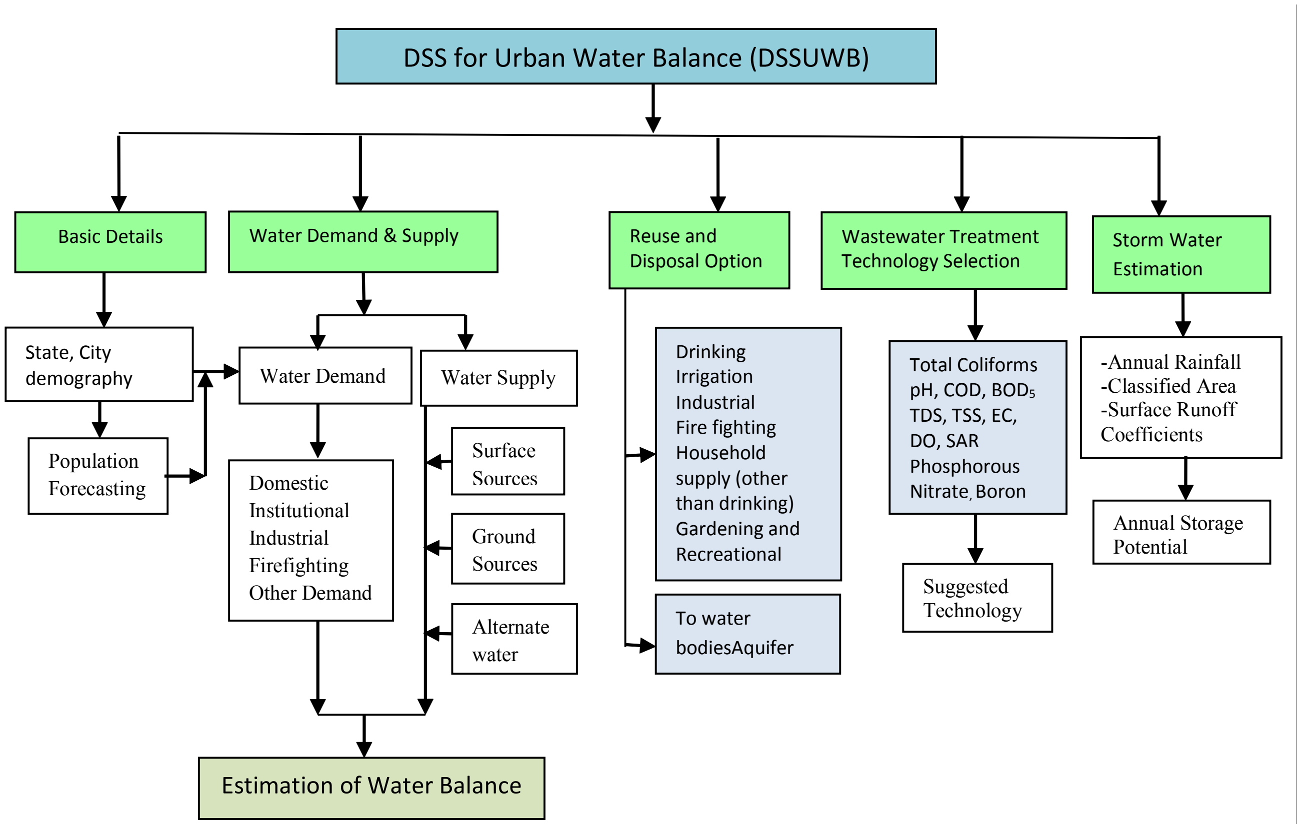

Fig. 1: Proposed framework for urban water balance.

2003). In addition, some objectives like demand-supply equilibrium and economic efficiency can be achieved by using multi-criteria decision making in order to retain the sustainability (Rousta &Araghinejad 2015).

DECISION SUPPORT SYSTEM FOR URBAN WATER BALANCE (DSSUWB)

The idea of integrating all aspects of water is to balance the urban water cycle in which demand can also be fulfilled by alternative sources rather than only freshwater sources. Thus, it results reduction in present freshwater consumption for an urban region. The framework proposed for the urban water balancing has several modules termed as Basic Details, Water Demand & Supply, Reuse & Disposal Options, Wastewater Treatment Technology Selection and Storm Water Management (Fig. 1). The system design for the proposed framework needs various data and criteria which are discussed below in detail.

Basic Details

It is the module in which details of the urban area are required through which the analysis of urban water balancing starts. The present population data (domestic demand) and other different demands (institutional, industrial and firefighting) data are required to calculate total water demand of the city. Zone map, pumping locations and land use map may be provided by the administrator for the detailed planning of city on the local level.

Water Demand and Supply

This module helps to estimate the urban water demand and supply. Demand is calculated considering five major categories, i.e. domestic, institutional, industrial, firefighting and other demands (if any).

In urban region, supply is done through conventional sources, i.e. surface water source and groundwater source. But the depleting freshwater sources compel to rethink over other available source which is termed as alternative water (i.e. reclaimed water and storm water). Storm water needs to be considered for surface water augmentation and groundwater enrichment through rainwater harvesting. Reclaimed water may be useful in reuse and direct augmenta-

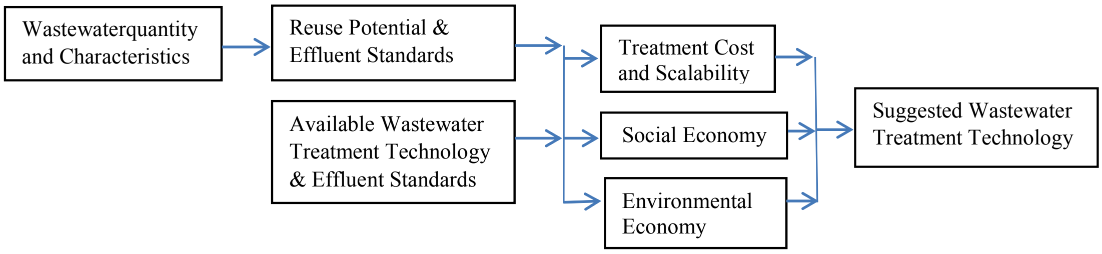

Fig. 2: System design for the decision support of wastewater treatment technology selection.

tion in surface water and groundwater (through artificial recharge). The overall process of demand and supply will help to evaluate the water balance of the area.

Reuse and Disposals Options

Reclamation of water is categorized as conventional reuse practices (drinking, irrigation, industrial, firefighting, household supply other than drinking, gardening and recreational), two disposal options, one is discharged to water bodies and other is artificial aquifer recharge through soil aquifer treatment (SAT) method. Based on the different type of reuses, physico-chemical standards are given by relevant government agency/regulatory department.

Wastewater Treatment Technology Selection

This module has functionality to select efficient treatment technology selection based on urban reuse potential and required quantity of treatment. Seven frequently practiced technologies for treatment of wastewater namely wastewater stabilization pond (WSP), trickling filter (TF), up-flow anaerobic sludge blanket (UASB), activated sludge process (ASP), moving bed biofilm reactor (MBBR), sequence batch reactor (SBR) and reverse osmosis (RO) were added in the module. Their different costs viz. capital cost, land requirement, operation and maintenance (including annual energy cost, chemical cost, repair cost and manpower cost) and observed removal efficiency to required physico-chemical parameters have been considered for technology comparison. In Fig. 2, process framework is defined for the selection of appropriate wastewater treatment technology.

Storm Water Management

Storm water management is a typical practice as it requires infrastructure according to its implementation. The annual surface runoff is to be calculated for centralized/decentralized collection scheme. In this framework, six land use classes as built-up, sub-urban, playground and parks, open space, agriculture, forests with their respective runoff coefficients (built-up 0.95, sub-urban 0.45, open space 0.50, playground and parks 0.30, agriculture 0.60, forests 0.15) and annual rainfall are considered for calculation (Shakya et al. 2016).

Data and Methodology

SUWM includes various data for the implementation of the system. Primarily, we focused on city population as water demand (per capita consumption) is directly dependent on it and wastewater generation (with factor of 0.7 to 0.9 to total demand); moreover forecasting of population and water demand requires previous decade's population for wastewater quantity prediction. Total water demand is calculated by addition of domestic demand, institutional demand, industrial demand and other demand (if any). Water supply needs quantity of water extraction from surface

Table 1: Per capita water availability in India.

Reference	Year	Population (millions)	Per capita water availability (m^3/year)
Government of India, Ministry of water resources (2009)	1951	361	5177
	1955	395	4732
	1991	846	2209
	2001	1027	1820
	2025	1394	1341
	2050	1640	1140
Central Water Commission, India (2010)	2010	1206	1588
Government of India, Ministry of Water Resources (2012)	2011	1221	1545

Table 2: Zone wise total water demand in Varanasi city during study.

Name of Zone	Domestic Water Demand (MLD)	Institutional Demand (MLD)	Industrial Demand (MLD)	Total Water Demand (MLD)
District1	68.8	4.6	0.0	73.5
District 2A	79.0	10.8	0.0	89.9
District 2B	14.2	0.6	0.0	14.8
District 2C	16.4	0.7	0.0	17.0
District 2NSA2	4.6	0.4	0.0	4.9
District 2NSA1	7.0	0.6	0.0	7.6
District 2FSA1	3.5	0.1	0.0	3.6
District 3	13.9	2.7	0.0	16.6
FSA4	9.2	0.4	0.0	9.6
District 4 FSA2	14.3	2.2	4.0	18.5
District 4 FSA2	12.3	0.0	2.0	14.3
Total	243.3	23.0	6.0	272.3

source, pumping from ground source and water loss rate. Wastewater treatment technology selection is based on reuse potential of the city and could be done by comparing various costs incurred during wastewater treatment plant setup and its functioning.

Storm water is estimated over annual rainfall using six different classes of land use and land cover, namely built-up, sub-urban, open space, parks and gardens, agriculture, and forests. Breakthrough of city area among different classes are evaluated by image classification, i.e. built-up 71%, sub-urban 17%, open space 4%, agriculture 7.2%, parks and playgrounds 0.5% and forest 0.3%. The annual storage calculation based on method:

Annual storage potential (m^3) = $\sum$ Annual rainfall (mm) × area of individual class × runoff coefficient of individual class × 10^{-6}.

For the wastewater treatment, reuse potential of city is needed and on the basis of reuse selection, the technology will be suggested with their respective costs and treatment efficiency. Here, the data of reuse classes from A to E of Central Pollution Control Board, India are considered for system validation and technologies list are considered on the basis of treatment technologies used recently in Indian scenario provided by the government reports (CPCB 2008).

System design (Fig. 2) of treatment technology selection is a three step process in which the first step needs characteristics and quantity of the generated wastewater. Then the second step consists the details of treatment technology, reuse potential and the expected treated effluents standards. In the third step we get the suggested wastewater treatment technologies and the overall evaluation of sustainability on the basis of several criteria. In the intermediate step, expert views are required to get the final results.

Table 3: Contribution of surface water and ground water in water supply scheme in Varanasi City.

Type of Water Supply	Source of Water Supply	Water Supplied (MLD)
Ground Water Supply	Tube wells(140)	146.3
Surface Water Supply	River Ganga	131.6
Total Water Supply	Ground Water + Surface Water	277.8

Treatment technology selection needs decision making tool as the treatment technology costs (Castillo et al. 2016) and the wastewater characteristics, reuse potentials in and around the particular urban area due various sustainability indicators are multitudinous in nature (Balkema et al. 2002). In such complex problems, multi criteria decision making (MCDM) approach may be applied for further optimization, but here we are more concerned about the conceptual framework rather than optimum technology selection, thus we considered only economic constraints and scalability factor.

RESULTS AND DISCUSSION

In water perspective, Varanasi city (total area 82.1 km^2, 1.62 million population) is divided into 11 zones (Uttar Pradesh Jal Nigam) (Fig. 3). Estimated water demand for year 2015@150 LPCD using developed model is 272 MLD which includes 243 MLD of domestic, 23 MLD of institutional, and 6 MLD of industrial demand (Table 2). Supply is calculated as 277 MLD in which 146 MLD is through groundwater source (140 tube wells) and remaining 131 MLD through surface source (river Ganges) (Table 3). It shows that there is surplus supply of 5 MLD water and expected return wastewater should be 221.6 MLD. Wastewater observed in the city is 300 MLD reported by JICA (2005) considering water supply @185 LPCD. Thus, through back

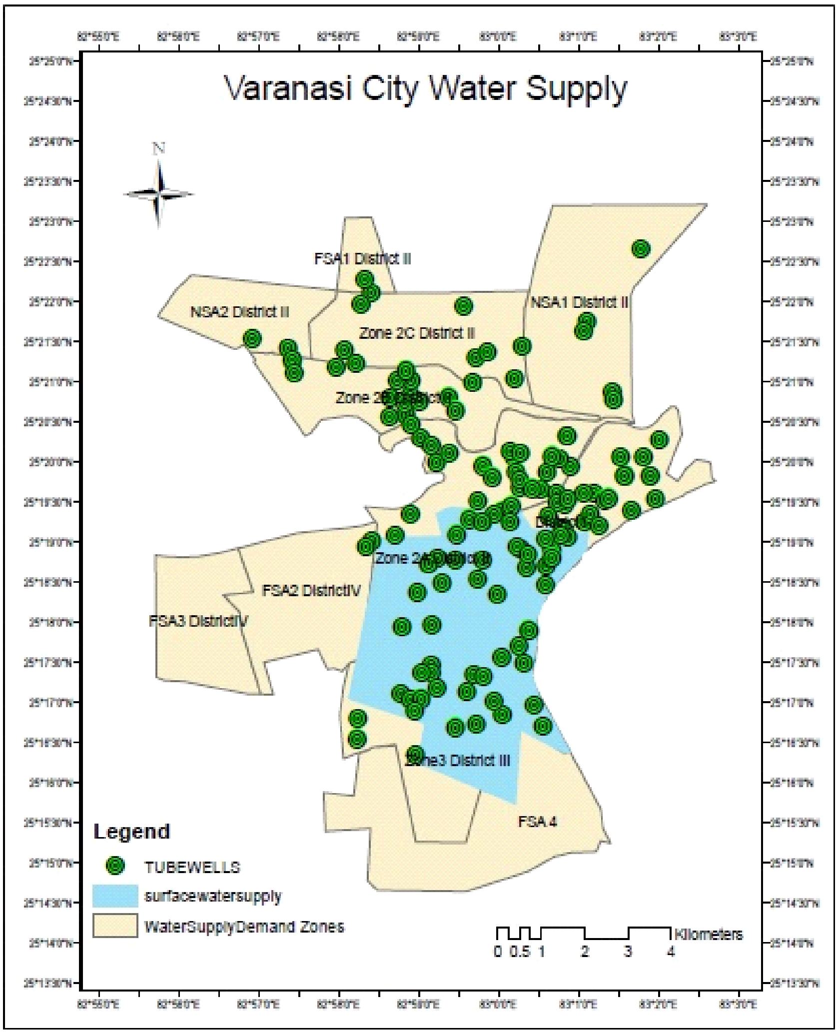

Fig. 3: Contribution of surface and ground water in existing water supply scheme of study area.

calculation, total water consumption must be 375 MLD which is much more than the present demand.

This difference is observed due to over consumption of 98 MLD of water through private pumping. Presently, 100 MLD out of 300 MLD total wastewater (80MLD Dinapur, 12 MLD DLW and 8 MLD Bhagwanpur) is being treated using ASP technology and remaining 200 MLD wastewater is discharged into Varuna river and Ganges river through open drains. The reuse and disposal options of treated wastewater are identified as irrigation and discharge to Ganges. Designed system suggests that WSP, TF and ASP are the best three technologies for wastewater treatment for irrigation and discharge to water bodies. However, preference could be given to ASP over WSP and TF by considering the unavailability of space in the city and efficiency respectively. JICA report and prediction of designed model forecasted increment of 37% in the domestic water demand by 2030 (JICA 2005). The supply side is already facing water stressed situation which compel to find the alternative water resources.

The annual storm water storage potential estimated based on six classes of land use and land cover classification and annual rainfall (828 mm) is 55.41 MCM. Annual pumping of water through ground source and surface source is 53.3 MCM and 47.8 MCM respectively, whereas wastewater generation of 109.5 MCM (assuming that 80% of total water consumed) indicates the total annual extraction of 136.9 MCM from all sources. Since, the surface water source is regulated completely by the government authorities, so the extra pumping of 35.8 MCM is through groundwater source. Hence, the total water extraction through groundwater source is 89.1 MCM which may cause city under water stress

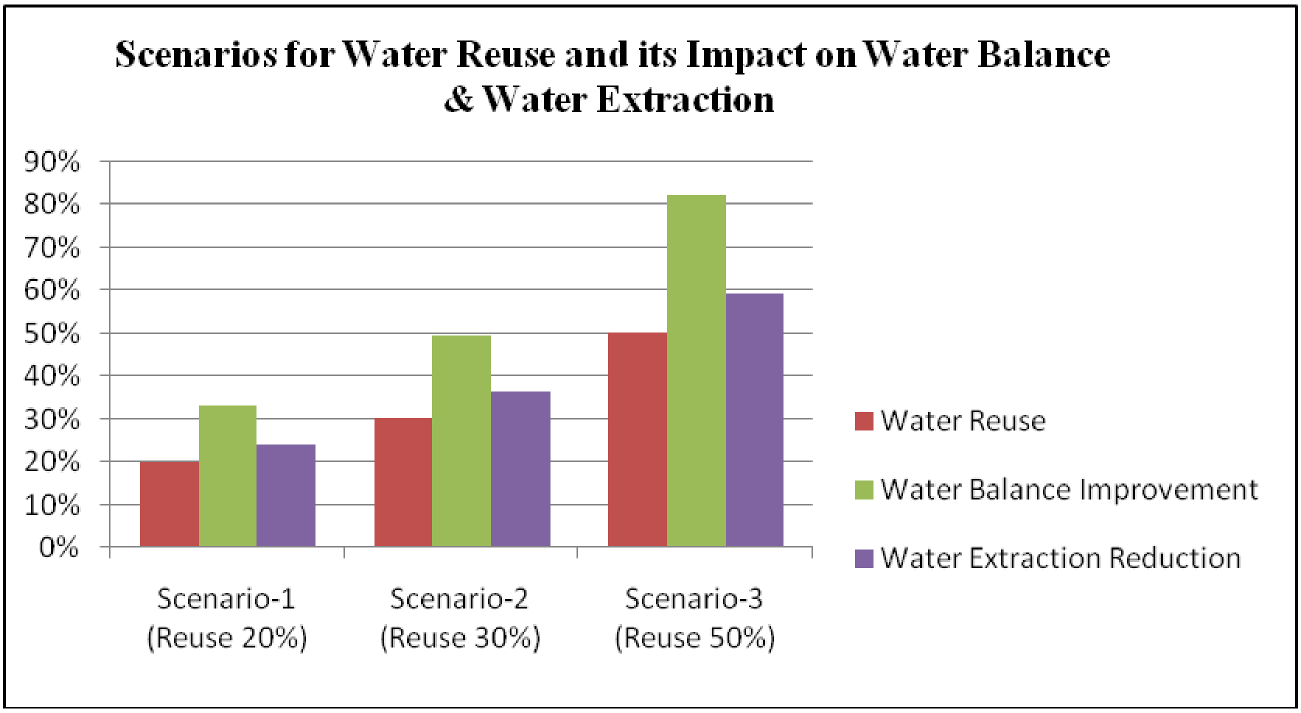

Fig. 4: Different water reuse scenarios of the study area and its impact on water balance and water extraction.

condition very soon. In order to check the annual balance, the following equation is used.

Water balance (annual) = Total extraction through all sources - (Total reuse of treated wastewater + Total discharge to environment after treatment + usable stored storm water)

Assuming no storm water contribution in this calculation considered as storage is not achieved through planning for Varanasi city; 36.5 MCM of wastewater is treated, but it is not in direct reuse but discharged to environment (Ganga River). Hence, water balance equation shows that water balance is -100.4 MCM which is very low for Varanasi city (Table 4). If we consider reclaimed water (storm water & treated waste water) to subsidies water balance, then the sustainability may be improved. Different scenarios of water reuse have been generated (Fig. 4) which show that if water reuse capacity increased to 20%, 30% and 50%, then water balance will improve by 32.9%, 49.27% and 82.12% and water extraction will reduce by 24.1%, 36.14% and 59.10% respectively.

CONCLUSION

The present framework has been proposed and a system is designed to evaluate the possible quantitative water balance for urban landscape from its source of generation to its reuse and final disposal. The system is capable to suggest the management of natural and alternative water resources to fulfil futuristic water demand and urban development in spatial domain for the sustainable growth in water prospects. In addition, the model can suggest more efficient solution for wastewater treatment technology selection applying sustainability indicator including health and environment. There is immense scope of further refinements to

Table 4: Calculation of water balance for 2015 and estimation of future water demand for 2030.

Sr. No.	Year	Population (million)	Demand (MLD)	Supply (MLD)	Supply through Ground Water (MLD)	Return to Wastewater (MLD) estimated by JICA		Storm water Storage Potential (Annual)	Water Balance (Annual)
						Total	Treated		
1.	2015	1.62	272	277	146+98.1	300	100	55.4 MCM	-100.4 MCM
2.	2030	2.22	362	-	Additional 67	344	-	-	-

improve sustainability of an urban area considering local environmental, social and financial constraints.

ACKNOWLEDGEMENTS

The authors are thankful to Municipal Commissioner Varanasi city (Uttar Pradesh, India) and Assistant Engineer of Ganga Pollution Prevention, UP Jal Nigam, Varanasi for their high co-operation and data sharing.

REFERENCES

Balkema, A. J., Preisig, H. A., Otterpohl, R. and Lambert, F.J.D. 2002. Indicators for the sustainability assessment of wastewater treatment systems. Urban Water, 4: 153-161.

Bouguerra, L. 2007. Foreword on water resources in the 21st Century. International Conference on Water Challenges in the 21st Century Water Mobilising Programme of the Alliance for a Responsible and United World, Paris, 1-2.

Castillo, A., Porro, J., Garrido-Baserba, M., Rosso, D., Renzi, D., Fatone, F., Gomez. V., Comas, J. and Poch, M. 2016. Validation of a decision support tool for wastewater treatment selection. Journal of Environmental Management, 184(2): 409-418.

Chanan, A. and Wood, P. 2006. Introducing total water cycle management in Sydney: a Kogarah Council initiative. Desalination, 186: 11-16.

Chu, J., Chen, J., Wang, C. and Fu, P. 2004. Wastewater reuse potential analysis: implications for China's water resources management. Journal of Water Research, 38(11): 2746-2756.

CPCB 2008. Guidelines for Water Quality Management. Central Pollution Control Board, India.

Dass, A., Jethoo, A.S. and Poonia, M.P. 2014. Integrated wastewater management in Jaipur City, Rajasthan, India. Nature Environment and Pollution Technology, 13(3): 637-640.

JICA 2005. Final report on water quality management plan for Ganga river. Vol. I, pp. 30-38.

Kenway, S., Gregory, A. and McMahon, J. 2011. Urban water mass balance. Journal of Ecology, 15(5): 693-706.

Kumar, R. and Singh, J. 2003. Regional water management modeling for decision support in irrigated agriculture. Journal of Irrigation and Drainage Engineering, 129(6): 432-439.

Rousta, B. A. and Araghinejad, S. 2015. Development of a multi criteria decision making tool for a water resources decision support system. Water Resources Management, 29: 5713-5727.

Seckler, D., Barker R. and Amarasinghe U. 1999. Water scarcity in twenty-first century. International Journal of Water Resources Development, 15(1-2): 29-42.

Shakya, C., Pandey, M.K. and Raju, K.N.P. 2016. Institutional responsibilities to recharge ground water need for policy implementation: A case study of Banaras Hindu University campus. International Journal of Groundwater Research, 5(2): 37-43.