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Identification of indicators for sustainable urban water development planning

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ABSTRACT

Rapid urbanization has put tremendous pressure on the extraction of natural water resources. Uncontrolled extraction of water has further created water stress in the urban sector. Therefore, it is the need of the day to have a positive water balance for sustainable development of an urban area. The sustainability of water cannot be simply seen as quantitative adequacy but it has other environmental dimensions such as depleting of the groundwater table, drainage problem, and pollution of surface water bodies etc. The present paper focuses on the development of a single index based on a combination of Integrated Urban Water Management (IUWM) and pressure-state-response (PSR) frameworks. In the proposed framework twenty-two sub-indicators have been brought down into seven broad categories to measure the relevant indicators. This single index termed as Water for Development Planning Index (WDPI) may be used for further development planning which will incorporate all aspects of urban water systems. Formulation of WDPI has been established for urban water planning as a decision making tool. A Graphical User Interface (GUI) of the proposed framework has been developed and applied to Varanasi city where water supply is managed traditionally. The WDPI for Varanasi city is 4.09 (less than 5) which lies in critical condition. Hence, the future planning of the water sector of Varanasi city must reduce the extraction of the water from the natural sources and promote non-conventional practices.

1. Introduction

Globally, approximately 80% of GDP is produced, and 75% of the global energy and material flows are consumed in cities (Swilling et al., 2013). Water resource stress is identified not only as quantitative but also qualitative too on account of increasing pollution in water bodies (Ilias Mariolakos, 2007). In an era where urbanization is expanding very fast, ensuring sustainable development becomes a challenging issue. Consequently, urban sector water supply, sanitation systems, industrial and other developments put a great thrust on available water resources. The increased water demand for domestic supply, industrial, commercial and other development activities has developed immense pressure on the supply-demand balance of the existing system. Water sustainability defined as a continual supply of clean water for human uses does not specify exactly how much water we have, nor does it imply the unrestrained, infinite availability of water (Schnoor, 2010). Rather, it refers to the sufficient availability of water into the foreseeable future. As the regenerative capacity and renewable resources on earth are limited (Hoekstra and Wiedman, 2014), environmental pressure of the cities need to be reduced provided that adequate living standards are maintained (Mori and Yamashita, 2015). The increasing complexity of water management problems has undoubtedly been one motivation for the development of methods that allow multiple impacts to be explicitly considered in decision analysis (Chung et al., 2011).

To achieve water sustainability, Integrated Urban Water Management (IUWM) has been used for managing freshwater, wastewater, and stormwater as components of a basin wide management plan (Tucci et al., 2010). The urban water management is often locked in to the large scale, centralized infrastructure approaches limiting the option of more flexible and resilient technologies and approaches such as fit-for-purpose water use, nutrient, and energy recovery from wastewater, and blue-green infrastructures (Brown et al., 2011). In various studies, at the macro or micro scale five major criteria viz. social, economic, institutional, technical and environmental have been considered to measure sustainability. To measure sustainability on defined criteria several indicators and their corresponding sub-indicators have been developed. However, the changing urban development scenarios, use of wastewater need to be integrated into the urban water cycle. The strategic urban planning process is primarily based on the identified stakeholders' available information for baseline assessment. With this changing context, there is a need to modify the indicator's selection.

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Table 1
Previous frameworks and indicators covered under the urban water cycle.

Sr. No.	Frameworks of sustainable indicator	Indicators covered related to Urban Water Cycle	Source
1.	Urban Sustainability Indicators	Water consumption, citizen participation	Mega and Pedersen (1998)
2.	European Common Indicators	water supply, water bodies, production to consumption and disposal	European Commission (2003)
3.	OECD Key Environmental Indicators	municipal waste generation intensities, wastewater treatment connection rates, the intensity of use of water resources	OECD (2004)
4.	Global City Indicators	water consumption, system leakages, wastewater system treatment, water efficiency, and treatment policy	Global Cities Institute (2007)
5.	European Green City Index	residential water supplies per property, Water utilities services, public participation	European Green City Index (2009)
6.	Sustainable Cities Index	water consumption per capita, water system leakages, water quality policy, water sustainability policy, the share of wastewater treated, public participation	Australian Conservation Foundation (2010)
7.	Asian Green City Index	water access rate, domestic water consumption, wastewater treatment rate, domestic treatment rate, public water supply coverage, total water consumption	Denig (2011)
8.	China Urban Sustainability Index	urban density, wastewater treatment, public water supply, water efficiency	Li et al. (2013)
9.	Community Sustainability Indicators	population density, water uses, water supply by source, waste generation per capita	Sustainability City Report (Issaquah, WA, USA), (2016)

2. Existing frameworks for urban water management

Urban water supply has its own social, financial and environmental setting in which water managers have to operate. An indicator is a key term which bridges the final objectives and relevant criteria to achieve the set targets. An indicator quantifies and aggregates data that can be measured and monitored to determine whether the change is taking place. But in order to understand the process of change, the indicator needs to help decision makers recognize why the change is taking place (FAO, 2012). Water scarcity, water pollution, and flooding amplified urban water vulnerabilities. The performance indicator which is mainly dependent on water consumption or the use of water savings does not specify exactly how much water we have, nor does it imply the unrestrained, infinite availability of water. Assessment of sustainability in urban water systems identified indicators under environmental, social, economic and technical criteria. Based on the suggested Indicators City Blueprint Framework (CBF) (Leeuwen et al., 2012), Integrated Urban Water Management (IUWM) etc. (European Commission, 2003; UN, 2007; Popawala and Shah, 2011; Ulian et al., 2017) are developed. In a broader prospect, many sustainability indicator frameworks have been developed by various researchers which are summarized in Table 1. All these indicator frameworks do not include each component of urban water systems. The most common reason for the failings of an indicator system is the selection of unsuitable or unavailable data sources (Pires et al., 2014). Anderson (2000) claimed that water conservation and water recycling measures are the key elements in integrated urban water planning.

The pressure-state-response (PSR) model is a widely accepted framework for the compilation of sustainability performance indicators. The model links the causes of environmental changes (pressure) to their effects (state) and finally to the projects, actions, and policies (response) designed and undertaken to tackle these changes (Mega and Pedersen, 1998). Organization for Economic Development and Co-operation (OECD, 1998) included two sets of indicators i.e. water quality and water resources. Water quality concerns runoff of untreated wastewater and other polluted water which pollutes the existing surface water. Water resources related to quantitative measure of intensity of water exploitation. Moreover, to retain desired sustainability there is need for a quantitative measure of water resources on the spatial and temporal scale within the boundary.

WATERinCORE project (2012) implemented under the transnational program of European Territorial Cooperation has identified twenty-nine common indicators based on Driving force-Pressure-State-Impact-Response (DPSIR) framework which focused on water preservation and avoidance of water stress. Leeuwen et al. (2012) considered twenty-four indicators which are sub-divided into eight broader categories i.e. water security, water quality, drinking water, sanitation, infrastructure, climate robustness, biodiversity and attractiveness, and governance for assessment of water sustainability in city setup.

The impacts of human activities on water quality and quantity are changing the existing system rapidly. Hence, to measure sustainability with the objective of new development planning there is a need to know the thrust on the existing system, the present condition of the existing system and possible options to improve the system. Therefore, the indicators need to be categorized on the basis of the above mentioned factors.

3. Water for development planning index (WDPI) in urban water supply sector

Integrated Urban Water Management (IUWM) framework facilitates planning, designing, and managing urban water systems. It is a flexible process that responds to change and enables stakeholders to predict the impacts of interventions. Usually, fresh water is being used in domestic demands for drinking, cooking, flushing of wastes etc., horticulture, industrial, construction or other such purposes. Growing competition, conflicts, shortages, waste and degradation of water resources make it imperative to rethink conventional concepts to shift from an approach that attempts to manage different aspects of the urban water cycle in isolation to an integrated approach supported by all stakeholders (GWP, 2013). Mitchell et al. (2003) noted that several components i.e. water usage, reuse of wastewater, stormwater and change in water storage within the system are still unaddressed and need to be integrated into the urban water cycle.

Moreover, recycling and reuse of treated wastewater play an important role in the sanitation cycle and it may be used as an alternate source of water supply. Anderson et al. (2001) noted reclaimed water is currently one of the top priorities in sustainable water resource utilization which is one of the goals of IUWM. However, identification of reuse potential of any urban area is challenging as it depends on seasonal demand variation, habits of people, number of open drains available for flushing, area for irrigation, horticulture, and availability of wetlands near river courses (UNICEF, 2013).

Anderson (2006) observed that the new planning requirements significantly increase the opportunities to integrate recycled water into urban water supply systems to increase the available supplies and also to minimize environmental impact. Thus, water required for new developments may consider reuse, recycle and recharge easily which will reduce pressure on the existing supply system. In this context, there is a need to reclassify the sustainability criteria, the relevant indicators, and their corresponding sub-indicators.

The goals of IUWM are defined by many authors but could not be covered the extent of its real impact. This necessitates adopting a modified approach for IUWM framework. DPSIR framework and PSR

Table 2
Modification required in the existing framework based on the PSR framework and expected goals.

Goals of IUWM Framework at Municipality Level (Rees, 2006)	Issues need to be addressed (Giordano and Shah, 2014; Pires et al., 2014)	Suggested Modification(s)	Final Goals Expected of present study
1) Conserve supplies and reallocate supplies 2) Improve health and basic needs 3) Increase Investment 4) Source protection or quality protection	1) Identification of context rather than universal sustainability criteria 2) Non-availability of suitable data sources	1) Integration of PSR to IUWM framework 2) Finding a new measures/indicators 3) Development of WDP framework for urban water management system	A single index to evaluate the available water for new developments

framework (OECD, 1998) may be considered to meet the objectives of IUWM. The improved model will result in the estimation of water for development planning which ultimate goal is holistic use of urban water (Table 2).

Trend and Pressure Framework (TPF) was introduced to revise the City Blueprint indicators (Koop and Leeuwen, 2015). It has been observed that various frameworks and a large number of indicators cover a larger horizon. Nevertheless, how it may be used as a decision support system especially in essential services since urban water supply is still a big question. In this paper, framework of Water for Development Planning (WDP) based on pressure-state-response (PSR) has been derived. Thereafter, an attempt is being made to develop a single decision support index Water for Development Planning Index (WDPI) to investigate the scope of further development of the city with a specific context to water for development planning (Fig. 1).

A framework (Fig. 2) has been proposed for water for development planning index (WDPI) calculation which is inspired by the PSR framework taking the pressure, state and response component. The framework consists of seven indicators i.e. 1) water security, 2) investment scope, 3) water quality, 4) water quantity, 5) infrastructure, 6) reuse, recycle & recharge, and 7) governance. Out of seven indicators, four are taken from literature i.e. water security, infrastructure, water quality, governance (Leeuwen et al., 2012). With increasing urbanization, the exploitation of fresh water resource and the generation of waste water in urban sector create pressure on the water security. The waste water generation and urban drainage and mixed disposal practices affects the water quality. Consequent to these pressures, the infrastructure and governance of urban water management play an important role for policy makers. Therefore, water security, water quality, infrastructure and governance measure are taken as indicators in the present work. Three new indicators are introduced i.e. water quantity, reuse, recycle & recharge, and investment scope (Koop and Leeuwen, 2015) with slightly modification. The reasons for the selection of these new indicators are briefly discussed below:

Water quantity indicator ensures the sufficiency of available water within the closed boundary. Adequate quantity of water must be available, and its service reliability should be ensured for the domestic supply. The other fact is extra consumption of water affects the water quantity. Hence, the above facts must be considered for water quantity measures.

Investment Scope (Koop and Leeuwen, 2015) has been considered as a measure for revised city blueprint indicators, here it is considered as an indicator. This indicator has a single measure i.e. economic pressure which is estimated by taking the ratio of the fund required by an urban area for water projects and fund allocated by the regulating authority.

Reuse, recycle and recharge is the essential component of the urban water cycle. Water balancing modeling expected to maximize the reuse of water and minimize fresh water extraction (Lundin and Morrison, 2002; Barton et al., 2009). Reuse of treated wastewater may help the cities to improve, human and environmental health while supporting economic activities (Brown, 2009). For the purpose, local reuse, recycle potential must be known. Treated wastewater available for reuse, runoff storage, recharge potential other than natural processes and the economic efficiency for these options is required.

Coverage area is a measure to present condition of infrastructure (Okeola and Sule, 2012). Here, water supply coverage area, wastewater collection coverage area, and stormwater coverage area have been considered separately.

Each Indicator is associated with the objective function i.e. pressure, state and response included in WDPI evaluation. Further, sub-indicators/measures are associated with each indicator which is depicted in Table 3.

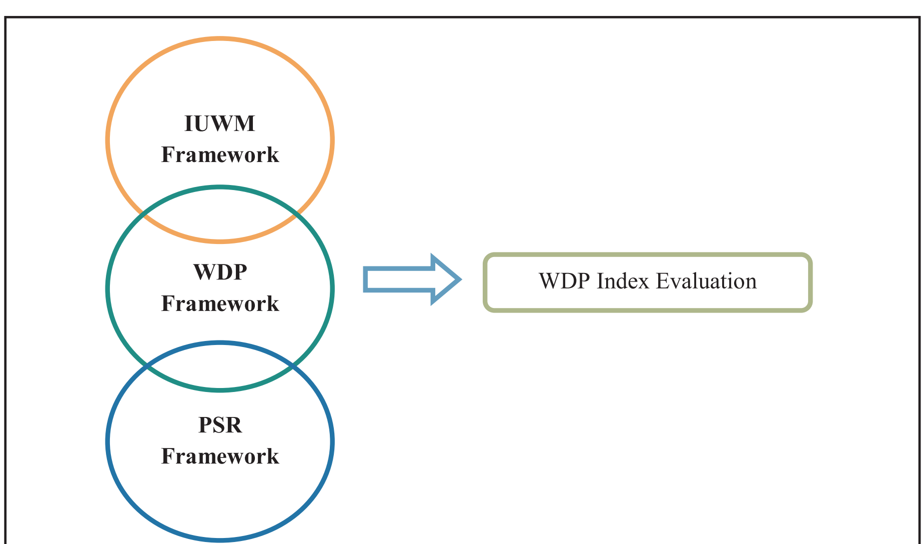

Fig. 1. Interaction among IUWM, WDP and PSR framework to evaluate WDPI.

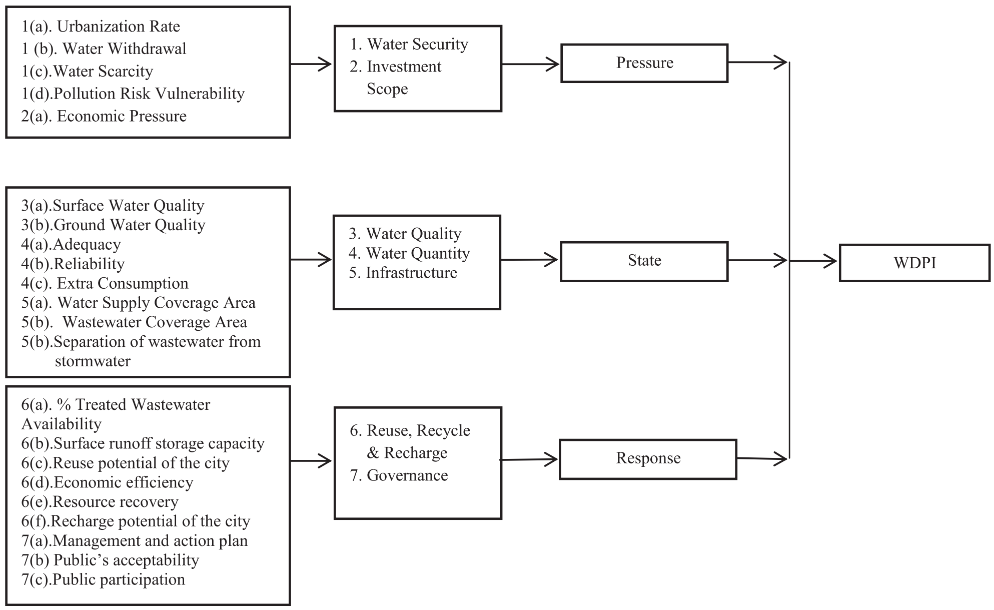

Fig. 2. Framework of Water for Development Planning Index (WDPI).

4. WDPI – a single index for integrated urban water management (IUWM) using Pressure-State-Response (PSR) framework

In urban water supply management, the exploitation of freshwater resources and the generation of wastewater create Pressure (PR) on the environment. The pressures, in turn, affect the State (ST) of the water supply and demand environment. This refers to the quality of the various environmental media (water) and they are consequent ability to support the demands placed on them (for example, supporting human and non-human life, supplying resources, etc.). The Response (RE) demonstrates the efforts of the governance (e.g. decision makers) and society (public participation, perception etc.) to solve the problems identified by the assessed impacts, e.g. policy measures, and planning actions. Using this concept, a single index, Water for Development Planning Index (WDPI) may be calculated (eqn. 4, eqn. 5) in line with Alternative Evaluation Index (AEI) (Chung and Lee, 2009). In present framework, pressure-state-response has been considered as objective function (OF). Indicator (I) value is calculated through the defined sub-indicators (SI) values and its corresponding weight value (w) (eqn. 1). Based on indicator value (I) and weight (W) assigned to it, OF is calculated (eqn. 3). Weight assignment of the indicators is based on scheme followed by the Environmental Performance Index (EPI) (Table 4). Weights of each sub-indicator have been decided by conducting a desk based survey with technical field experts. Weight factor for each indicator has been calculated by taking the ratio of total number of sub-indicators within the particular indicator to total number of sub-indicators within objective (eqn. 2). Weight factor for objectives have been calculated by taking ratio of total number of sub-indicators within objective to total number of sub-indicators used in WDPI.

$$I = \sum_{i=1}^{n} SIi\text{xwi} \tag{1}$$

where,

SI = sub-indicator value
w = weight of sub-indicator
I = indicator value
n = total number of sub-indicators within indicator

$$Wj = SI_I/SI_O \tag{2}$$

where,

W = weight of indicator
SI_I = Total number of sub-indicators within indicator
SI_O = Total number of sub-indicators within objective

$$OF = \sum_{j=1}^{m} \text{Wjx}Ij \tag{3}$$

where,

OF = Objective Function (i.e. Pressure/State/Response)
m = total number of indicators within objective

$$WDPI = W_P \times PR + W_S \times ST + W_R \times RE \tag{4}$$

$$W_P + W_S + W_R = 1 \tag{5}$$

where,

PR = Pressure
W_P = weight factor of pressure
ST = State
W_S = weight factor of state
RE = Response
W_R = weight factor of response

A computer based graphical user interface (GUI) has been developed using Visual Studio 2008 and mySQL database software and visual basic programming language. The sub-indicators have been derived through primary/secondary field data. Further, the measures of the sub-indicators have been normalized to a single scale 0–10. Normalization is based on analysis of the available data using different methods required according to sub-indicator type (Eq. (4)). A snapshot of the developed application has been shown in Fig. 3.

$$\text{Normalized Value} = (\text{Range value} - \text{Field Value})/\text{Range Value} \tag{4}$$

$$\text{Where,} \quad \text{Range Value} = \text{Max Value} - \text{Min Value} \tag{5}$$

Range value has been calculated by the study of previous data available for a particular measure values (Table 5). Data are derived from data provided by local government authorities like Varanasi Municipal Corporation, Varanasi Jal Sansthan, City Development Plan Varanasi.

Table 3
Indicators and relevant sub-indicators with their description categorized for WDPI development.

Indicator	Sub-Indicator/Measure	References	Purpose	Description	Calculation Method
Water Security	Urbanization rate (UR)	Ulian et al. (2017)	The measure of population increase	% of population increase per annum under urban boundary	(Annual population change/Present population) × 100
	Water withdrawal (WW)	Lundin & Morrison (2002) Okeola and Sule (2012)	Sustainable development of City, Region	% of the water that is extracted from ground sources	(Ground water withdrawal/Total water production) × 100
	Freshwater scarcity (FWS)	OECD (2004)	The measure of water providing	A ratio of total water footprint to total renewable water resources (recharge + reuse)	(Total renewable water/Total water required for all services) × 100
	Pollution risk vulnerability (PRV)		A measure of water pollution extent	Percentage of wastewater collection and its treatment	(Volume of waste water treatment/Total waste water generated) × 100
Investment Scope	Economic pressure (EP)	IMF (2013)	A measure of economic pressure	A ratio of funds required to available for water projects and infrastructure maintenance	(Total fund available for water projects/ Total fund required for water projects) × 100
Water Quality	Surface water quality (SWQ)	Ulian et al. (2017)	The requirement for environmental and public health	Assessment of the water quality preferably based on standard	(Present quality level/Required quality level) × 100
	Groundwater quality (GWQ)	Ulian et al. (2017)	The requirement for public health	Assessment of the water quality preferably based on standard	(Present quality level/Required quality level) × 100
Water Quantity	Adequacy (ADQ)		The requirement for human livelihood & health	% of the city population with water production	(Population served/Total Population of the city) × 100
	Reliability (REL)	Xiaoqin (2009)Okeola and Sule (2012)	Use efficiency	Water produced per capita/domestic water consumption per capita	(Total water demand/Total water availability) × 100
	Extra consumption (EC)		Present water consumption	Water demand per capita/Water produced per capita	((Water produced-Water demand)/Water demand) × 100
Infrastructure	Water supply coverage area (WSCA)		A measure of service coverage	% of infrastructure for water treatment and distribution	(Total water supplied to city/Total water demand of the city) × 100
	Wastewater collection coverage area (WWCCA)		A measure of service coverage	% of infrastructure for wastewater collection	(Area covered for waste water collection/ Total area of the city) × 100
	Separation of wastewater and stormwater (SWSW)	Bahri et al. (2016)	A measure of uses of resources	% of separation of infrastructures for wastewater to a storm water collection	(Total coverage area of storm water/Total area of the city) × 100
Reuse, Recycle & Recharge	Percentage of treated wastewater availability (ATWW)		A measure of reclaimed water quantity available	Availability of treated wastewater quantity within the city, region	(Total treated waste water/Total waste water produced) × 100
	Surface runoff storing capacity (SRS)		A measure of green water storage potential	Infrastructure available to store storm water within the city, region	(Total area covered for storm water/Total area of the city) × 100
	Reuse potential of the city, region (RP)		A measure of reuse potential	Total reuse potential from the various requirement of the city, region	(Total reuse potential of the city/Total treated waste water) × 100
	Economic efficiency (EE)		The measure of recycling cost	The total cost of water produced/Total cost of treated water (recycled)	(Total cost of water produced/Total cost of recycled water) × 100
	Resource recovery (RR)	Makropolous et al. (2008)	The measure of recovery cost	% of total cost recovery based on willingness to pay/tariff	(Total income/Total investment cost) × 100
	Recharge potential (RP)		The measure of recharge through green water	% of the impervious surface in the city, region	(Roof-top recharge + pond area/Total area) × 100
Governance	Management and action plan (MAP)		The measure of participatory, adaptive coordinated and integrated management	Measures of local and regional commitments to adaptive, malfunction, infrastructure and design for IUWM	Desk data provided by water authorities/ Social survey
	Public participation (PP)	Xiaoqin (2009)	The measure of local community strength and willingness	A proportion of individuals who volunteer for group or organization as a measure of local community strength and willingness of residents to engage in the activities for which they are not remunerated	
	People's acceptability (PA)	Brown (2009)Okeola and Sule (2012)	A Measure of local acceptance of the policy	The degree of acceptance of local people to water services and policy	

Table 4
Weight calculation scheme for sub-indicators, indicators and objectives.

Objective (PR/ST/RE)	Indicator (I)	Sub-Indicator (SI)	Weight of Sub-indicator (w)	Weight of Indicator (W)	Weight of Objective (W_P/W_S/W_R)
Pressure	Water Security	Urbanization rate	0.20	W_1 = 0.80	0.23
		Water withdrawal	0.40		
		Freshwater scarcity	0.30		
		Pollution risk vulnerability	0.10		
	Investment Scope	Economic pressure	1	W_2 = 0.20	
State	Water Quality	Surface water quality	0.50	W_3 = 0.25	0.37
		Groundwater quality	0.50		
	Water Quantity	Adequacy	0.40	W_4 = 0.375	
		Reliability	0.40		
		Consumption	0.20		
	Infrastructure	Water Supply Coverage Area	0.35	W_5 = 0.375	
		Wastewater Collection Coverage Area	0.35		
		Separation of wastewater and stormwater	0.30		
Response	Reuse, Recycle & Recharge	% Availability of treated wastewater for reuse	0.10	W_6 = 0.67	0.40
		Surface runoff storing capacity	0.20		
		Reuse potential of the city, region	0.20		
		Economic efficiency	0.05		
		Resource recovery	0.15		
		Groundwater Recharge potential	0.20		
	Governance (3/9)	Management and action plan	0.40	W_7 = 0.33	
		Public participation	0.40		
		People's acceptability	0.20		

For each measure, the range value has been converted into percentage value then this value is downscaled to a scale of 10. However, data given as percentages were divided by a factor of 10 to obtain the normalized values within the scale 0–10.

WDPI has been evaluated at a scale of 0–10 which consists of three objectives pressure, state and response. Based on WDPI the performance has been categorized as follows:

(i) < 3: Poor
(ii) 3–5: Critical
(iii) 5–8: Fair
(iv) > 8: Excellent

5. Test check of framework and discussion

The test check of the proposed framework has been performed for water supply management of Varanasi city, Uttar Pradesh (India). Varanasi is the fourth largest city of the state of Uttar Pradesh, having an area of 81 Sq. Km and a population of 1.49 million (2015). Varanasi is divided into 11 Zones of Water Supply and 90 administrative wards.

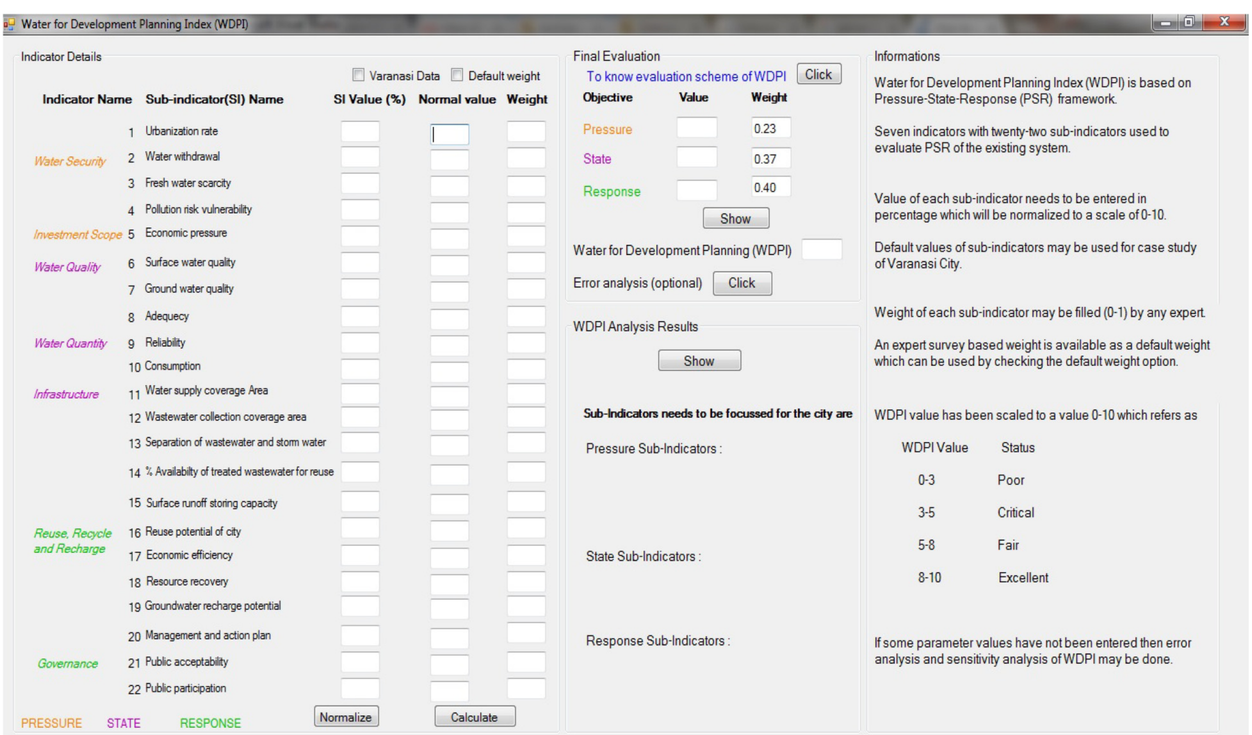

Fig. 3. Developed application to generate Water for Development Planning Index (WDPI).

Table 5
Value of the measure (twenty-two measures) for base year 2015.

Sr. No.	Measure	Value (in percentage)
1.	Urbanization rate (per annum)	2.6
2.	Water withdrawal (per annum)	93
3.	Fresh water scarcity (per annum)	85
4.	Pollution risk vulnerability	70
5.	Economic pressure	20
6.	Surface water quality	55
7.	Ground water quality	75
8.	Adequacy	100
9.	Reliability (Days/Annum)	100
10.	Extra Consumption	33
11.	Water Supply Coverage Area	65
12.	Wastewater Collection Coverage Area	30
13.	Separation of wastewater and storm water	30
14.	% Availability of treated wastewater for reuse	100
15.	Surface runoff storing capacity	27
16.	Reuse potential of city, region	0
17.	Economic efficiency	27
18.	Resource recovery	40
19.	Groundwater Recharge potential	10
20.	Management and action plan	10
21.	Public participation	5
22.	People's acceptability	5

The city has an average water demand of 275 million liters per day (MLD). However, the water production in the city is 277 MLD (152 MLD from tube well and 125 MLD from river Ganges) as reported by UP Jal Nigam. 140 Tube wells have been bored to extract 152 MLD from groundwater source as fresh water and 250 MLD treatment plant is installed in the city to treat the surface water. The total wastewater generated in the city is reported as 300 MLD (observation based) which indicates that some other unaccounted sources are functional in the city which is also contributing to the wastewater generation. The reason for this is unauthorized extraction of groundwater which needs to be monitored. Total 141 large/small ponds (surface water bodies) exist within the city boundary reported by Varanasi Nagar Nigam. The average annual rainfall of the city is 828 mm.

At present, Varanasi city has no legislation on rainwater harvesting. A number of state governments have made rainwater harvesting compulsory for new buildings according to their plot sizes in various Indian cities (Ministry of Water Resource (India), 2013). In the present study, roof-top area in Varanasi city has been calculated using satellite imagery and have been classified under three categories > 1000 sqm, 1000–500 sqm, and 500–300 sqm and initially it has been considered that all buildings having a roof-top area greater than 1000 sqm will have roof-top harvesting facilities.

The results of the indicators for the existing scenario (2015) are found as 2.77, 8.0, 6.5, 8.66, 4.22, 2.89 and 0.43, for water security, investment scope, water quality, water quantity, infrastructure, water reuse, recycle and recharge, and governance respectively. The values of pressure, state and response are 3.80, 6.45 and 2.08 respectively and the value of WDPI is found as 4.09 which showed that the water management of Varanasi city is under critical condition. The sub-indicator urbanization assigned a range value 0–4 as maximum urbanization taken as 4% per annum. Similarly, reuse potential assigned a range value of 0–5, groundwater recharge potential has assigned a range value 0–4, surface storage capacity has a range value 0–6 and economic efficiency has range value 0–7. Sub-indicators like fresh water scarcity, economic pressure are reciprocal to the objectives; their values are inversed during calculation of WDPI (Table 6).

In Fig. 4(a), reviewing the value of pressure w.r.t. the performance scale (0–10) it appears that fresh water exploitation is under critical condition which needs an attention of the policy makers. Whereas, the quality of water and infrastructure for domestic water supply are a fairly good. The Varanasi city does not focus on recharge, recycle, and reuse potentials which are being reflected in response value. In

Table 6
Calculation of WDPI for Varanasi city.

Sub-Indicator	N_SI	w	I	W	OF	W_P/ W_S/ W_R	WDPI
Urbanization rate	3.5	0.20	2.77	0.80	3.8	0.23	4.09
Water withdrawal	3.3	0.40					
Fresh water scarcity	1.5	0.30					
Pollution risk vulnerability	3	0.10					
Economic pressure	8	1	8.00	0.20			
Surface water quality	5.5	0.50	6.50	0.25	6.45	0.37	
Ground water quality	7.5	0.50					
Adequacy	10	0.40	8.66	0.375			
Reliability	10	0.40					
Extra Consumption	3.3	0.20					
Water Supply Coverage Area	6.5	0.35	4.22	0.375			
Wastewater Collection Coverage Area	3	0.35					
Separation of wastewater and storm water	3	0.30					
% Availability of treated wastewater for reuse	9.4	0.10	2.89	0.67	2.08	0.40	
Surface runoff storing capacity	4.6	0.20					
Reuse potential of city, region	0	0.20					
Economic efficiency	4	0.05					
Resource recovery	1.5	0.15					
Groundwater Recharge potential	1	0.20					
Management and action plan	1	0.40	0.43	0.33			
Public participation	0.5	0.40					
People's acceptability	0.5	0.20					

Fig. 4(b), the relevant sub-indicators show a value of contribution within their respective indicators. Abbreviations used for sub-indicators in Fig. 4(b) are detailed in Table 7.

The increasing demand for water supply on account of city development is going to make it further critical. To address the future urban water planning issues of Varanasi city the proposed framework indicates the following options for consideration.

- Reduction in extra water extraction
- Surface runoff storage
- Rooftop harvesting through rain tanks
- Rooftop harvesting through groundwater recharge
- Reuse of treated wastewater
- Management & action plan, and public participation

To study the futuristic urban water planning scope of Varanasi city, an attempt has been made to work out the WDPI for the year 2030, and 2040. A target based future PSR and WDPI for the target year 2030, and 2040 have been calculated by considering the potential of non-conventional sources of water such as reuse recycle & recharge, governance as indicated in the present study. Fig. 5 shows a trend analysis of pressure-state-response and WDPI of Varanasi city. From the figure, it can be concluded that the use of non-conventional sources in urban water planning and improvement over the governance have a positive effect and contribute significantly to improve the WDPI score and upgrade the scenario from critical to fair condition.

6. Conclusion

To address the ultimate goal of sustainability of urban water management, a number of indicators comprised of concerned quantitative and qualitative parameters were developed. However, the large number of indicative measures in urban water supply management sector added complexity to achieve the goals of sustainability due to undefined integration of various indicators. In this paper, the concept of Water for

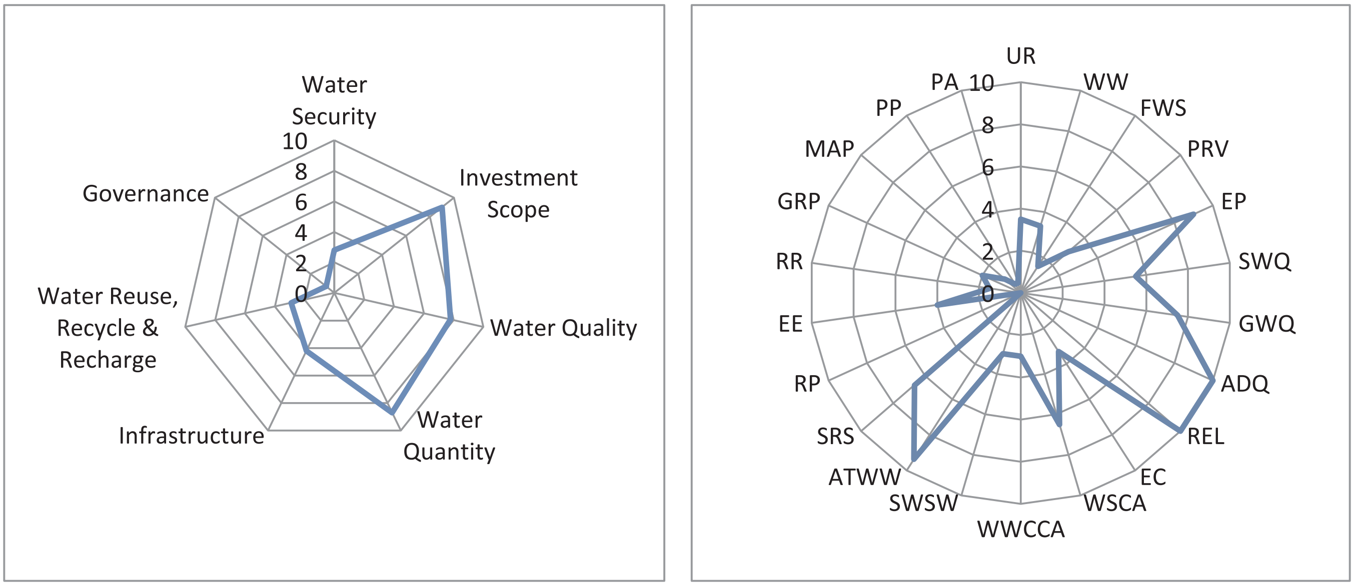

Fig. 4. (a) Performance of indicators and (b) respective sub-indicators for Varanasi city with an existing system.

Table 7
Abbreviations used for sub-indicators.

Abbreviation	Description
UR	Urbanization Rate
WW	Water Withdrawal
FWS	Fresh Water Scarcity
PRV	Pollution Risk Vulnerability
EP	Economic Pressure
SWQ	Surface Water Quality
GWQ	Ground Water Quality
ADQ	Adequacy
REL	Reliability
EC	Extra Consumption
WSCA	Water Supply Coverage Area
WWCCA	Waste Water Collection Coverage Area
SWSW	Separation of Wastewater and Storm Water
ATWW	Available Treated Waste Water
SRS	Surface Runoff Storage Capacity
RP	Reuse Potential of City
EE	Economic Efficiency
RR	Resource Recovery
GRP	Groundwater Recharge Potential
MAP	Management and Action Plan
PP	Public Participation
PA	Public Acceptance

Development Planning Index (WDPI) as a single measure (scaled at 0–10) has been developed considering pressure, state and response. In this framework, twenty-two sub-indicative measures are broadly categorized in seven groups of indicators viz. 1) water security, 2) investment scope, 3) water quality, 4) water quantity, 5) infrastructure, 6) reuse, recycle & recharge, and 7) governance to assess the objective functions i.e. pressure, state, and response. To calculate objectives functions and WDPI, a Graphical User Interface (GUI) has been developed and applied on Varanasi urban water supply system as a test check. It has been observed that proposed framework for WDPI is helpful to identify the area of concern which needs to be addressed by the decision makers and may be used as a tool to choose the possible options for a sustainable urban water development futuristic plan. Moreover, the proposed framework is capable to indicate the existing condition as well as to take a possible course of actions on the indicated area of concern to achieve the sustainability of urban water systems.

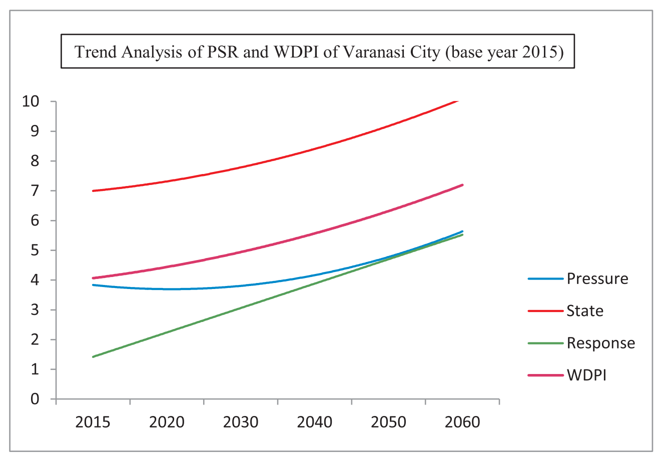

Fig. 5. Trend Analysis of Pressure, State, Response and WDPI (2020, 2030, and 2040) of Varanasi city with the existing scenario (2015).

7. Limitations of the study

There are a few limitations with this study. Availability of data is a major concern for WDPI calculation. Statistical validation of weights of sub-indicator could be done which can improve the accuracy of WDPI. Moreover, the weights may depend on the geological feature, practices and priorities of the urban area.

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