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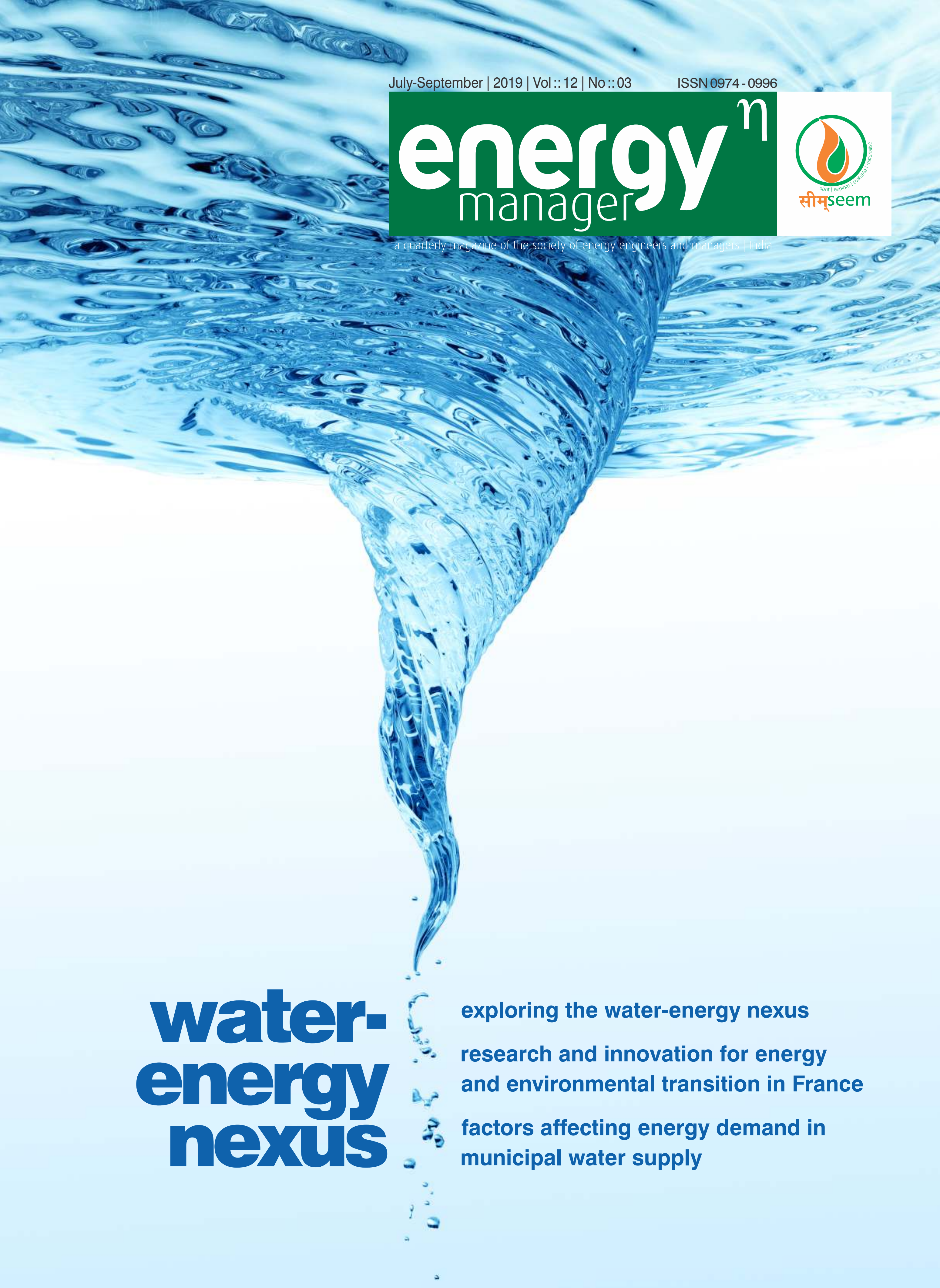

water-energy nexus

exploring the water-energy nexus

research and innovation for energy and environmental transition in France

factors affecting energy demand in municipal water supply

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contents

Cover feature

Energy Management

factors affecting **energy demand in municipal water supply**

This paper focuses on identifying the spatial parameters that affect the energy consumption of the municipal services, especially in the water supply system, understanding their impacts and establishing a relationship between them.

Sachin S, Shivani Chouhan & Mona Iyer

Introduction

India is ranked third in the list of highest electrical energy consumers in the world. The energy consumption of the country has increased by 49% in the past decade (Energy Data, 2018). Due to the dynamic socio-economic growth and increasing urbanization, the energy consumption of India is expected to continue to rise in the future as well (Energy Information Administration, n.d.). In India, the total energy consumption in the delivery of municipal sector accounts to around 28 TWh. This approximates to 3% of the total energy consumption. However, though the consumption value is considerably low in the national scale, the municipal services sector possesses the second-largest potential for energy conservation as it accounts for 23% of energy use inefficiency in the country (Vasudevan, Cherail, Bhatia, & Jayaram, 2011). An overview of the energy services in India suggests that, on an average, the utilities spend over 60% of their annual budget for the energy costs of water pumping and 10-15% of the total budget for street lighting. Considering the rapid rate of urbanization in India and the increasing demand for clean energy, augmenting municipal services becomes an important task for energy conservation.

This paper primarily focuses on identifying the spatial parameters that affect energy consumptions of the municipal services, especially in the water supply system. Further, the paper also intends to understand the impact of the spatial parameters on the energy consumption in the municipal water supply system and attempts to establish a relationship between the same.

Background

Governments have undertaken many efforts at the national and state levels to encourage the Urban Local Bodies (ULBs) to monitor their energy consumption. Further, there have also been many initiatives to enhance the operating efficiency of the systems associated with the delivery of municipal services. Table 1 summarizes the learning from the review of such initiatives undertaken by various institutions/programmes in India.

Table 1: Initiatives undertaken for monitoring municipal energy services - a review

Initiatives Undertaken	Coverage of the Initiative	Key highlights
JnNURM (2007-2014)	National level: (65 cities)	Reforms at the state and the city level to mandate - ◆ Monitoring of energy consumption in municipal services through regular energy audits. ◆ Water audits for monitoring losses. *(Government of India. Ministry of Urban Development, 2009)*
AMRUT (2015-2020)	National Level: (434 cities)	Reforms to mandate ULBs for ◆ Optimization and conservation of energy in the municipal services. ◆ Water audits for monitoring losses *(Government of India. Ministry of Urban Development, 2009)*
BEE (2002)	National Level	BEE is a statutory body set up by Ministry of Power, GoI, for bringing up programmes for enhancing energy-efficient sustainable practices and creating awareness among ULBs on energy efficiency and energy conservation *(Ministry of Power, n.d.)*
Municipal Demand Side Management (MuDSM)Programme (2007-2012)	National Level: (175 ULBs)	Launched during the 11th Five Year Plan to enhance the overall efficiency of the ULBs and reduce energy consumption in the municipal services. ◆ Situational surveys were conducted in selected ULBs for assessing the functioning of water pumping stations, sewage pumping stations, street lightings, and buildings. ◆ Detailed project reports were prepared by ULBs based on situational surveys for undertaking an Investment Grade Energy Audit (IGEA).

Initiatives Undertaken	Coverage of the Initiative	Key highlights
		• 12th Five Year Plan focused on selecting sample ULBs and implementing the projects on the ground. As Gujarat had already carried out several energy conservation and related projects, the state was not chosen for programme implementation. *(Ministry of Power, n.d.)*
Municipal Energy Efficiency Programme (MEEP)	National Level: (All cities above 1 Lakh population)	Central government initiative undertaken in association with the Ministry of Home and Urban Affairs (MoHUA) and Energy Efficiency Service Ltd. (PSU under Ministry of Power). • Focused on retrofitting inefficient municipality pump sets in water pumping stations and sewage pumping stations in 500 AMRUT cities. • Aimed at replacing inefficient pumps in 100 selected cities under smart city mission. *(Energy Efficiency Services Limited, n.d.)*
Street Light National Programme (SLNP) (2015)	National Level	Central government programme for replacing conventional lights with energy-efficient lighting with the objective of: • Replacing over 305 crore street lights across the country. • Reducing energy consumption in street lighting and thereby assisting distribution companies in managing peak demand. The programme estimated an overall annual energy saving of 9000 million KWh and an annual cost reduction of Rs. 5500 crore for the ULBs. *(Ministry of Electronics and Information Technology, n.d.)*
Supervisory Control and Data Acquisition (2014-2019)	ULB Level	Installing energy meters and flow meters in water supply and wastewater management systems for monitoring and collecting data on flow rate, energy consumption etc. and qualitative data sets such as pH, turbidity, chlorine level etc. Ahmedabad Municipal Corporation (AMC) has installed SCADA system for the water supply and wastewater sector, gathering data with a granularity of 15 minutes' interval for water supply and 1-hour interval for wastewater systems. As a part of Pan City proposal under the Smart Cities Mission, some of the selected cities have proposed to install SCADA system.
Energy Efficiency Cell (EE Cell)	ULB level (Surat, Ahmedabad)	Surat Municipal Corporation (SMC) set up an EE Cell in 2001 with the aim of delivering basic services to the citizens at an optimum cost and in an energy-efficient manner. Under the supervision of this cell, SMC conducted energy audit in 34 services that are having a contract demand of more than 75kwh. A similar cell has been replicated in Ahmedabad, to reduce energy consumption without depleting performance. *(Ahmedabad Municipal Corporation, n.d.)*

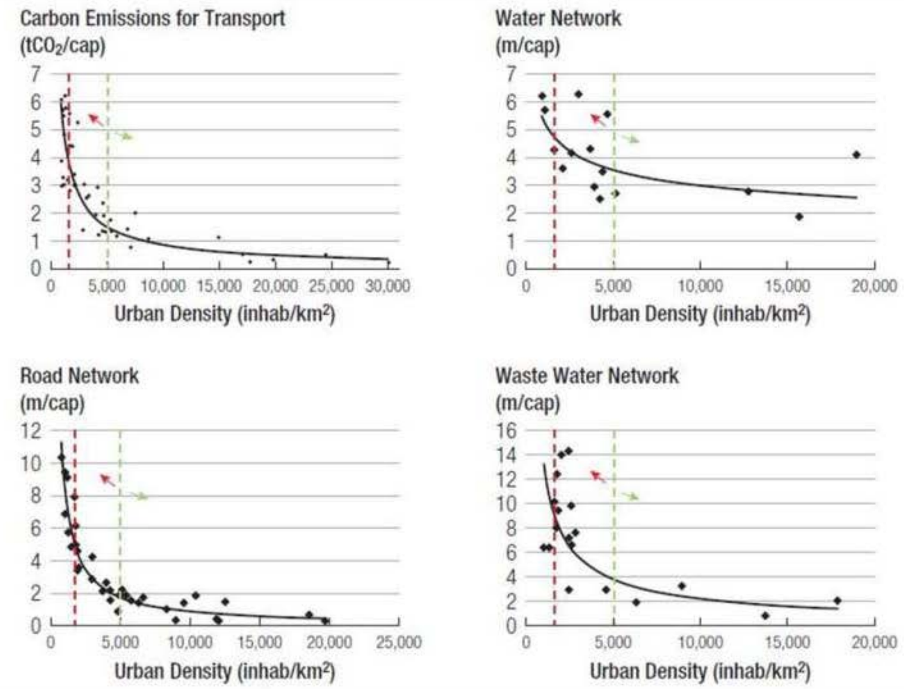
The majority of the initiatives undertaken by the governing bodies at different scales towards enhancing the efficiency of the municipalities have been focused on either providing them with an alternative renewable source of energy or conducting audits to understand the running efficiency of the utilities. However, the guidelines and manuals for the municipal energy efficiency projects also do not consider the effect of the spatial parameters and the urban pattern on the municipal energy services. Therefore, the current study finds its immense significance in understanding the effects of spatial parameters and urban development patterns in the municipal services. This paper attempts to establish the nexus between water and energy considering the urban development parameters and the service level parameters at the urban scale.

Parameters affecting energy consumption in water supply

There have been many studies at the national and international levels aimed at understanding the effects of urban form and urban development patterns on the energy consumptions of cities. The Energy Sector Management Assessment Program (ESMAP) documents the studies pertaining to various cities across the globe to understand the relationship between the physical forms of the cities such as spatial distribution of the built area, building typology, street pattern and the travel pattern of the residents on their energy consumptions (Salat, Chen, & Liu, 2014). Further, the World Cities Report by the UN-Habitat also highlights the effects of the physical form of the cities such as built characteristics, the relation of the transport corridors with the population density and the pattern of the open spaces on the energy usage and the future growth pattern of the cities.

Figure 1 represents the effects of one of the physical forms, densification, on the efficiency of the municipal services and the infrastructure cost (Salat et al., 2014).

The density in terms of households and population also has a similar effect on the energy consumption in the delivery of the municipal services as the provision of these services will be directly



Note I Impact of urban density on carbon emissions for transport and infrastructures: road, water, and wastewater network lengths (various cities in developing and developed countries). The business-as-usual urbanization scenario corresponds to the red arrow and would lead growing cities toward automobile dependency and high energy consumption per capita for transport, as well as higher infrastructure costs per capita. The green dotted line represents the current situation in Chinese cities, with an average density around 5,000 people/km². The red dotted line corresponds to the average gross density of new urban developments in China, with a density below 2,500 people/km². Moving in the direction of the green arrow would promote sustainability.

Source I *Salat and Bourdic 2013; Müller et al. 2013.*

Figure 1: Impacts of densification of cities on their efficiency and infrastructure costs

proportional to these densities (Bigio et al., 2014). As mentioned earlier, the household density and the population density will also have impacts on the infrastructure cost. Cities with higher densities tend to lower the per capita infrastructure length and thereby reduce the life cycle cost per capita (DB et al., 2013). Further, it is also observed that the wastewater network, water supply network and the road length per capita are inversely proportional to the population density. Although densification and compact cities are highly debated concepts for city development and provisioning of city infrastructure, densification is expected to lower infrastructure costs as described in the charts shown in Figure 1.

Apart from density, there are many other parameters as well that impact the energy consumption in the delivery of the municipal services based on the urban form, shape, size and the urban policies of the cities. Some of those parameters and their definitions as identified from the literature review are described below:

Parameters affecting energy consumption	Source of literature	Definition of the parameter
The physical form of the urban centre	(Salat et al., 2014), (UN-HABITAT, 2016)	The generic form of the city or the physical expanse/ area of continuously built-up urbanization
The density of household and population	(Larson & Yezer, 2014)	• Residential or household density is defined as the number of dwellings per hectare (dw/ha) • Population density is a measure of the intensity of land use, expressed as a number of people per square kilometre or hectare.
Land use and FAR	(Bigio et al., 2014), (Salat et al., 2014)	• Land-use planning often leads to land-use regulation, which typically encompasses zoning. Zoning regulates the types of activities that can be accommodated on a given piece of land, as well as the amount of space devoted to those activities, and the ways in which buildings may be situated and shaped. • Floor area ratio (FAR) is the ratio of a building's total floor area (gross floor area) to the size of the piece of land upon which it is built.
Road network and density	(UN-HABITAT, 2016), (Salat et al., 2014)	• The road network is the system of interconnected roads designed to accommodate vehicles and pedestrian traffic. • Road density is the ratio of the length of an area's total road network to the total area of the given land.
Climate	(Salat et al., 2014)	Climate is the statistics of weather over long periods of time. The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents.
Topography	(Salat et al., 2014)	The topography is the study of the shape and features of land surfaces. The topography of an area could refer to the surface shapes, natural and artificial features.
A socio-economic indicator like economic density	(Salat et al., 2014)	• Economic density is the total land area divided by gross domestic product (GDP) at market prices in the current currency rate. • Net State Domestic Product (NSDP) is defined as a measure, in monetary terms, of the volume of all goods and services produced within the boundaries of the State during a given period of time after deducting the wear and tear or depreciation, accounted without duplication. Similarly, the gross domestic product is also available at the city level.

Identification and classification of parameters

As explained earlier, there are many parameters affecting energy consumption in the municipal water supply. A few of the parameters identified from the available literature that affect the energy consumption in the municipal water supply are categorized into Urban Development Parameters and Service Level Parameters.

Urban development parameters:

These are the parameters that are characteristics of the city. The urban development parameters that are considered for the current study are listed below:

1. Urban form - Population Density, Household density

The urban form of the city comprises of parameters such as population density and household density that affect the energy consumption in the delivery of water supply. In order to understand the effects of the same, a hypothesis was contemplated at the start of the study which is as described below.

The absolute increase or decrease in the population de-facto increases or decreases the total electrical energy consumption in the city. But density as an indicator of area and population determines the consumption pattern of services in a city. In this case, the higher the density, the lower the electrical consumption for water supply and wastewater services. Household as an indicator of the population also determines the total consumption pattern in a city by obtaining the number of water supply connections in the city. Therefore, the increase in the total number of households in the city increases the total energy consumption in the city.

The cities considered for the study are classified based on the density and the size of the cities as per the Urban and Regional Development Plans Formulation and Implementation (URDPFI) guidelines.

- Cities in the density range between 150 to 75 people per hectare
- Cities in the density range between 74 to 25 people per hectare
- Cities of density less than 25 people per hectare

2. Urban Morphology- Building typology

Urban morphology includes parameters such as building typologies and building heights that affect energy consumption in the delivery of water supply. The structure of the city is often determined by the typology of buildings and the Floor Space Index (FSI) provided for the consumption/consumed. The hypothesis contemplated at the start of the study to understand the energy consumption in the water supply is that the higher the FSI consumed in the city, the lower is the municipal electrical energy consumption for water supply and wastewater services. The more the typology of apartments in a city, the lower is the municipal electrical energy consumption for water supply and wastewater services. However, the same cannot be ascertained for the total energy consumption of the city.

As the data pertaining to the FSI is not available for most of the cities that are considered in the current study, the building typology has been considered by assessing the percentage of households residing in apartments. Therefore, the cities that are considered for the study have been classified into two as explained below:

- Cities with more than 15% of the households residing in apartments and have a water supply connection
- Cities with less than 15% of the households residing in apartments and have a water supply connection

Service level parameters:

These are the parameters that are characteristics of the municipal water supply service. The service level parameters that are considered for the current study are listed below:

- Coverage of the network - Population served, Total area served
- Per-capita water supplied
- Non-revenue water
- Source of water supply - Groundwater or Raw bulk purchase

These parameters that are associated with the level of service of the water supply affect the energy consumption in the delivery of the service. The hypothesis contemplated at the start of the study to understand the relation of these parameters with energy consumption is that the increase in the levels of service provided will increase the consumption of electrical energy. It is presumed that the higher the area coverage and per capita water supplied, the higher would be the energy consumed. Lowering the non-revenue water would lower the energy consumed.

Source of water determines the electrical energy consumed in delivering of water-supply, as the electricity costs account for charges from source to the treatment plant until the distribution system. The assessment would reckon the difference in consumption when sourced primarily from the ground-source or purchased from the raw bulk source. Table 2 provides a brief regarding the classification of the service level parameters.

water supply value chain occurs at the pumping station and distribution systems. Hence, cities with water supply networks were selected for the study.

ii. Network length

To understand the electrical energy consumption taking place in the network length of water supply services, it is vital to have data pertaining to the total length of the network.

Table 2: Classification of cities based on service level parameters

Service Level Parameters	Classification of cities	Source referred for classifying cities
Population served with the water supply	• Above 1 Lakh • 99,999 to 50,000 • 49,999 to 20,000 • Less than 20,000	Based on the census classification of Indian cities
Service Area	• Above 40 sq. km. • Less than 10 sq. km.	Based on a stratified sampling of the available data, keeping in mind the distinction between large, medium and small-sized cities
Per capita water supplied	• More than 135 LPCD • 90 to 135 LPCD • Less than 90 LPCD	Stratified sampling referring the Central Public Health and Environmental Engineering Organisation (CPHEEO) guidelines for water supply which mandates 150 LPCD for metropolitan cities, 135 LPCD for large cities and 90 LPCD for medium-sized cities.
Non-Revenue Water	• More than 20% NRW • Less than 20% NRW	Classified based on the considered permissible level of NRW as per benchmarks

Cities considered for the study

After identifying the parameters, the cities for the study were selected from the states of Gujarat and Maharashtra, as they accounted for two of the highest energy-consuming states in India (Alliance for an Energy-Efficient Economy- AEEE, 2018). The Performance Assessment System (PAS) project at CEPT University has the parameter-wise service level data sets collected and stored for 170 cities of Gujarat and 393 cities of Maharashtra. Out of these, the case cities required for the current study were selected on the basis of the following three criteria:

i. Presence of networked system

The study is limited to cities with networked water supply service as it targets the conveyance systems and the electricity consumption associated with them. The major share of electricity consumption in the

iii. Electricity charges

Data pertaining to the electricity charges is very important to identify the relation between energy consumption and the water supply. Though most of the cities in the PAS data sets have data pertaining to the energy charges, in most of the cases they include the fuel charges and energy charges related to the faecal sludge management and sewage conveyance. So, only the cities that were having networked water supply services and data pertaining to the electricity charges in the water supply were considered for the current study.

Based on the above-mentioned criteria, a total of 93 sample cities were selected from Gujarat and Maharashtra. Out 93 cities, 61 were selected from Gujarat and 32 from Maharashtra. The class and the type of cities selected are represented in Table 3. Further, the table represents the spatial distribution of the 93 sample cities.

Table 3: Size and Class of the case cities selected for the study

State	Municipal Corporation	Class A	Class B	Class C	Nagar Palika
Gujarat	6	9	19	16	11
Maharashtra	13	4	7	6	2

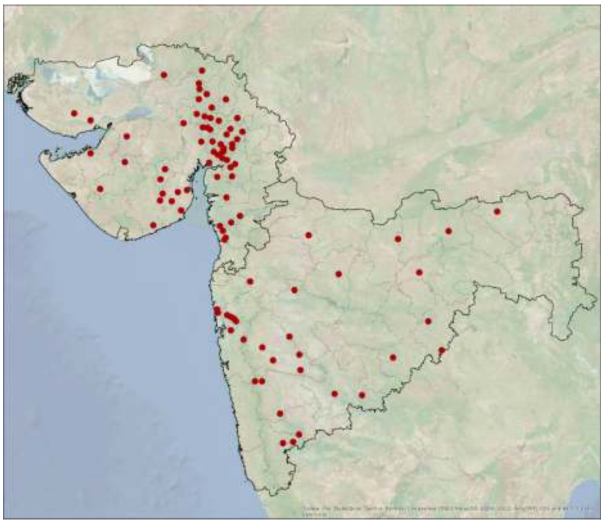


Figure 2: Spatial location of the cities selected from Gujarat and Maharashtra

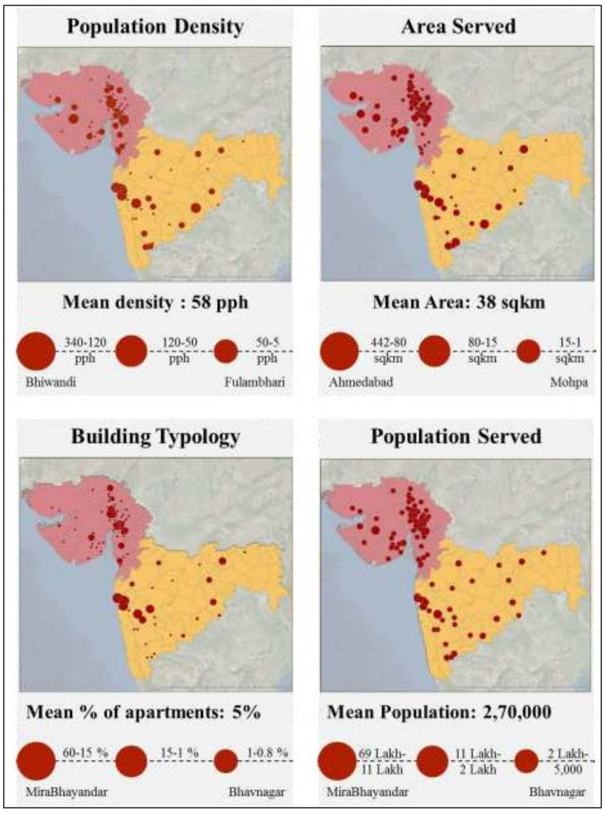


Figure 3: Variation in characteristics

The cities selected were spatially distributed across the two states. Further, they also represent the distributed variation in urban characteristics and morphologies. These variable characteristics of the sample cities will assist in understanding the variation in energy consumption across the cities of different urban characteristics. Figure 3 represents the diversity in the characteristics of the case cities.

Statistical and analytical methods used

As described in the earlier chapters, the study attempts to address the field of energy consumption and conservation through macro-level assessment. The macro factors and parameters are derived from the literature study to understand the relationship between urban characteristics and energy consumption in the municipal water supply. The impact of the identified parameters on the energy consumption in the production of water and the supply of water is studied for the 93 case cities selected. In order to understand the relationship between the variable parameters, it is important to understand the level of dependency between them. The level of dependency and the kind of association between the parameters are studied using statistical tools such as Correlation, Regression, and Variance.

- Correlation

The degree of dependency between two variables is referred to as correlation. This tool determines the relationship shared between the variables measured. The study uses linear correlation to measure the relationship between the variables. A correlation value of -1 represents a perfectly negative relationship and +1 represents a perfect positive relationship. 0 indicates that there is no relationship between the variables. A visual representation of the scatter plots in the correlation is depicted in Figure 4.

- Linear regression analysis

The Regression Equation is the algebraic expression of the regression lines. It is used to predict the values of the dependent variable from the given values of independent variables.

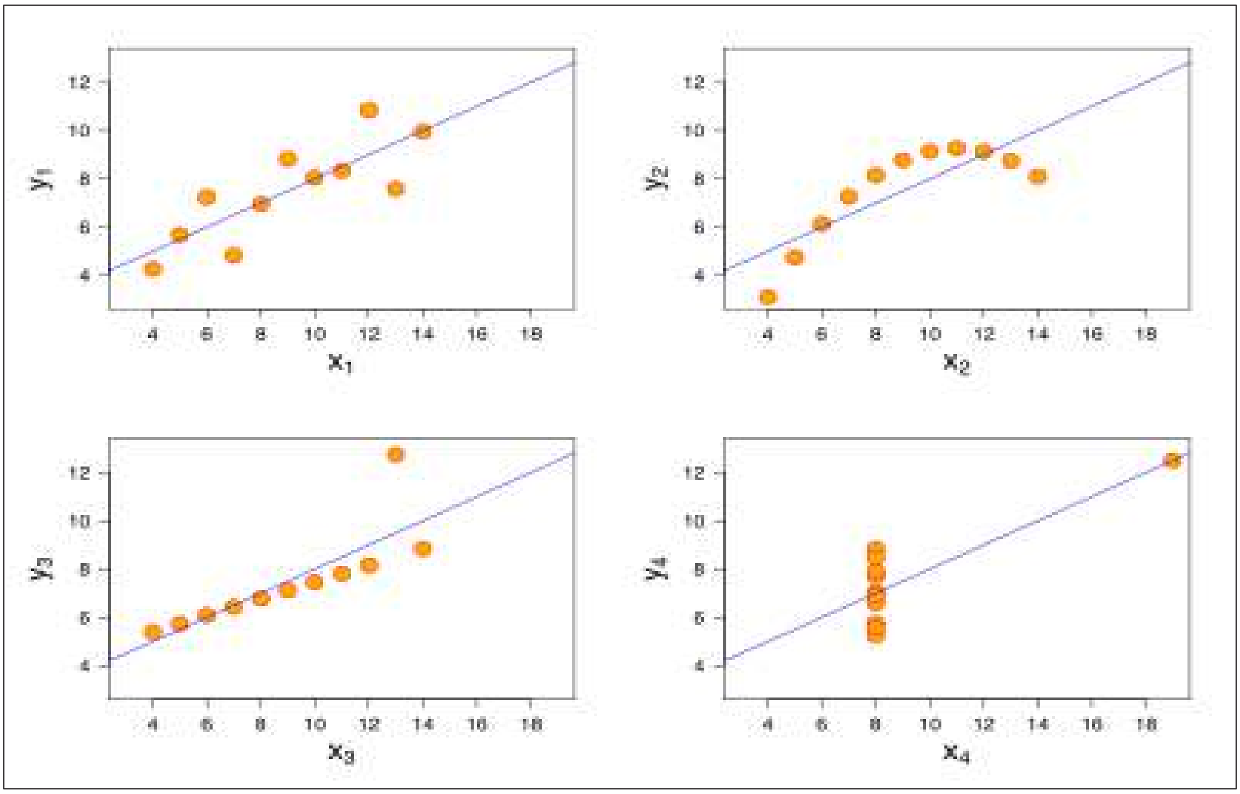


Figure 4: Sample scatter plots showing correlation

Ye = a + bX

'a'= Level of the fitted line i.e. the distance of line above or below the origin

'b'= Slope of the line i.e., Change in the value of Y for one unit of change in X

- Variance (P- Value)

All hypothesis tests use a *p*-value to weigh the strength of the evidence (what the data tell you about the population). The *p*-value is a number between 0 and 1 and interpreted in the following way: A small *p*-value (typically $\leq$ 0.05) indicates strong evidence against the null hypothesis so that the study rejects the null hypothesis. A large *p*-value (> 0.05) indicates weak evidence against the null hypothesis so that the study fails to reject the null hypothesis. *p*-values very close to the cut-off (0.05) are marginal.

Conclusion and Synthesis

In the Indian context, while municipal energy requirements are predicted to grow and efforts for conservation remain abysmally low, the study has attempted to address the field of energy consumption and conservation through macro-level assessment. To understand this, the study looked into two relative units of consumption to measure unit consumed in the production of water, and the unit consumed per 100-metre length in the supply of water.

The variation in unit consumed for the production of 1 kilo-litre of water in the selected 93 cities has a spread between maximum consumption of 1.56 kWh/m^3, to a minimum consumption of 0.02 kWh/m^3. The average consumption of the selected cities is 0.52 kWh/m^3. The variation has been spatially depicted in Figure 5.

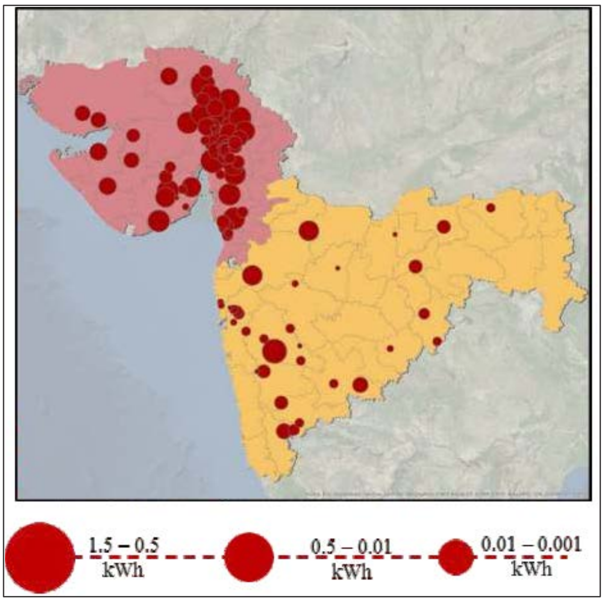


Figure 5: Unit electric energy consumed for the production of 1 KL of water (kWh/m^3)

The variation in unit consumed to supply water for the 100 m length in the selected 93 cities has a spread between maximum consumption of 9800 kWh/100 m, to a minimum consumption of 4.8 kWh/100 m. The average consumption of the selected cities is 2800 kWh/100 m. The variation has been spatially depicted in Figure 6.

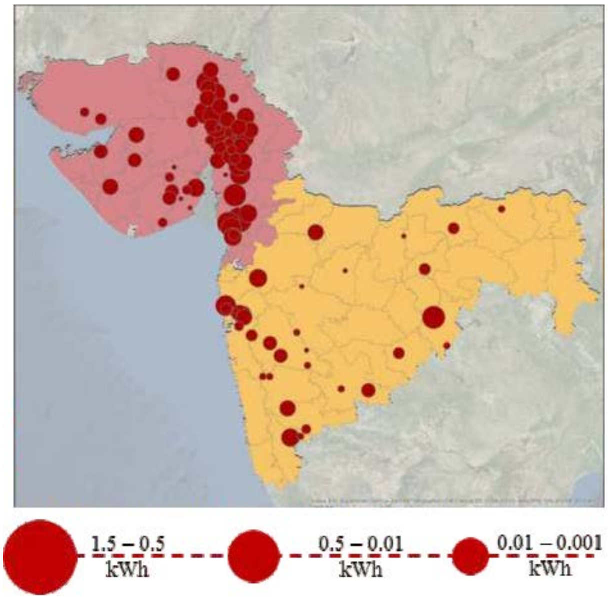


Figure 6: Unit electric energy consumed per 100 m supply of water

The study perceives that the electrical energy consumed for the production of water shares a negative relationship with most of the parameters. The study establishes a weak negative relationship with density where unit consumption decreases for every unit increase in density. Similarly, it is observed that energy consumed per 100 m length supply of water also shares a weak negative relationship with density. This establishes that densification assists in reducing the energy consumed in the production and the delivery of municipal water supply service.

Similarly, upon studying the relationship between the urban morphology, percentage share of apartments, and the energy consumed in production, a negative relationship was observed. Further, it is also observed that the energy consumed in 100 m length supply of water also shared a negative relationship with urban morphology. Thus, the study establishes that the energy consumed in the delivery of water supply service reduces with the increase in the share of apartment typology of housing. This study limits itself to municipal level consumption, without assessment of building-level consumption.

The study also investigates services like per-capita water supplied in the cities and their relationship with energy. It was observed that the unit consumed for the production of water shared a negative relationship with per-capita water supplied. This brings out the theory of economy of scale, as the per-unit cost decreases with an increase in the volume supplied. But, for unit consumed per 100 m length supply of water, the relationship shared is positive in nature. This suggests that municipal energy consumption increases with an increase in the volume of water in the network.

The study also perceives that energy consumed for the production of water shares a negative relationship with the area served in the area covered with the water supply service. However, the energy consumed per 100-metre length of water supply shares a positive association with the energy consumed. This means that although the unit cost of production of water decreases with increase in the area served with service due to factors like the economy of scale, the energy consumed in pumping and supply per 100 meter is higher with an increase in the area of supply. This can also be attributed to the impact of the population served with the water supply service.

The study also assesses variations in the parameters to interpret the principles that need to be focused on for optimal energy consumption in municipal services at a macro scale. The statistical tool of variance is used to understand these variant characteristics. This facilitated in bringing up the differences in the pattern of consumption that could not have been acknowledged only through assessment at a gross urban scale. This assessment has obtained the different levels of association each variance in parameter displays, along with its level of dependency.

With the aim to understand the variation in energy consumption between highly dense cities (between 150 PPH and 75 PPH), mid-dense cities (between 74 PPH and 25 PPH) and low dense cities (lesser than 25 PPH), the study examined their association with units of electrical energy consumption. It was observed that energy consumed in production and supply of water is lower in highly dense cities. This can be attributed to the economy of density which allowed the lowering of unit cost by enabling synergy of services. Mid-dense and low dense cities are observed to consume higher energy. The study also looks into the variation in urban morphology and its association with energy consumption. As building typology is chiefly considered as the percentage of apartment households for this study, the study essentially examines the effect of a high-rise building on energy consumption. The cities with a lower share of apartments (less than 15 per cent of households residing in apartments) have higher unit consumption of energy for production and supply compared to cities with a higher share of apartments (more than 15 per cent of households residing in apartments). This goes on to suggest that municipal energy consumption is lesser in cities with a higher share of the apartment as the energy spent is up to the apartment itself, not the household. The study does not contemplate the energy consumed at the building level. Thus, the study focuses only on municipal energy consumption and does not account for the overall energy consumption in the city.

Along with urban development parameters, the study also examines variance in the level of services to understand its association with energy consumption. This has been assessed by exploring the effect of the area and population served, as well as municipal service level parameters like per-capita supply, non-revenue water and source of supply. The study deduces that energy consumption per unit production is lower in the larger population served (above 50,000) compared to cities with the lower population served (lower than 20,000). This can be attributed to the principle of the economy of scale where the unit cost of production is lowered due to the scale. The unit cost for supply is higher in both extremes, i.e., very large population served (above 1 lakh) and very low population served (below 20,000). Similarly, the unit consumed for production is lower for large cities (above 40 square Kilometre) compared to smaller cities (less than 10 square Kilometre), decreasing with per unit increase in area. The unit of energy consumed for supplying water increases with an increase in area for both large and small cities but the cost is optimized in larger cities where it increases by 13 times compared to 423 times in smaller cities. The observations for per-capita supply are similar in the sense that although the consumption shares a positive association with per-capita supplied, the unit energy consumed is higher for lower per-capita supply (less than 90 litres per person per day) compared to higher per-capita supply (above 135 litres per person per day). This brings attention to the principle of economy of scale where the higher the unit, the greater the optimization of energy in municipal services.

Although it is assumed that issues like non-revenue water (NRW) affect energy by increasing consumption, it was observed that cities with a higher NRW decrease consumption while lesser NRW increases it. This is because a higher NRW leads to a higher volume of water being lost in transmission leading to a reduction of the energy consumption in supply. However, this is not a measure of optimizing energy; the parameter provides insight into the function of energy with services. Further, on the subject of the source of supply, it is identified to not have any variation in energy consumed for the production of water upon whether the source of supply is groundwater or raw bulk purchase. But, the unit consumed in supplying it is far lower for groundwater-dependent cities by 36 times due to cost spared on account of overlooking treatment. This observation does not intend to mean the cities relying on groundwater sources perform better in terms of energy consumption. But, it provides us an idea regarding why the ULBs might prefer quick-fix solutions like groundwater extraction over purchasing raw water.

The outcomes from the study can be synthesized by regarding the energy consumption in water supply service by considering it in the following perspectives:

i. **As a resource:** The outcome of population density and building typology assessment shows that cities need to aspire for compact development, with high densities, higher built-density and a higher share of high-rise buildings which would be a function of the economy of density. The perspective is visually represented in Figure 7.

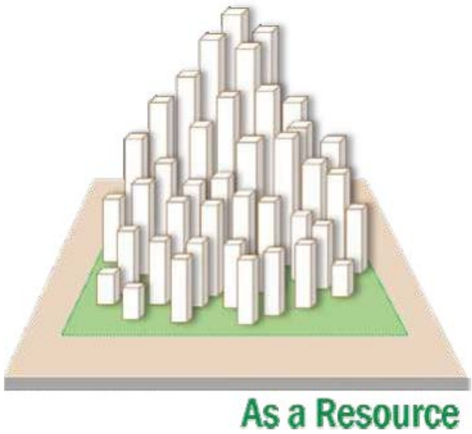


Figure 7: Synthesis in perspective of Resource

ii. **As a product:** It is observed that the per-unit cost of production decreases significantly with an increase in the levels of services, which is a function of the economy of scale. This reduces per-unit energy consumption. But, it may lead to diseconomies of scale; the scenario is highly unlikely to occur considering the context of Indian cities. The perspective is visually represented in Figure 8.

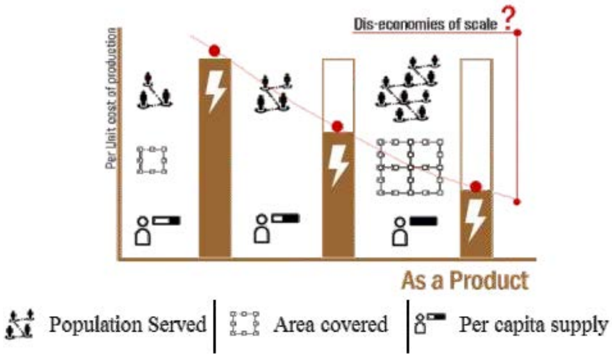


Figure 8: Synthesis in perspective of product

iii. As a service: The outcome of the study establishes that the unit cost per length is highest when the scale of service levels is smaller and the unit cost is higher when the scale of service levels is larger. But, it is lowest when the scale is optimum. This brings up the perspective of the decentralized approach for optimization of energy consumption in the services. The perspective of water supply as a service is visually depicted in Figure 9.

This approach for service provisioning ranges between:

- Population served: 20,000 - 1, 00,000
- Area served: 1 - 30 Sq. Km
- Per capita supply: 90 - 135 LPCD

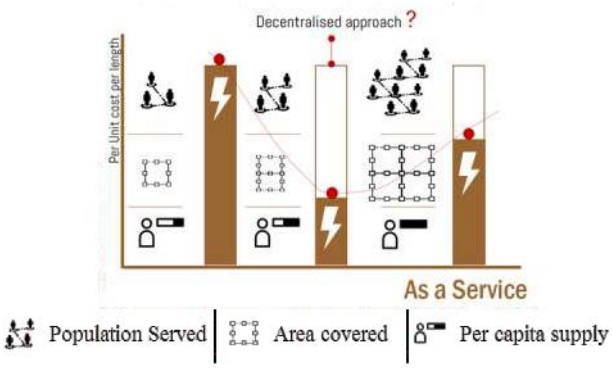


Figure 9: Synthesis in perspective of service

iv. As a system: Assimilating the outcomes from the study in perspective of water supply as a system, it can be observed that decreasing energy consumption as a goal is not always beneficial when water is viewed as a resource. Though the greater reliance on groundwater source and the increased percentage of non-revenue water reduces the energy consumption in the service, these scenarios will lead to more serious negative impacts such as lowering of groundwater table and water losses. Thus, these measures cannot be advised in optimizing energy consumption. The perspective is visually represented in Figure 10.

Figure 10: Synthesis in perspective of system

As highlighted earlier in the paper, the relationship between spatial planning and energy consumption in municipal services is yet to be acknowledged in programmes and policy. The study signifies the necessity to address these aspects effectively under a dedicated segment in the National Energy Policy. It can be inferred that as a spatial tool, compact cities as a function of densification and an increase in the share of high-rises can help cities to reduce and optimize their energy consumption. As a tool for service provisioning, the cluster-based approach needs to be further explored. It also conclusively implies that the economy of density and economy of scale are the driving principles to optimize the unit cost of energy consumption spatially.

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...continued from page 04

To answer this, one may want to adopt a more sophisticated economic analysis of conservation projects. This includes considering the "true cost of water" at the facility, which is the cost of water plus the cost of the energy and chemicals required to move, heat/cool, and treat it. Even more sophisticated analysis would consider the environmental costs of energy utilization and water use.

Often, the water-energy nexus is simplified to quantifying how much energy is used to provide water and how much water is used to produce energy. But, this does not capture the opportunities afforded by and the complexity of the water-energy nexus. A deeper understanding of it will facilitate benefits towards the sustainable use of water and energy and help us meet the most critical challenges of the 21st century.