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Urban Water Management with a Full Cost Recovery Policy: The Impact of Externalities on Pricing

Sanju John Thomas [1,*], Mukund Haribhau Bade [2], Sudhansu Sekhar Sahoo [3], Sheffy Thomas [4], Ajith Kumar [1] and Mohamed M. Awad [5,*]

[1] Department of Mechanical Engineering, Cochin University of Science and Technology (CUSAT), Cochin 682022, India
[2] Department of Mechanical Engineering, Sardar Vallabhai National Institute of Technology (SVNIT), Surat 395007, India
[3] Department of Mechanical Engineering, Odisha University of Technology and Research (OUTR), Bhubaneswar 751029, India
[4] Department of Electronics and Instrumentation, Federal Institute of Science and Technology (FISAT), Angamaly 683577, India
[5] Mechanical Power Engineering Department, Mansoura University, Mansoura 35516, Egypt
* Correspondence: sanjujohnthomas@gmail.com (S.J.T.); m_m_awad@mans.edu.eg (M.M.A.)

Abstract: Water has complex cost dimensions and is considered a scarce commodity under a reduced-recycle-reuse system with a full cost recovery strategy. The impact of externalities from the social, economic, and ecological aspects of exploiting water resources are often not accounted into the pricing mechanism. We discuss the current work model as well as a pricing strategy for a water infrastructure program with a full cost recovery strategy. Single and multi-block pricing models are created, and their effect on water pricing is discussed. The impact of externalities is accounted for, and respective cost components, namely, environmental cost, opportunity cost, and ecological imbalance cost are included in the water pricing, to analyze the impact on the cost of produced water. A comparison under the normalized, single-block and multi-block pricing strategy are discussed and the payback period is found. It is seen that the unit cost of potable and non-potable water is brought down from 0.94 USD/m^3 and 0.51 USD/m^3 to 0.62 USD/m^3 and 0.29 USD/m^3, respectively using a multi-block pricing strategy. It is recommended that policy interventions in a full cost recovery water pricing strategy should consider the cost of externalities with a multi-block pricing system for breakeven in water infrastructural investments.

Keywords: water pricing; urban infrastructure; multi-block pricing; externality costing; single-block pricing

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1. Introduction

Water scarcity is a huge challenge across the globe, especially in the region of the Middle East and North Africa (MENA), affecting cropping patterns and decisions on the import and export of cereals [1]. Over-consumption of water, non-metering, exploitation of new water resources, treatment cost of below-par quality water, and transformation of resources, demand a shift in egalitarian pricing strategy in water management programs [2]. It is found that addressing the energy, water, and food (WEF) nexus as a single entity shall address the water crisis in line with constraints, possible policy interventions, and meet sustainable development goals [3]. Analysis models to analyze the efficiency of water usage in the urban-peri-urban region in line with the WEF nexus to assess the importance of water usage optimally have proved successful [4]. Reformed price structures, direct benefit transfers, demand-side management, and the use of efficient technologies at the source are mechanisms that can compensate for the higher price demands. Water use and recycling for application in the WEF nexus is important to address the use of water efficiently including agriculture which is found as the optimized way to address scarcity [5,6]. Two strategies that can address water scarcity are (i) providing incentives and taxation to meet the additional cost of water infrastructure and (ii) adopting pricing strategies with price discrimination [7]. Water pricing should focus on the socio-economics of the region and be aptly priced to keep the sustainable initiatives considering the naturally available resources and new technology [8]. Flat rate, uniform rate, block rate, and complex rate structures are the basic types of water pricing explored for urban-municipal corporations [9]. However, different pricing models were studied and experimented with to improve demand-supply management. Full cost recovery in water management programs with environmental cost components directly proportionated to respective impacts is an effective method of control [10]. The full cost with efficient use is the crucial strategy for optimal use of water resources in urban area water management programs [11]. The increasing block pricing is not idle for developing countries, considering the social justice for use of water. It is better to consider the old pricing strategy with rebates and discounts [12]. High uniform water pricing can be a direct intervention to curtail water use, while its impact on social rights for water to meet minimal needs can be questioned [13]. Increasing block pricing, which is a mix of efficient pricing strategy and egalitarian pricing philosophy, is an effective mechanism to curtail water waste, however, the sizing of blocks in a multi-tier social structure will be critical [10].

An exhaustive study on water management programs in a few cities across the globe shows that non-metered flat pricing privileges consumers to use water till the marginal benefit becomes zero resulting in aggregate consumption mismatches [2]. The study shows that pricing below the 'full cost' results in the ineffectiveness of water management, while the cities which used an increasing block pricing strategy have resulted in meeting social inequality and motivating the individual user to use water efficiently. The multi-block pricing system has shown effective results to bring a conscious effort to reduce the consumption of water [14]. The impact of block pricing, to improve water use efficiency, conclude that identifying the size of block and price slabs is difficult in a divergent socio-economic group [15].

The pricing structure for any naturally available resource should be based on the social parameters, environmental conditions, and cost recovery mechanism [7]. The water pricing should be done on three principles which are equality, efficiency, and environment [16,17]. Sustainable use of water is to use exhaustible renewable resources within their regeneration limits while having the rational judgment to use non-renewable resources or their availability for prolonged periods. Any impact whose reason can be traced back to human involvement and whose cost is not accounted for among the economic decision-makers can be considered an externality. The type of event, the scale of impact, system boundaries, and the social group determine the decision-making for reactive or pro-active decision-making and actions [16,17].

Water consumption and pricing strategy should consider water to be administratively priced to include the cost of externalities, as an incentive or subsidy [16]. There is a strong interlinking between energy, water, and food nexus, and sustainable initiatives should move immediately from concept to practice [18]. Along with block pricing, non-pricing interventions, such as raising social conscience for water use are proven as successful initiatives [13]. A range of options including pricing, restrictions, awareness, and efficient technologies can effectively control supply-demand management, for the benefit of suppliers and customers [16]. The full cost pricing and efficient use of water alone cannot control the sustainable use of water, but policy and instrumental changes to consider water as a limited natural resource are mandatory [19].

The literature survey concludes that earlier efforts for full cost recovery pricing have not taken the cost of externalities into the water pricing system for the water management scheme to be self-sustainable. In the current work, an urban water management program with water sources such as natural reservoirs, recycled water, and desalinated water are considered as water sources to meet the potable and non-potable requirements of the city. The possibilities of levelized cost, single-block, and multi-block pricing systems are explored. Efforts are made to create a sustainable water pricing model, for different water quality levels for multiple water requirements. Considering the high capital cost of water infrastructural projects, the cost of externalities is included in the water pricing model, for a better cost breakeven. Social costs due to greenhouse gas emissions, opportunity costs due to depleting naturally available water resources, and ecological imbalance are costs accounted for impacts due to externalities. The structure of this paper adopted the following methodology: (1) Design the objective function to minimize the water infrastructural cost for efficient demand-supply management in a multi-resource variable demand environment; (2) Identify the unit cost of produced water under a single-block pricing strategy; (3) Identify the externalities and corresponding impacts whose costs can be accounted; (4) Structure an appropriate multi-block pricing slab to motivate efficient utilization of water; (5) Account the 'cost on externalities' into a multi-block pricing model to identify the impact on the cost of produced water. Identify policy interventions required for a full cost recovery pricing model in water infrastructure programs.

2. Design of the Water Infrastructure Model

The water infrastructure model for a greenfield industrial city with a full cost recovery strategy is modeled. Treated river water and desalinated seawater are considered potable water resources, while treated sewerage and industrial effluent are considered non-potable water resources. A water treatment plant (WTP) is considered for treating river water to potable standards. Since the river water is not a perennial source, water from a seawater reverse osmosis (SWRO) desalination plant is considered the second source of potable water. To promote sustainable activities, a renewable energy-based hybrid technology desalination plant, termed energy-efficient desalination (EED), is considered the third source of potable water. The produced water from WTP, SWRO, and EED is expected to provide potable water to total dissolved solvent (TDS) levels less than or equal to 200 ppm. The wastewater after human needs for washing and sanitation from residential and industrial establishments is recycled to reuse standards of 500 ppm and less by a sewerage treatment plant (STP). A common effluent treatment plant (CETP) recycles wastewater from industrial processes to TDS levels less than or equal to 500 ppm.

2.1. Assumptions Considered in the Water Management Program under Study

The assumptions considered for the design of the water management program are:

i. The water consumption per head is taken as 200 LPD (higher by 25% than normal standards) considering the future developments in a Greenfield project.
ii. The availability of the water in the river is seasonal and cannot meet the potable water requirement through all seasons. Hence the water treatment plant (WTP) is sized 40 MLD, half the size of the total potable water requirement for the city. The potable water network for the city is based on an 80 MLD design.
iii. To increase the reliability of potable water supply, seawater desalination is considered the second source of supply, with the size allotted at 50% of the total potable water requirement for the city. Out of 40 MLD, 35 MLD will be met by conventional seawater reverse osmosis (SWRO) technology, while 5 MLD will be met by a renewable energy powered, hybrid technology energy-efficient desalination (EED) plant.
iv. The recycled, treated water from the sewerage treatment plant will be the first source for the non-potable applications. The sizing of the STP is done based on the consumption of 80 MLD potable and 320 MLD non-potable by the city population. The non-potable water distribution network is designed based on STP sizing.
v. It is assumed that 80% of potable and non-potable water consumption can be recycled, which makes 320 MLD in total. However, to meet any uncertainty or shortfall, an additional 40 MLD of industrial effluent is treated by a common effluent treatment plant (CETP) to a quality of <500 TDS, for supply as a non-potable requirement.

vi. It is assumed that the water requirement for the process applications of industries is met by the federal administration on a chargeable basis. This water network is not considered in the current study.
vii. The cost of the potable and non-potable utility network lines, and sewerage/effluent collection network lines are not considered for the current analysis. It is assumed that this cost is borne by the urban administration.

The technology considered for the STP is a sequential batch reaction, automated to address variable parameters which are generally used by large municipalities. The common effluent treatment plant (CETP) is based on an activated sludge process (ASP), trickling filter (TF) technology and a tertiary treated reverse osmosis plant, which is an established combination for industrial effluent treatment. The water treatment plant is on the technology of settling, floatation, adsorption, ultrafiltration, and disinfection, ideal for surface water, including river water treatment. The seawater desalination plant considered in the analysis is multi-pass reverse osmosis technology, which is widely accepted [20–23]. The renewable energy-based, energy-efficient desalination plant will use combinations of technologies with reverse osmosis after the first pass to increase the recovery rate. The plant will operate on solar photovoltaic power, without battery backup, hence triple-sized, to operate on design size during sunlight hours [24]. The water infrastructure for a Greenfield city is modeled with the design conditions, costs, and assumptions from previous studies [20,25–30]. The parameters for design and modeling are described in Tables 1 and 2, respectively.

Table 1. Design parameters and assumptions are considered for problem modeling.

Population	2 Million Individuals
Potable water requirement (person/day), drinking and cooking	40 L
Water for sanitation (person/day)—Non-potable	80 L
Water for washing (person/day)—Non-potable	80 L
The efficiency of STP (BOD removal rate)	90%
The efficiency of CETP (BOD removal rate)	90%
Life of the plants	25 years
Interest on investment	4%
Discount rate/Return rate	4%
Acceptable total dissolved solids (TDS) for drinking	<200 ppm
Acceptable TDS for washing	<500 ppm
Acceptable TDS for sanitation	<500 ppm

Table 2. Cost parameters of various water infrastructures.

Source	Capital Expenses USD/MLD (Million)	Yearly Operational Expenses (%)	Operational Expenses USD/MLD (Million)
Water Treatment Plant (WTP)	0.4	8	0.03
Seawater Reverse Osmosis (SWRO) Plant	1.2	14	0.17
Energy-Efficient Desalination (EED)	5.14	6.5	0.33
Sewerage Treatment Plant (STP)	0.64	7	0.04
Common Effluent Treatment Plant (CETP)	1.36	12	0.16

[31–35].

While the capital cost of the EED is the highest, the operational cost of the SWRO and CETP is the highest. The operational cost and the trend of operational cost with a 5% annual increase are shown in Figures 1 and 2, respectively.

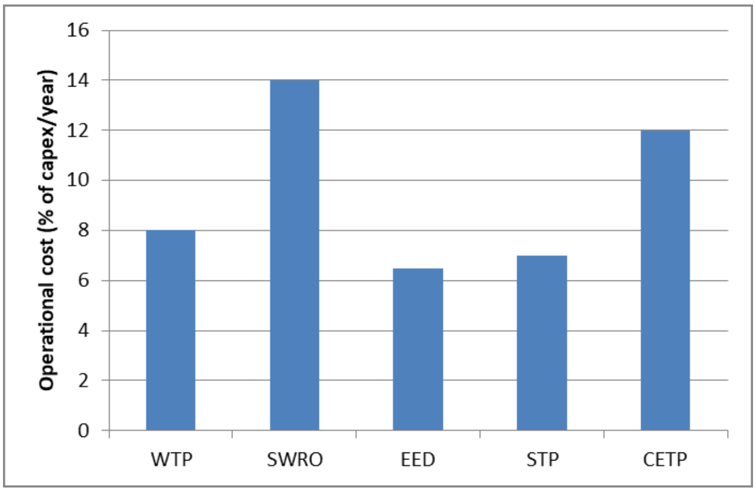

Figure 1. Operational cost percentage.

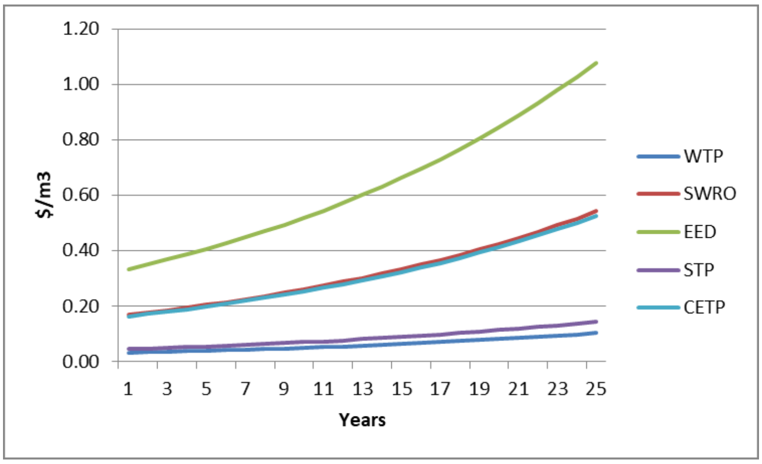

Figure 2. The trend with a 5% annual increase.

It is seen that there is a considerable difference between the components regarding capital cost and operational cost. This shows that there will be a considerable difference between various components concerning payback and the levelized cost of production.

2.2. Formation of the Objective Function for Multi-Resource and Variable Demand Allocation Model

The objective of the problem formation is to reduce the total cost of the water infrastructure program, by optimally allotting the capacities for each water source. The parameters and attributes used for modeling the problem statement are represented in Table 3, and the abbreviations used are as defined at the end of the paper.

Table 3. Parameters and attributes of the problem statement.

S N	Sources			ATC per Capacity of the Plant	Demands		
	Water Source Index	Total Water Available	TDS		Water Demand Index	Total Water Required	TDS
1	WS_1	Wa_1	Ws_{TDS1}	ATC_{S1}	WD_1	W_{r1}	Wd_{TDS1}
2	WS_2	Wa_2	Ws_{TDS2}	ATC_{S2}	WD_2	W_{r2}	Wd_{TDS2}
3	WS_3	Wa_3	Ws_{TDS3}	ATC_{S3}	WD_3	W_{r3}	Wd_{TDS3}
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
N	WS_n	Wa_n	Ws_{TDSn}	ATC_{Sn}	WD_m	Wr_m	Wd_{TDSm}

WS = Water source, WD = Water demand, W_r = Water required (MLD), TDS = Total dissolved solids (ppm), W_{STDS} = TDS of water at the source (ppm), W_{DTDS} = TDS of water required at the demand (ppm), ATC_i = Annualized total cost of source 'i', it includes annualized capital and operating cost for the i^{th} source (USD).

The objective function of the problem is written as in Equation (1). The objective function is to minimize the overall cost meeting the demand with the optimized allocation of resources.

$$Minimize \sum_{i=1}^{n} \sum_{j=1}^{m} ATC_i * W_{i,j} \quad (1)$$

where,

i = index for number of water sources from 1, 2, 3 . . . . n

j = index for number of water demands from 1, 2, 3 . . . . m

$W_{i,j}$ = allocation of W resource from i^{th} source to j^{th} demand

The constraints for the objective function are expressed through Equations (2)–(5); Equation (2) states that each demand is satisfied completely by all the sources in TDS for the source is lower than or equal to the minimum limiting value of that demand:

$$\sum_{j=1}^{m} \sum_{i=1}^{n} W_{i,j} - WD_j = 0 \quad (2)$$

Each source is less than or equal to addition of all demands if TDS for source is lower than or equal to minimum limiting value of that demand, as indicated through Equation (3).

$$\sum_{i=1}^{n} \sum_{j=1}^{m} W_{i,j} - WS_i \leq 0 \quad (3)$$

Allocation of source and demand is feasible only when TDS for source is lower than or equal to a minimum limiting value of the demand TDS as explained through Equation (4), while the non-negativity constraint is expressed as in Equation (5):

$$For\ feasible\ W_{i,j}\ allocation,\ TDS_i \leq TDS_j \quad (4)$$

Non-negativity constrains:

$$\sum_{j=1}^{m} \sum_{i=1}^{n} W_{i,j} \geq 0 \quad (5)$$

The objective function is solved using a linear programming problem (LPP), simplex algorithm, and the tot of infrastructure cost is derived.

3. Water Pricing on Single-Block Theory

The following assumptions are made to determine the cost of potable and non-potable water under single-block pricing.

1. The cost of each source needs to be recovered completely so that economic feasibility will be established.
2. Water is considered a social commodity, and everyone has an equal right to water, irrespective of consumption quantity.

The unit cost of water under the single-block pricing strategy is found using Equation (6):

$$W_iC_{Bi} = ATC_i \tag{6}$$

The unit cost of water derived with a single-block price analysis is listed in Table 4. With the single-block approach pricing, it is found that the cost of water produced from SWRO and EED is multi-fold higher than the cost of water produced from WTP. Adopting a single-block pricing strategy will not be a viable option, considering breakeven in water infrastructure investments. Since the supply of a minimum quantity of water to meet social needs is a commitment, water cannot be higher priced to meet the infrastructural cost. Therefore a multi-block pricing strategy with increasing block tariff is investigated, considering the costs due to the impact of externalities.

Table 4. The unit cost of produced water from various resources in a single-block pricing strategy.

Source	Cost of Water (USD/m^3)
WTP	0.02
SWRO	0.79
EED	2.00
STP	0.26
CETP	0.75

4. Externality Components in Water Pricing

The environment cost, opportunity cost, and ecological system imbalance costs are the various externalities considered to account for the multi-block pricing strategy approach. The cost of emission of greenhouse gases (GHG), the opportunity cost of water from natural resources, and the cost incurred due to damage to ecological systems are taken as externalities in the current paper.

4.1. Environment Cost

Environment cost is defined as the cumulative monetary unit of the effects of environmental impacts through socio-economic activities to obtain water as a resource. The environmental impacts and their effect on cost structure are very complex to have a standard method of calculation [19].

For the current study, cost due to emission of greenhouse gases (C_{EGHG}) is accounted which is determined as units of electricity consumed from conventional energy sources for the generation of 1 L of water * cost of electricity produced by renewable energy source, which is mathematically given as in Equation (7):

$$C_{EGHG} = \left(\frac{\text{The total energy required for the process} - \text{Energy used from the renewable energy}}{\text{Quantity of water generated}}\right) \times \text{Cost of energy generated per unit by renewable energy sources in India} \tag{7}$$

The cost of the impact of the emission of GHG per unit of electricity (1 kWh_e) generated from conventional sources is considered equivalent to the cost of green energy, which is USD 0.064/kWh [36]. The cost due to the emission of greenhouse gases by each water source is found using Equation (7) and is represented in Table 5.

Table 5. Cost per MLD on produced water considering emission through conventional electricity.

Source	Power Consumption (kWh/MLD)	Cost (USD/m^3)
Water treatment plant (WTP)	345	0.02
Seawater reverse osmosis plant (SWRO)	5000	0.32
Sewerage treatment plant (STP)	476	0.03
Common effluent treatment plant (CETP)	546	0.04

[37–39].

4.2. Opportunity Cost

Marginal opportunity cost is defined as the economic benefits lost in not allotting the additional unit of water for the second-best alternative for economically productive use. Hence estimation of opportunity cost is important in the process of efficient allocation of water while assessing the future infrastructure investments in water programs [40]. In the current work, the opportunity cost is considered as the cost of not allotting the freshwater (water from the river) for agricultural produce. The benefits that could have been recovered by using this water for the next better option, agriculture is 0.2 USD per m^3, considering the water requirement of 10 mm per square meter per day, with a yield of USD 2857 per acre per year [41–43]. The equation for opportunity cost is described in Equation (8):

$$C_O = \text{Income from yield per acre of land per year/Water requirement per year per acre of land} \quad (8)$$

4.3. Ecological System Imbalance Cost

Though seawater desalination is a reliable source of potable water, the brine rejection will have large environmental impacts, affecting the local ecology and marine life at the intake and reject locations. The ecological system imbalance cost due to desalination is defined as the change in gross domestic production (GDP) in the catchment area of the project due to the introduction of a technology derived per liter of desalinated water [44]. Advanced seawater reverse osmosis (SWRO) technologies have a 45–55% recovery ratio, with brine management costs accounting for 20–60%, of the produced water. Not much study is done on the direct impact on GDP due to brine rejection (Venkatesan, 2015), hence the ecological imbalance cost is taken as 20% of the cost of water produced by SWRO and EED, as indicated in Equation (9).

$$\begin{aligned} C_E &= The\ cost\ to\ ecology\ due\ to\ brine = cost\ for\ brine\ management \\ &= 20\%\ of the\ cost\ of\ produced\ water\ by\ SWRO\ and\ EED\ in\ single \\ &-block\ pricing \end{aligned} \quad (9)$$

5. Multi-Block Water Pricing Strategy

In a multiple block pricing system, water is considered a social and economic commodity. In this paper, two-block pricing is explored with quantity in block 1 taking care of minimum water requirement for potable requirements, considering water as a social commodity alone. To avoid the wastage and overuse of water, a second block is proposed setting only 10% of the total water quantity. The objective of the multi-block pricing strategy is to (i) Promote low-quality water for non-potable applications; (ii) Restrict usage of potable water beyond the social needs; (iii) Recover investments in water infrastructure; (iv) Self-sustainability of water infrastructure projects, to avoid incentives and subsidies. The quantities of water requirements allotted in each block for various applications are shown in Table 6.

Table 6. Allocation of water quantity in multi-block scenario.

Potable Water		Non-Potable	
Block 1	0 to 25 L	Block 1	0 to 125 L
Block 2	>25 L	Block 2	>125 L
Water consumption in Block 1	72 MLD	Water consumption in Block 1	288 MLD
Water consumption in Block 2	8 MLD	Water consumption in Block 2	32 MLD
Total water consumption	80 MLD	Total water consumption	320 MLD

The relation between the cost of potable water in block 1, to the cost of non-potable water in block 1 and the cost of water in block 2 is provided in Table 7. The multiplying factor is based on the quality of water, application to meet social causes, and measures for misuse or overuse of water.

Table 7. Relation of cost components in blocks 1 and 2 concerning potable water in block 1.

Cost Components	Relation with CPW_{B1}
Cost of potable water in block 1	CPW_{B1}
Cost of potable water in block 2 CPW_{B2}	$1.5 \times CPW_{B1}$
Cost of non-potable water in block 1 $CSWW_{B1}$	$0.6 \times CPW_{B1}$
Cost of non-potable water in block 2 $CSWW_{B2}$	$0.75 \times CPW_{B1}$

Considering the externalities in multi-block pricing, the cost balance of water is represented in Equation (10):

$$C_{B1} + C_{B2} + C_{EGHG} + C_O + C_E = ATC_{STP} + ATC_{CETP} + ATC_{WTP} + ATC_{SWRO} + ATC_{EED} \quad (10)$$

The socio-economic cost of potable water in Block 1 is found using Equation (10) and the cost of potable and non-potable water in block 1 and block 2 are found using the relation of potable water in block 1 concerning other water components as in Table 7. The calculated values of potable and non-potable water in different blocks are indicated in Table 8.

Table 8. Cost component due to various factors in block 1 and block 2 water pricing.

Cost of Water under Various Portfolios	Cost (USD/m^3)
The socio-economic cost of potable water in Block 1	0.41
The economic cost of potable water in Block 2	0.62
The socio-economic cost of non-potable water in Block 1	0.25
The economic cost of non-potable water in Block 2	0.31
The opportunity cost of water resources	0.04
Cost due to ecological imbalance due to brine	0.08

To obtain the cost competitiveness among various water sources and promote sustainable sources, while calculating the cost of produced water from each source, the cost of emission of greenhouse gases (C_{EGHG}), opportunity cost (C_O), and cost due to effect of brine discharge (C_E) are considered as an externality cost component.

The cost of producing unit water in multi-block pricing strategy from WTP, SWRO, and EED are given in Equations (11)–(13), respectively. The average cost of producing potable water is given in Equation (14). The cost of producing unit water for washing and sanitation from the STP and CETP are given in Equations (15) and (16), respectively. The average cost of producing water for washing and sanitation is given in Equation (17).

Cost of unit water from Water Treatment Plant,

$$CW_{WTP} = \left(\frac{CPW_{B1} * W_{WTPB1} + CPW_{B2} * W_{WTPB2} + C_{EGHG} * W_{WTP} + C_{O} * W_{WTP}}{W_{WTP}}\right) \quad (11)$$

Cost of unit water from seawater reverse osmosis process,

$$CW_{SWRO} = \left(\frac{CPW_{B1} * W_{SWROB1} + CPW_{B2} * W_{SWROB2} + C_{EGHG} * W_{SWRO} + C_{E} * W_{SWRO}}{W_{SWRO}}\right) \quad (12)$$

Cost of unit water from seawater through energy-efficient desalination process,

$$CW_{EED} = \left(\frac{CPW_{B1} * W_{EEDB1} + CPW_{B2} * W_{EEDB2} + C_{E} * W_{EED}}{W_{EED}}\right) \quad (13)$$

Average Cost of potable water per unit liter,

$$CPW = \left(\frac{W_{WTP} * CW_{WTP} + W_{SWRO} * CW_{SWRO} + W_{EED} * CW_{EED}}{W_{WTP} + W_{SWRO} + W_{EED}}\right) \quad (14)$$

Cost of unit water produced through a sewerage treatment plant,

$$CSWW_{STP} = \left(\frac{CSWW_{B1} * W_{STPB1} + CSWW_{B2} * W_{STPB2} + C_{EGHG} * W_{STP}}{W_{STP}}\right) \quad (15)$$

Cost of unit water produced through a common effluent treatment plant,

$$CSWW_{CETP} = \left(\frac{CSWW_{B1} * W_{CETPB1} + CSWW_{B2} * W_{CETPB2} + C_{EGHG} * W_{CETP}}{W_{CETP}}\right) \quad (16)$$

The average cost of non-potable water,

$$CNPW = \left(\frac{W_{STP} * CSWW_{STP} + W_{CETP} * CSWW_{CETP}}{W_{STP} + W_{CETP}}\right) \quad (17)$$

Based on Equations (11)–(17), the cost of water from various resources under a multi-block pricing system considering the externalities is mentioned in Table 9.

Table 9. Cost of water under Multi-block pricing strategy.

Source	Capacity (MLD)	Cost of Water (USD/m^3)
Water Treatment Plant	40	0.57
Seawater Reverse Osmosis Plant (SWRO)	35	0.77
Seawater Energy-Efficient Desalination (EED)	5	0.51
The average cost of potable water		0.66
Non-potable water—Sewerage Treatment Plant (STP)	320	0.28
Non-potable water—Common Effluent Treatment Water (CETP)	40	0.29
The average cost of non-potable water		0.28

It is seen that the cost of producing water from the SWRO is brought close to the cost of water from WTP. Similarly, the cost of produced water from the EED has become cheaper than the water produced from the WTP. The average cost of produced water is brought to USD 0.66/m^3. Similarly, the cost of recycled water from the STP and CETP are brought to almost the same, with the average at USD 0.29/m^3. To improve cost competitiveness and to promote green energy sources, cross-subsidy may be given among various water resources.

6. Results, Discussions, and Policy Interventions

Water pricing is predominately based on a single-block strategy without considering the externalities of the system. However, the current study has compared the feasibility of multi-block pricing against single-block taking into consideration the externalities. The comparison of three scenarios, namely, levelized cost, and single-block and multi-block pricing strategies are shown in Figure 3. It is found that the levelized cost strategy cannot be considered a correct approach considering the high pricing for potable and non-potable components. The single-block pricing has brought down the price component considerably, but there is a huge disparity between the pricing of potable and non-potable components. The produced water from WTP is very much affordable, while the produced water from EED cannot be sold. Similarly, the water produced from STP is cheap, while the CETP-produced water is high-priced. The payback period for the single-block pricing strategy as shown in Figure 4, shows that few components in the potable and non-potable system may not be feasible with high payback periods. The multi-block pricing strategy has included the environment, opportunity, and cost towards the ecological imbalance thus making the unit cost of the produced water better than under the single-block and levelized cost pricing strategy. Large water infrastructure projects will have an impact on society, economy, and ecology, which are often not accounted into the cost economics.

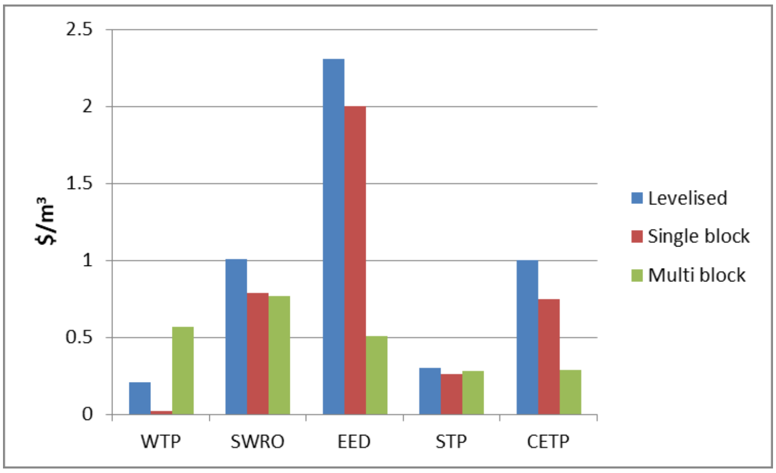

Figure 3. Unit cost under different scenarios.

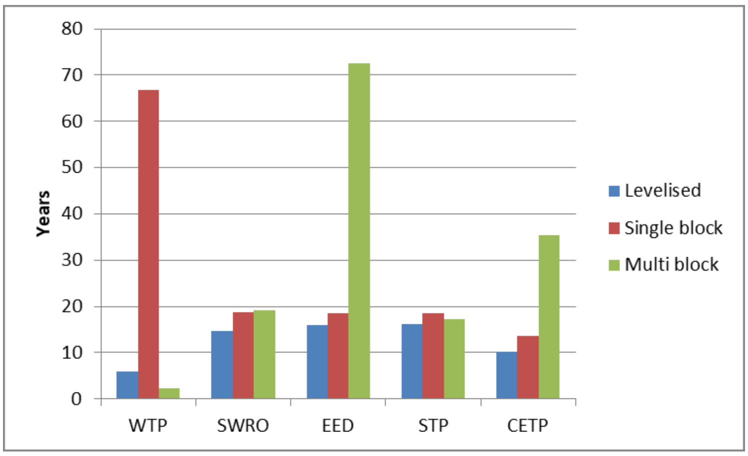

Figure 4. Payback under different scenarios.

The average cost of three potable and two non-potable sources under scenarios of levelized, and single-block, and multi-block pricing strategies are considered and depicted in Figure 5. It is seen that the multi-block pricing has shown a better sellable pricing strategy with potable and non-potable water sources at USD 0.62/m^3 and USD 0.29/m^3, respectively.

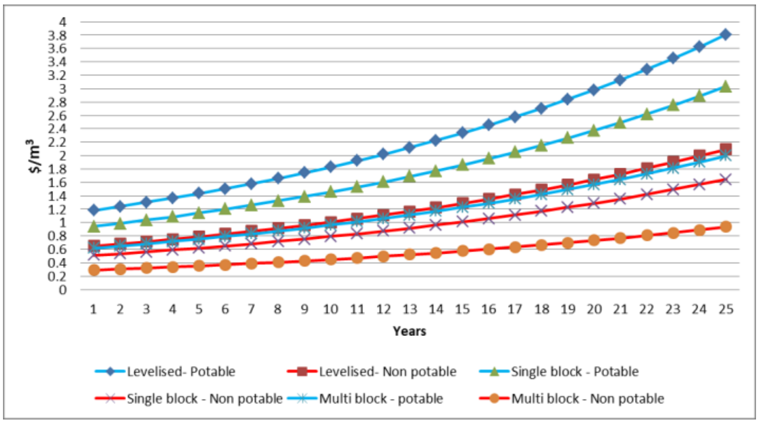

Figure 5. The unit cost of potable and non-potable water under different scenarios.

The payback period as indicated in Figure 6 shows that it is better to consider the potable and non-potable components as blocks than consider them individually. The multi-block pricing strategy has a higher payback, but the unit pricing can be normalized.

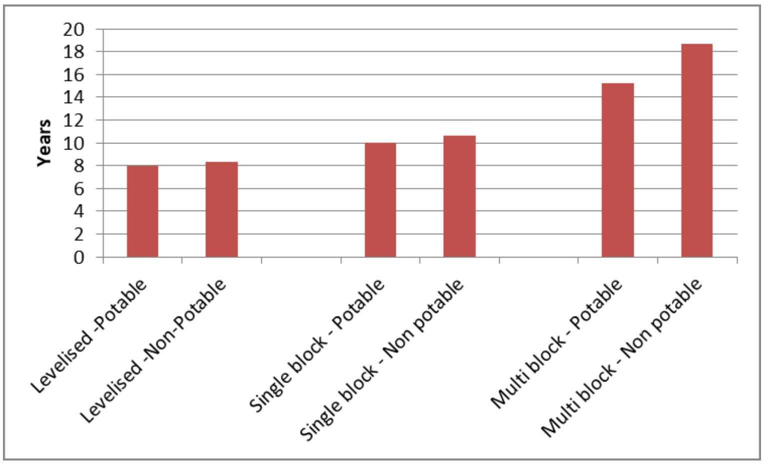

Figure 6. Payback period of potable and non-potable infrastructure under different scenarios.

Water is a social commitment to society and becomes the priority for urban administrations to native populations. Hence the financial impact of externalities often skips the cost assessment. However, a multi-block pricing strategy, factoring the impacts of externalities can normalize the cost of externalities and provide workable business models.

The following policy interventions are suggested:

(i) The outcome of the study indicates that multi-block pricing can be recommended with a full cost recovery objective. The full cost recovery requires considering the externalities due to the use of conventional power as a penalty or the use of renewables as an incentive.

(ii) The use of recycled water should be subsidized in a multi-block pricing philosophy which will extend the areas of use of recycled water. An accountable difference in the unit price of fresh and recycled water can make a difference in water consumption.

(iii) Incentivizing water from the high levelized cost of water (LCOW) resources and penalizing the use of low LCOW water resources in a multi-block water pricing system could normalize the unit cost of produced water. Cross subsidies should be considered from the cost breakeven perspective, effects of externalities, and depletion of naturally available resources.

7. Conclusions

In this research, single-block and multi-block pricing strategies were utilized to formulate a water infrastructure issue in a multi-resource variable demand context. The objective function is framed to minimize the overall cost, and the problem statement and constraints are specified. Demands are satisfied by the optimal distribution of resources. The issue statement was resolved using the linear programming problem approach. Investigated is the effect of single-block and multi-block pricing strategies. The goal of the single-block pricing method is to allocate the generated water's unit cost to completely recover the cost. While considering multi-block pricing, the impact of externalities of the project is considered. The impacts due to emission of greenhouse gases, the opportunity cost of naturally available water resources, and the cost due to ecological imbalance because of seawater intake and brine rejection are the externalities considered. While considering the size of the blocks, the following are given priority (i) water is considered more a social commodity than an economic one; (ii) encourage maximum use of recycled water; (iii) obtain breakeven on investments in water infrastructure projects. The single-block pricing strategy shows that the unit cost of water produced by SWRO and EED is many times higher than the unit cost of water produced by WTP. Hence the investments made on high CAPEX water infrastructure may not breakeven. The analysis of the multi-block pricing strategy shows that the high unit cost of produced water from SWRO and EED can be normalized. Similarly, the high unit cost of recycled water from CETP can be normalized to that of recycled water from STP.

Multi-block pricing blocks must be scaled to enforce optimal water usage and to maximize the use of recycled water, with water being considered a social commodity. Water infrastructure projects include externalities that the water price system does not take into account. The high manufacturing costs can be made more reasonable by including cost factors for externality implications. By including the impact of externalities into a multi-block pricing method, the high capital expenditure for integrating renewable energy into water infrastructure projects may be normalized. The significance of governmental action to require the inclusion of the cost of externalities in pricing models is stressed by the paper's conclusion. Future studies may examine the application of dynamic pricing in water management plans, taking into account the hours when renewable energy is available, the hours when water use is at its highest, and the amount of electricity used by dependable water sources.

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Abbreviations

W_{WTPB1}	Quantity of potable water with block 1 pricing underwater treatment plant production
W_{WTPB2}	Quantity of potable water with block 2 pricing underwater treatment plant production
W_{WTP}	Quantity of water produced by the water treatment plant
W_{SWROB1}	Quantity of water with block 1 pricing under seawater reverse osmosis treatment produce
W_{SWROB2}	Quantity of water with block 2 pricing under seawater reverse osmosis treatment produce
W_{SWRO}	Quantity of water produced by seawater reverse osmosis method
$W_{SWEEDB1}$	Quantity of water with block 1 pricing under seawater energy-efficient desalination method
$W_{SWEEDB2}$	Quantity of water with block 2 pricing under seawater energy-efficient desalination method
W_{SWEED}	Quantity of water produced by seawater energy-efficient desalination method.
W_{STPB1}	Quantity of water with block 1 pricing under sewerage treatment plant produce
W_{STPB2}	Quantity of water with block 2 pricing under sewerage treatment plant produce
W_{STP}	Quantity of water produced by the sewerage treatment plant
W_{CETPB1}	Quantity of water with block 1 pricing under common effluent treatment plant produce
W_{CETPB2}	Quantity of water with block 2 pricing under common effluent treatment plant produce
W_{CETP}	Quantity of water produced by the common effluent treatment plant
CPW_{B1}	Cost of potable water in block 1
CPW_{B2}	Cost of potable water in block 2
CW_{WTP}	Cost of water from the water treatment plant
CW_{SWRO}	Cost of water from seawater reverse osmosis process
CW_{SWEED}	Cost of water from seawater energy-efficient desalination process
CW_{STP}	Cost of water from the sewerage treatment plant
CW_{CETP}	Cost of water from the common effluent treatment plant
CPW	The average cost of potable water
CSWW	The average cost of water for sanitation and washing
C_S	Sustainability cost
C_{EGHG}	Cost due to emission of greenhouse gases
C_{EE}	Cost due to environmental effects

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