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Development of a Water-Pricing Model for Domestic Water Uses in Dhaka City Using an IWRM Framework

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Abstract: Dhaka city is experiencing high water use and rapid declination of groundwater. The current water price in the city is low and based on a uniform rate. To arrest the resource degradation along with pursuing cost recovery and promoting social equity, this paper develops a new pricing model for domestic water uses using the integrated water resources management principles. The development is accomplished through estimation of domestic water usage, evaluation of current water prices, and assessment of groundwater degradation externalities in the Tejgaon area of the city using both primary and secondary data. Two economic and two environmental externalities are incorporated. The model is based on an increasing block tariff strategy, and the estimated unit prices for the first and second blocks are respectively 5% and 75% higher than the existing price. The model has the potential to reduce the domestic water use in the city by up to 27%, increase the revenue for the Dhaka Water Supply and Sewerage Authority by up to 75%, and reduce the water bill for poor households by up to 67%. The model has a great potential for practical deployment and the concept can also be applied to other cities and water uses.

Keywords: water pricing; integrated water resources management; domestic water use; increasing block tariff; resource degradation externalities

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1. Introduction

Water is one of the most important resources for maintaining the needs of humans and the environment. Unfortunately, water resources are diminishing despite their unlimited importance. Several human activities, such as unconscious water use and pollution, are the underpinning factors for the decreasing state [1]. According to the United Nations Development Program, over 40% of the global population is affected by water shortages, and the percentage is anticipated to exceed half of the population (57%) by 2050 as a consequence of climate change [2,3]. To deal with the scarcity, different countries are adopting various management strategies, such as managed aquifer recharge (MAR), low impact development (LID)/green infrastructure (GI), and grey water reuse [4–8]. India has started practising MAR in Uttar Pradesh, Andhra Pradesh and Tamil Nadu for groundwater recharge and achieved two to nine times higher recharge rates than normal infiltration processes [4,9–11]. Moreover, the concept of greywater recycling and reuse has gained significance in many water stressed countries including Australia, Germany, USA, Brazil, Malaysia, Middle East, Japan and China over the years [4,6–8,12,13]. LIDs/GIs, including modern practices adopted in Germany, the United States, and Japan to build healthy urban water cities, have also succeeded in improving water infiltration to the ground [14]. However, in developing countries, most of the water conservation methods in addressing the water crisis remain ineffective and have low adoption because of the associated costs, inaccessibility, and technical knowledge requirements [15].

Integrated water resources management (IWRM) has been highlighted several times as an effective policy paradigm for the management of water scarcity issues in both developing and developed countries [16–23]. It is a process that encourages the coordinated development and management of water based on three core principles—economic efficiency, social equity, and environmental sustainability [24–26]. The concept is now widely used in the implementation of overarching water policies and legislations that employ basin-wide management, water rights, water pricing, and participatory decision-making [23,27–32]. The principles of IWRM direct that the water tariff is to be designed such that economic efficiency, environmental integrity, and social equity can be achieved to provide the greatest benefit with the limited available water resources, to account for the social and environmental costs of sustaining the management of resources, and to ensure equitable access to an adequate quantity of water for the marginalized and poorer user groups, respectively [25,33–35]. The recovery of costs with a reflection of economic value is the first precondition for ensuring economic efficiency in the pricing system [36–39]. The efficacy of a water-pricing system is contingent on the type of tariff and its monetary value [40–45]. There is a bewildering miscellany of actual water tariff structures implemented by diverse water utilities, even within similar geographical conditions. The structures can be divided into two main categories: flat-rate charge (amount of consumed water has no bearing on the bill) and water use charge (water bill is dependent on the use). Based on the differences in the charging formulae, the water use charge is further subdivided into four main categories: uniform volumetric charge, increasing rate tariff, increasing block tariff (IBT) and decreasing block tariff [46–49]. Therefore, it is highly requisite for any water utility or community to choose a tariff system that fits well to its areal and socioeconomic characteristics [50–52].

The second principle of IWRM highlights the conservation of scarce water resources for the present and future generations. Thus, the total cost recovery should not only encompass the infrastructure construction, maintenance and management costs, but also include the environmental costs [36,37]. The extensive and wasteful use of resources results in several negative impacts on the environment [53] and leads the resources towards declination, which direct to the consideration of environmental externalities in water pricing [36,40,54,55]. That consideration can assist in full cost recovery, on one hand, and provide water conservation incentives, on the other.

In addition to efficient resource use and environmental integrity, the IWRM framework conveys comprehensive significance in ensuring equitable access for the poor marginal social groups [27,56]. However, it is often overlooked whether the needs of the poor groups are met or not [57,58]. For example, an absence of municipal water supply in the low-income communities, often controlled by power groups, can result in a high price burden for the communities. With the assistance of local powerful groups, private vendors provide substandard services and make money by taking advantage of water deprived poor people [57,59]. Hence, to ensure an equitable water access in a society, it is highly necessary to bring low-income people under an IWRM-based water-pricing structure.

The implementation of an IWRM-based water-pricing system often becomes a challenge. The underpinning factor is that the last principle of the framework, i.e., equity, contradicts the other two principles [42,60]. Provision of a subsidized low price does not satisfy the criterion of cost recovery on the one hand [56,60], and it reinforces the misuse of the valuable environmental resource and leads to its degradation on the other [61,62]. This conflicting issue, therefore, directs a use-specific water-pricing system to successfully integrate IWRM principles.

In the megacity Dhaka of Bangladesh, the Dhaka Water Supply and Sewerage Authority (DWASA), an autonomous government organization, supplies potable water to its residents [4,63]. Due to rapid population growth and unplanned urbanization, the water demand in the city is increasing day by day. However, the rivers, khals and wetlands in and around the city are being reduced due to encroachment and unplanned urbanization [64–68] and their water is becoming polluted by industrial and municipal wastes [69–74], making the city water supply dependent on groundwater. DWASA supplies a major part (up to 78%) of water from groundwater sources [75]. However, the water is supplied at a subsidized uniform volumetric charge, which is comparatively lower than most other neighbouring Asian cities including Delhi, Karachi, Kathmandu, Singapore, Jakarta, Manila, Beijing and Bangkok [76–83]. This low tariff encourages unconscious and excessive use of water [61]. Hardin, for the first time, pointed out the reason that whenever a product is free or undervalued, it promotes misuse rather than efficiency [84].

In Dhaka city, only domestic use has led to the abstraction of about 2.0 Mm^3 of groundwater every day [85], which is in excess of the recharge to the aquifer. The natural groundwater recharge in this metropolis is about 25% lower than the abstraction [86]. The city's subsurface geology consists of an aquitard layer called Madhupur clay, which is 6 to 12 m thick and prevents recharging from rainfall infiltration and riverbed seepage [87–89]. As a result, most aquifer recharge is received from subsurface horizontal inflow, which is insufficient to maintain the groundwater balance at the current pace of abstraction [4]. Thus, the city has experienced a drawdown of up to 80 m with an annual rate of 3.07 m [4,85,90].

The groundwater of the city is almost a common pool resource due to its lower price, which in turn has led to a severe decline in this valuable environmental resource. As the stock is not unlimited, the dynamic inefficiency makes one of the most valuable resources become scarcer day by day [62]. The declination of the groundwater has further negative implications (externalities) on the future water supply as well as on the environment [91,92]. A range of externalities, such as an increase in financial expenses for groundwater extraction, a reduction in longevity of the deep tubewells and damage to the aquifer, arise due to the depletion [54,92–97]. In addition, as a major user of energy, groundwater extraction contributes to a significant percentage of greenhouse gas generation, which not only causes environmental threats [98] but also fuels climate change [99]. This cost of externalities should be taken into account while the water price is set [36,40,55,100]. Unfortunately, the existing water-pricing policy of Dhaka city disregards the associated cost of groundwater externalities and is hinged only on the installation and operation and maintenance (O&M) costs. Hence, the users receive all the benefits of groundwater without paying the full cost [62,101]. Additionally, while the rich enjoy tapped water in their houses, most low-income communities rely on private vendors.

Slum dwellers pay about 7–14 times higher prices than residents of formal housing, which is about 12–15% of their monthly income [57]. As a result, the slum dwellers use 7.5–10 times less water in comparison with a middle-class household consumer in Dhaka city [102]. The main burden of water price is generally imposed on women due to their responsibility of maintaining the family [103,104]. Thus, the total water-pricing process of this megacity does not follow the three principles of IWRM, although it is a critical concern for many countries.

Although the need for reforming the water price with cost recovery has been underscored in many water-related policies of Bangladesh [105–109], only the DWASA has proposed in its water supply master plan for the Dhaka city, for the first time, an IBT structure to deal with affordability and cost recovery issues [110]. However, the proposed pricing structure does not include the cost of externalities, which underscores the necessity for redesigning the said structure. Moreover, though several studies addressed the role of IWRM in an efficient pricing system [25,27–30,33,34], none delved further into the development of an IWRM-based water-pricing model. This study fills in these knowledge gaps by developing a water-pricing model for domestic water use in the Dhaka city incorporating the core principles of IWRM to support water conservation and pro-poor water policy.

2. Materials and Methods

2.1. Study Area

This study was carried out in Dhaka city, where groundwater overexploitation is a major concern. The over-abstraction started since the early 1980s due to the uncontrolled urban growth [4,111], rapid population growth [112–114], diminution of water bodies [115], and hindrance to infiltration due to the increase in built-up areas [116,117]. The extent of groundwater declination has come to a point where it would not be feasible to dig more tubewells and increase the production rate [118]. The city is likely to face a great scarcity of groundwater if the abstraction continues at this excessive rate [119]. The existing groundwater depletion scenario requires a proper management policy.

This study focused on the Tejgaon area as a representative of the Dhaka city as a case study (Figure 1).The Tejgaon area is considered critical for future water supply as well as for posing a substantial risk of environmental degradation due to the drawdown of up to 70m in the groundwater level [76,120]. Hence, this was identified as a suitable location for studying the groundwater degradation externalities. In addition, the study aimed at evaluating the existing domestic water-pricing practices in both formal and informal settlements. The Tejgaon residential area represents the formal settlements with legal water connections, and the Tejgaon slum symbolizes the informal communities with illegal water connections. The Tejgaon residential area is under the ward nos. 25 and 26 of the Dhaka North City Corporation (DNCC). It is in a prime location of DNCC under zone 3 and zone 5. The Tejgaon slum is located alongside a railway line in ward no. 25 of DNCC (zone 3). The residential area has a population of 0.13 million in an area of 256 ha [121], whereas the slum has a population of about 1820 in an area of 2 ha. The combination of residential and slum areas in the same geographic location further helped obtain a comparative scenario of domestic water uses in different settlements and extrapolate the results to the city.

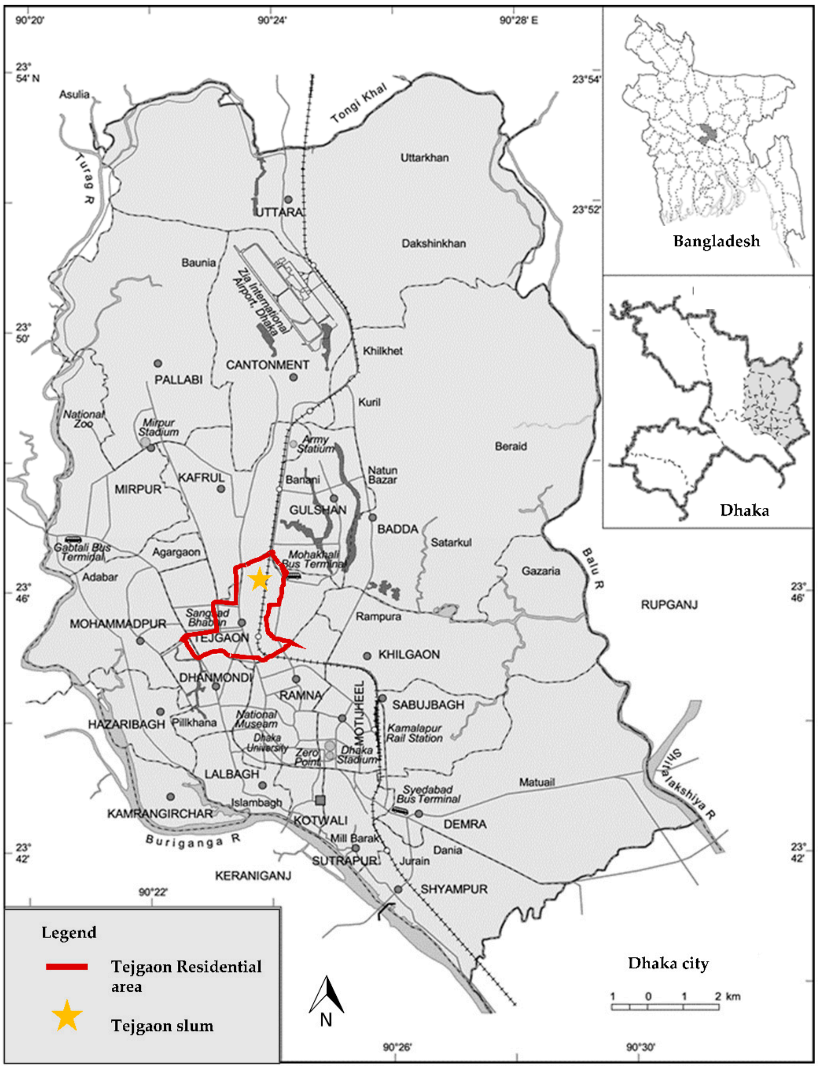


Figure 1. Location of the study area in the Dhaka city (Tejgaon residential area and slum).

2.2. Methods and Data

The study formulated a water-pricing model, which assimilated three aspects: cost recovery, affordability of water use, and amount of water use per capita to penalize high water users (Figure 2). Consideration of affordability for the users combined with penalization for overuse of water supplemented the equity ethics of IWRM-based water pricing. On the other hand, the reflection of the full economic cost not only attains the economic efficiency of water supply, but also makes the water users aware of their uses [62]. The full economic cost can be subdivided into two broad parts: cost of extraction and cost of resource degradation externalities. The cost of externalities symbolizes the compensation for continuous degradation of resources to the environment. It is further subdivided into economic and environmental externalities, which arise due to the declination of groundwater level, such as the cost of deepening tubewells and pumps, higher fuel cost, and greenhouse gas emissions caused by the greater use of energy [54]. The study thus embraces the three objectives of IWRM.

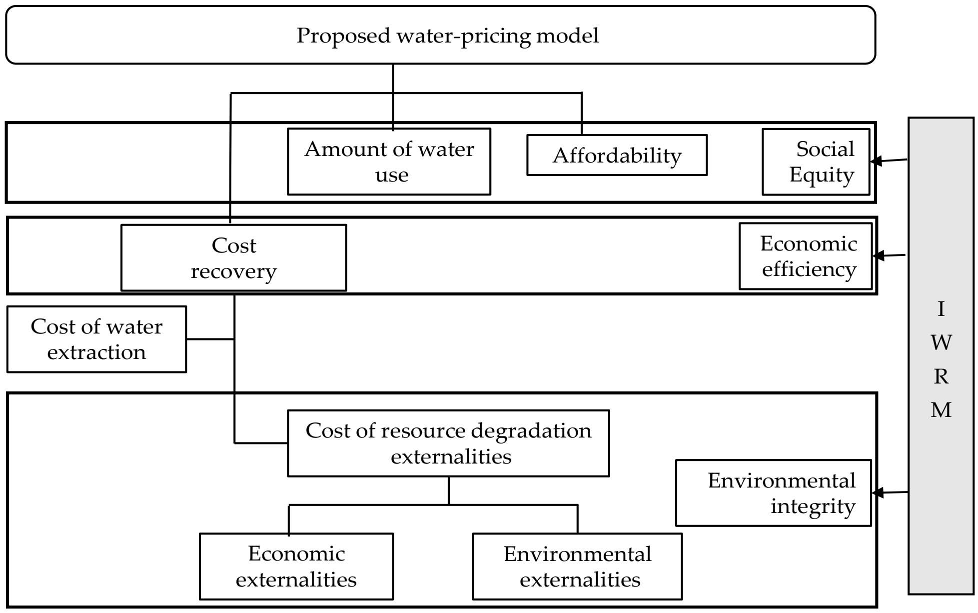


Figure 2. Conceptual framework of the proposed water-pricing model.

To develop the above IWRM-based water-pricing model, the study needed to accomplish a number of activities (Figure 3). Firstly, the domestic water usage was estimated to provide a basis for the amount of water used in both formal and informal settlements. Secondly, the current water-pricing system was evaluated on the basis of the factors of water pricing and its impacts on livelihoods were assessed to gain a good understanding on the affordability for water users. Thirdly, the groundwater depletion externalities in the study area were identified and the associated costs were estimated, which led to calculation of the full economic cost of water. Finally, a water pricing model was developed as a long-term solution for the existing negative impacts.

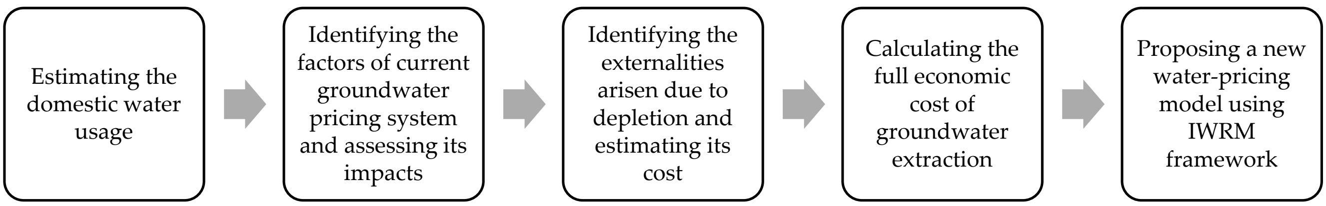


Figure 3. Methodological framework for developing water-pricing model.

The proposed water-pricing model follows an IBT strategy. Among the different water pricing schemes, IBT facilitates cost recovery while simultaneously penalizing large consumption and subsidizing basic use for the poor. The execution of IBT, therefore, supports IWRM because of its conservation-oriented design and advancement of equity and efficient water use [34,56,122–125]. The unit price of water is suggested such that the consumption in the first pricing block covers the extraction cost, while the use in the second block covers the cost of water degradation externalities. The World Health Organization (WHO) sets the standard domestic use to 50 lpcd, which is sufficient for assuring hygiene with a low risk of health [126,127]. Hence, the consumption limit of the first block is considered to be 50 lpcd in the proposed pricing model:

$$\text{If } Q \leq 50 \text{ lpcd}, \ P(Q) = EC \times Q \quad (1)$$

$$\text{If } Q > 50 \text{ lpcd}, \ P(Q) = MP \times Q \quad (2)$$

where Q is the quantity of water usage, and $P(Q)$ is the price of water. The unit extraction cost of groundwater (EC) and the modified price of groundwater (MP) are then estimated as:

$$EC = Current\ price + Subsidized\ amount\ of\ price \quad (3)$$

$$MP = EC + Cost\ of\ externalities = EC + (Cost\ of\ economic\ externalities + Cost\ of\ environmental\ externalities) \quad (4)$$

There are usually economic and environmental externalities in the over-exploitation of groundwater.The major economic externalities include increased energy consumption for the lowering of deep tubewells, and damage costs for the dryness of deep tubewells [54,94,95,128]. The major environmental externalities include the carbon footprint of water and health externalities [54]. The inadequate water use causes a great risk to the health of the slum dwellers and burdens them with extra treatment costs. Therefore, the treatment costs for water shortage related diseases were considered as health externalities [129]. The study estimated the cost of the externalities from the data of the last 24 years (1996 to 2020). Table 1 provides the formulae used for the monetary valuation of the above-mentioned externalities.

Table 1. Formulae used for monetary valuation of the economic and environmental externalities.

Externality	Formula
Increased energy consumption ($\boldsymbol{E_i}$) and energy cost ($\boldsymbol{C_{w.}\ ec}$)	$E_i(KWH) = m \times g \times \Delta h \times v \times 2.78 \times 10^{-7}$ (5) where m = plain water density = 1000 kg/m^3, g = acceleration due to gravity = 9.8 ms^{-2}, v = volume of water extracted in liters (or cubic meters), Δh = the change in water levels in the study period, $C_{w.}\ ec = E_i\ (KWH) \times unit\ energy\ price \times number\ of\ tube\ wells\ lowered$ (6)
Damage cost for dryness of tubewell ($\boldsymbol{C_{w.}dry}$)	$C_{w.}dry = N_{dry} \times C_{con}$ (7) where N_{dry} = no. of dried tubewells during the study period, C_{con} = cost of construction of a new tubewell in the study area.
Cost of carbon footprint of water ($\boldsymbol{C_w.cf}$)	$C_w.cf = C_d \times E_i$ (8) where C_d = cost of damage caused by greenhouse gas emissions for each kilowatt hour of electricity produced. In this study, C_d is calculated as $C_d = C_c \times \left(\frac{GEF}{1000}\right)$ (9) where, C_C = unit damage cost of CO_2e emission, GEF = grid emission factor = amount of CO_2e produced per MWH of electricity production.
Cost of health externalities ($\boldsymbol{C_w.he}$)	$C_w.he = Total\ treatment\ cost\ of\ water\ shortage\ related\ diseases\ due\ to\ high\ price = N_{ap} \times C_t$ (10) where, N_{ap} = Average no. of people affected by water shortage related diseases in the slum, C_t = Average yearly treatment cost per person (BDT)

To convert the cost of externalities into an annual uniform cost, the following uniform series capital recovery factor formula [130] was used:

$$Annual\ uniform\ cost,\ A = P\left[\frac{i(1+i)^n}{(1+i)^n - 1}\right] \quad (11)$$

where P is the present cost of externalities, i is the interest rate, and n is the economic life of a tubewell. The value of i was drawn from the published information by the Central Bank of Bangladesh. The average interest rate on bank loans at all state-owned commercial banks is 9% for the industrial category [131]. Moreover, the average economic useful life of a deep tubewell is now about 6 years in the Dhaka city.

Given the objectives of this study, both qualitative and quantitative data were collected using a questionnaire survey (sample size n = 100), and a number of participatory tools, namely focus group discussions (FGDs), key informant interviews (KIIs), in-depth interviews (IDIs), and pair-wise ranking. Data were collected during February to December, 2020. Firstly, after a reconnaissance survey to check the suitability of the slum as a representative study area, the pair-wise ranking tool was employed to identify the dominant water problems prevailing in the slum. Then a questionnaire survey was used for both the residential and slum areas (n = 50 from each settlement) to gather information on drinking water consumption, domestic water use, water price, affordability, and impacts of current price on water use, health and sanitation. A stratified random sampling technique was followed where both formal and informal settlements were segmented into smaller strata by location. The survey respondents were both male and female aged mostly between 20 and 40 years. The education level of the respondents was higher in the formal settlements (secondary and higher) than that of the informal settlements (secondary and below). To better understand the gendered impact of water pricing, four FGDs were conducted in the slum with men and women separately (two from each group) to avoid swaying in their opinions. Four IDIs were also conducted with the slum dwellers for pulling out their deep-rooted views on prevailing practices due to water pricing. The interviews also helped understand the water distribution system clearly. Finally, interviews of five key informants—two executive engineers from DWASA, an NGO school teacher, and two water suppliers to the slum—helped identify the externalities associated with groundwater over-extraction and shed light on how externalities rise with level of extraction.

The study also required different secondary data and information including groundwater level, water consumption, current water-pricing system, and the externalities arising from the excessive withdrawal of groundwater. The information was collected during April–September, 2020 from a few sources where DWASA contributed a major portion of the secondary data and information (including water use data of the Tejgaon residential area, factors of the current water-pricing system, and information on groundwater externalities including energy consumption for groundwater production, the number of shifted and dried deep tubewells in the study area, and cost of construction of new deep tubewells). The groundwater level data were collected from the Bangladesh Water Development Board, energy price data from the Bangladesh Power Development Board, the grid emission factor from the Department of Environment, and the unit damage cost due to greenhouse gas emissions from the World Bank.

3. Results

3.1. Existing Water Supply Scenario

In the Tejgaon residential area, every household has a DWASA domestic water connection and pays the water bill according to the price structure set by the organization. In contrast, although DWASA started providing water supply connections to low-income communities in 2010, the Tejgaon slum is still not included for such connections. As a result, the water supply system to the slum depends on a completely different setup (Figure 4). A group of businessmen working as middlemen provide water to the slum unethically. They obtain water connections from the DWASA to use for commercial or community purposes and sell it to the slum dwellers at a higher price for their profit. For conducting the water selling business, they have established reservoir tanks, toilets, and sometimes bathing points in specific places close to the slum households. At present, there are six reservoirs of water in the slum with different types of connections. In the Dhaka city, the role of NGOs in slum development is more visible in promoting access to public water and sanitation services. Unfortunately, no involvement of the NGOs working in the water sector is found in this slum. The whole illegal system is run through the assistance of goons. Hence, the slum dwellers collect water daily according to their needs and affordability from these reservoirs finding no other alternate options. They have to pay separately for the use of the toilet and bathroom on a per-use basis.

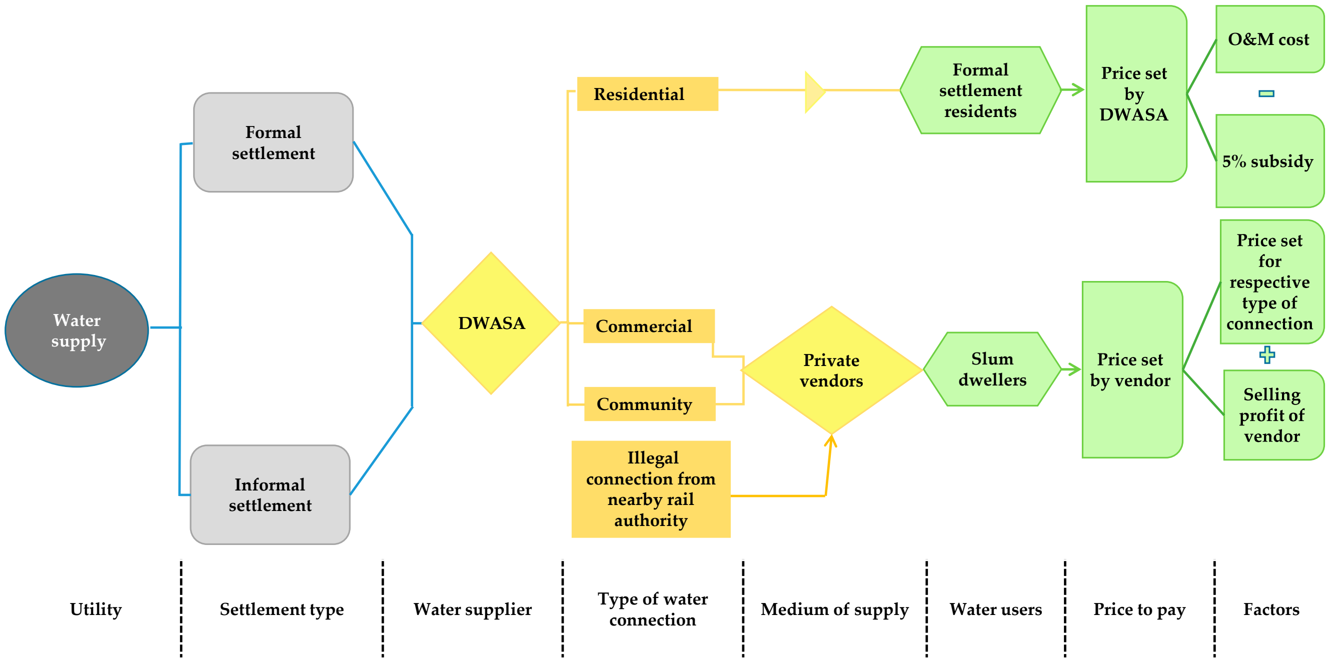


Figure 4. Water supply system in the study settlements of the Dhaka city.

3.2. Current Water-Pricing Practice and Its Impacts

The tariff for the DWASA domestic water connection was fixed at Bangladesh taka (BDT) 14.46 per 1000 L in 2020 (1 US$ = 84 BDT). Though this tariff in 2020 was nearly double the tariff in 2016 (BDT 8.09), it did not cover the full cost of extraction of water. As shown in Figure 4, the tariff structure of DWASA covers the O&M cost of water production and supply, which is also supported by a 5% subsidy from the government and other donor fundings. Thus, the residents of Dhaka enjoy one of the lowest water tariffs in the world. The slum dwellers, on the other hand, pay more than 17% higher price (BDT 250) for buying the same amount of water (1000 L) than the DWASA set price for domestic connections. Additionally, bathing and sanitation are charged separately on a use basis (BDT 10 and BDT 5 for one-time use, respectively). The engagement of local vendors in meeting their economic interests is the root cause of this massive pricing disparity. As uniform volumetric pricing is used by DWASA, there is no extra charge for a higher water use. Thus, vendors pay proportionally to their unusual higher water use and operate their water selling business at a high profit. The amount of profit of the vendors differs among the collection points, depending on the type of water connection (the unit price is kept equal at all the six collection points), the frequency of use of the water points, the distance of the water points, and the restrictions on use of the water points.

The existing water-pricing practices were assessed through a comparative breakdown between formal and informal settlements based on two surfaces: comparison with other South Asian cities and how it shapes their livelihood covering various socio-economic aspects, such as affordability, water use, health, and gender. The unit water prices in other cities, such as Beijing ($0.95), Manila ($0.78), Jakarta ($0.70), Gampaha ($1.44), Singapore ($2.74), Kathmandu ($1.11), Karachi ($0.34) and Delhi ($3.30) [76–82,132], are about 2–20% higher than that of Dhaka. Figure 5 shows that the per capita water use is higher in the Dhaka (representing Tejgaon residential area) and Karachi cities due to the low unit price. The water use in other cities are lower than the Dhaka city because of the higher prices. A negative correlation is identified (Pearson correlation coefficient of −0.487, p = 0.153 and Spearman correlation coefficient of −0.612, p = 0.060) between the water price and the water use in the above cities. This means that when the unit price is low, the per capita water use is more. Thus, there is a significant impact of water price on the amount of water used.

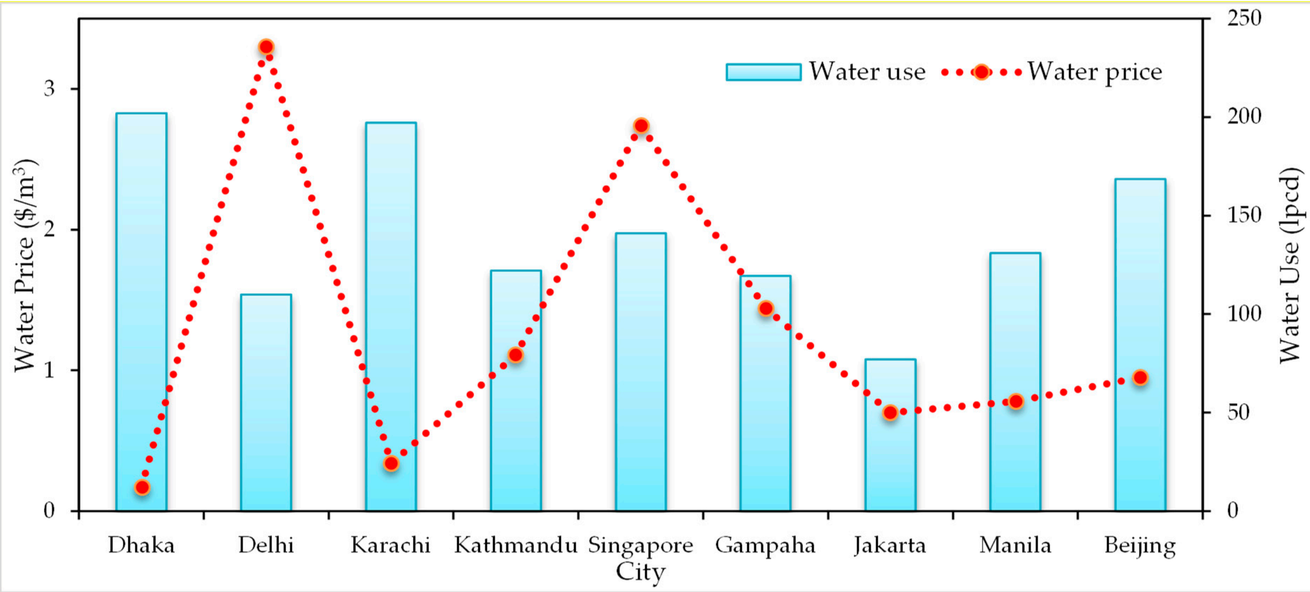


Figure 5. Relationship between water price and use.

Depending on the price elasticity, the use of water is influenced by the collective factors of income and water price. The average income of the residents of Tejgaon (BDT 42490) is almost seven times higher than that of the slum residents (BDT 6440). Due to low income and the high water price, a slum family uses on an average about 11 times less water than a formal residential family. Only a small portion of the surveyed formal residents (8%) mentioned that the water price was high (not affordable). In direct contrast, nearly 90% of the slum respondents criticized the existing water price for not falling within their affordability range. The combination of high water price with low income forces the slum dwellers to spend about 8–14% of their monthly income for water, while formal residents spend only about 1% of their monthly income for water on an average. As a result, with the increase in the number of members in a slum family, the monthly water consumption in the family hardly increases (r = 0.58, $p < 0.001$), resulting in a decrease in per capita water use (r = −0.77, $p < 0.001$) (Figure 6).

This deprivation from sufficient amount of water also gives rise to several inconsistencies in the livelihoods of slum dwellers (Table 2). About 64% of the slum dwellers claimed that they could not afford to pay for their required drinking water. The standard amount of drinking water use ranges from 2 to 5.3 L [127], but the slum dwellers consume barely 1.2 L on average. In contrast, only 2% of the formal residents claimed using less water for their sanitation due to their low affordability.

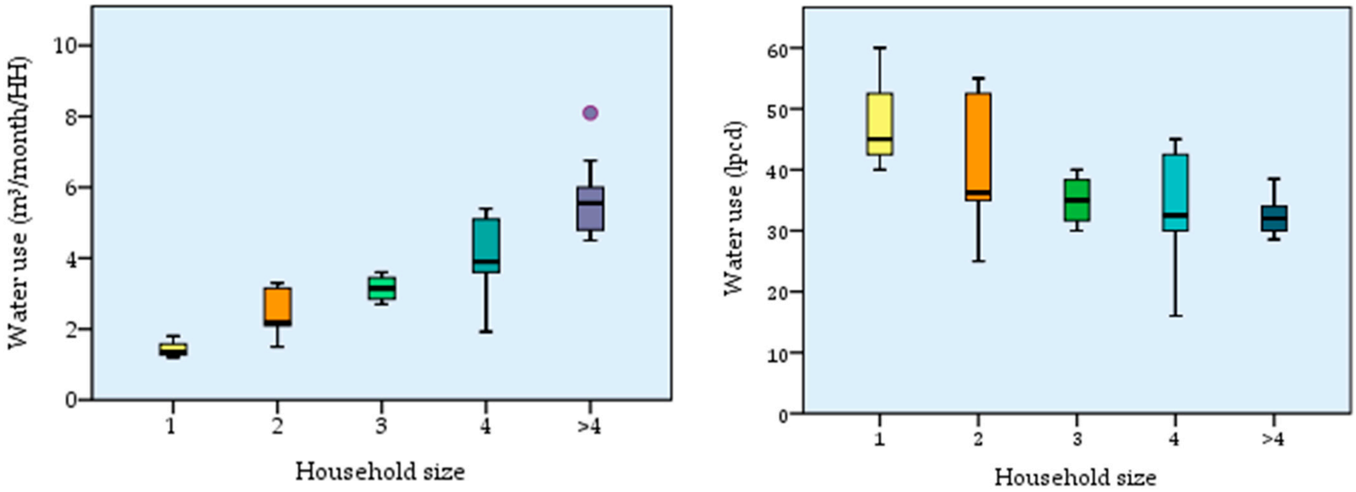
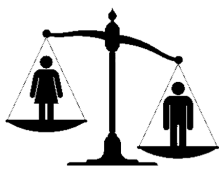


Figure 6. Relationship of household (HH) size with HH water use (**left**) and per capita water use (**right**) in the Tejgaon slum.

Table 2. Comparation of the impacts of water price and family income between formal and informal settlements in the Dhaka city.

Formal Settlement	Impacts	Slum
8% respondents claimed that price is high	 Affordability	88% respondents claimed that price is not affordable
Pay on average 1.03% of monthly income for water	 Income spent on water	Pay on average 8% of monthly income for water
Average water use per capita is 202 L	 Water consumption	Average water use per capita is 18 L
None complained about drinking less water due to price	 Drinking water consumption	About 64% of the slum respondents claimed not affording sufficient water for drinking
None complained about not bathing every day to reduce water bill	 Bathing	58% of the respondents take bath at 2–4 days interval
2% claimed using less water for Sanitation	 Sanitation	82% of the respondents claimed that the price of water is too high to afford, consequently leading to open defecation and unhygienic sanitation
Having comparatively little income, 2% HHs claimed of using less water than their need where the women of the family make this compromise	 Gender	80% of the women compromise their sanitation hygiene saving up to BDT 500 per month and complete their defecating and urinating at home

The overpricing of water for sanitation also adds numerous miseries to the life of the slum dwellers. As already mentioned, they have to pay per use basis for the community toilets and bathing points. Despite paying their monthly water charges, a family of five members have to pay an additional BDT 1500 for taking baths every day in a month, which makes bathing a luxury for the slum dwellers. As a result, only 12% of the slum dwellers take baths everyday. The interval of taking baths varies from one day in small families to four days in large families. Although there are two toilets within the slum and five toilets outside the slum, the slum residents, especially the children, have to defecate in the open place beside the railway track. The reason for open defecation is highly related to the cost of sanitation rather than the insufficient number of toilets. If a person uses the toilets three times a day, he has to pay BDT 450 per month. The excessive cost, therefore, results in an unhygienic and unclean sanitation practice in the slum families.

Additionally, the patriarchal society as well as the water managing responsibility of women forces the women to compromise on their sanitation hygiene in most of the families. In 80% of the households, at least one woman completes her defecation and urination at home and throws those wastes beside the railway track. Nearly 60% of the female respondents have claimed that they have stopped their menstruation cycles through uterus removal surgery called hysterectomy, because it saves from bearing the additional cost of maintaining menstruation hygiene.

Furthermore, insufficient water consumption affects a large percentage of the slum residents by causing various diseases. About 66% of the slum respondents complained of suffering from water shortage related illnesses, such as urine infection (18%), constipation (10%), itches (8%), diarrhea (6%) and more than one disease (24%) (Figure 7). Thus, because of the low affordability with high price, the necessity of water is being compromised for the slum dwellers.

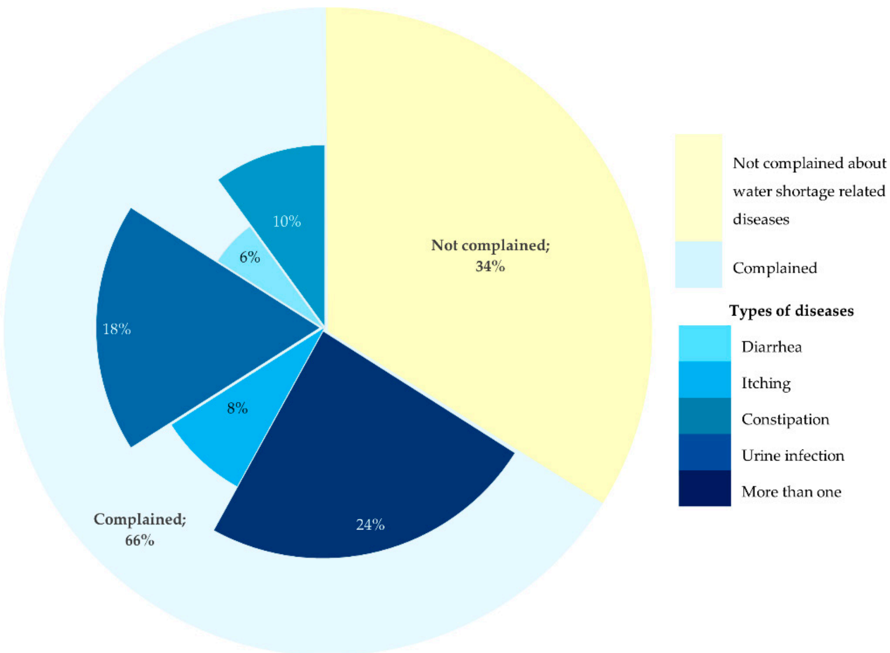


Figure 7. Occurrence of water shortage related diseases in the Tejgaon slum of the Dhaka city.

3.3. Proposed Water-Pricing Model

The proposed water-pricing model integrates the cost of groundwater degradation externalities into the pricing as a compensation for economic and environmental damages caused by groundwater depletion. The results obtained from the monetary valuation of the damage caused by the economic-environmental externalities are shown in Table 3. The total cost of externalities is estimated to be worth of BDT 443 million, indicating a severe groundwater depletion in the study area. Every year, the depletion costs around

BDT 92 million for increased energy costs and damage costs for dryness of deep tubewells. On the other hand, the carbon footprint of water and health externalities combined cost around BDT 7 million per year in the study area.

Table 3. Monetary values of economic-environmental externalities caused by overextraction of groundwater in the study area.

Externality	Total Cost (Million BDT)	Annualized Cost (Million BDT)
Increased energy consumption cost	247	55
Damage cost for dryness of deep tubewells	165	37
Cost of carbon footprint of water	28	6
Cost of health externalities	3	1
Total	443	99

For determining the unit price increment, the total annualized cost of externalities is further divided by the total amount of water drawn from groundwater. In the study area, DWASA supplies 12.43 billion liters of water on an average every year. As DWASA extracts 78% of its water from groundwater, the total amount of water extracted from groundwater in the study area is considered to be 9.69 billion liters. Thus, the cost of externalities for 1000 L of water production is calculated to be BDT 10.19. Table 4 shows the estimated price of water from the proposed water-pricing model. When the externality cost is incorporated, the price of water is estimated to be about 75% higher than the existing price. Considering the proposed water-pricing model, the new water rate will make water services more affordable to the poorest households. On the other hand, as water price rises with water use, excessive water consumption would be penalized severely.

Table 4. Development of water-pricing blocks for domestic water use in Dhaka city.

<table>
<tr><th>Block</th><th>Pricing Basis</th><th>Subdivision of Price</th><th>Monetary Value</th><th>Increase in Price</th></tr>
<tr><td rowspan="2">1st block ($Q \leq 50$ lpcd)</td><td rowspan="2">Extraction cost of groundwater (EC)</td><td>Current price = BDT 14.46</td><td rowspan="2">BDT 15.18</td><td rowspan="2">5%</td></tr>
<tr><td>Subsidized amount of price = BDT 0.72</td></tr>
<tr><td rowspan="2">2nd block ($Q \leq 50$ lpcd)</td><td rowspan="2">Full economic cost</td><td>EC = BDT 15.18</td><td rowspan="2">BDT 25.37</td><td rowspan="2">75%</td></tr>
<tr><td>Cost of Externalities = BDT 10.19</td></tr>
</table>

4. Discussion

Being non-renewable in nature, water is becoming scarcer in many regions because of growing population, rising incomes, and climate change. Water pricing is increasingly becoming one of the important policy tools to manage scarce resources more efficiently because of price-demand elasticity [133,134]. Multiple objectives are addressed by a well-designed water price structure, including economic efficiency, equity, and environmental and financial sustainability [41,43,135]. It has already been proved to be a viable strategy for incentivizing water consumption reduction, which in turn, assists the conservation of a valuable environmental resource, groundwater [48,56,125]. The two-tiered IBT pricing of urban water supply such as the proposed pricing model has a high probability of achieving the efficiency, fairness, and sustainability goals to direct the pathway of IWRM [55,122,136]. Considering the present inconsistencies in the prevailing water-pricing practice, this study developed a use-specific IBT tariff structure incorporating the cost of groundwater degradation externalities and validated the structure to determine whether it meets the key objectives of IWRM or not.

As shown in Table 3, the first block price adds the subsidized amount to the existing price and directs to the cost recovery even from low-use consumers. The second block price incorporates the cost of groundwater exploitation externalities to notify high water consumers about the true economic value of water. Furthermore, the increment in price brings about a great economic benefit to the authority. DWASA now earns about BDT 180 million and BDT 13,460 million annually from the Tejgaon residential area and the entire city, respectively, which can be increased by about 5% to 75% by implementing the first and second block prices.

According to the DWASA master plan for Dhaka city, the water demand-price elasticity in 2012 was 3%, which indicates that a rise in price by 1% would decrease the per capita daily water use by 3% [110]. However, considering the changes in additional factors, such as increase in household income and less options to cut the demand, DWASA estimated that the price elasticity would be 2.5% in 2020. If this elasticity factor is considered, the rise in water price will have a significant influence on reducing overall water demand in the city (Table 5). Due to the small increment in price, the water use would be reduced by about 2% in the first block and 27% in the second block. Although the amount of reduced per capita water consumption is comparatively lower for the first block users, the significance rises to a greater extent when it is considered on a large scale. For instance, the amount of annual household water use can be saved up to 0.22 and 4 billion liters in the first and second blocks, respectively, for the Tejgaon residential area only. Moreover, when it comes to Dhaka city, the water consumption can be reduced by up to 255 billion liters in a year from its present level. Thus, the pricing model would aid sustainable water management strategies by reducing the over-extraction of valuable groundwater resources and saving it for the future generations of the city. The reduced consumption in turn would reduce energy consumption and greenhouse gas emissions. As shown in Table 5, the implementation of the proposed pricing model also saves about 50–750 MWH of electricity in a year in the study area. Furthermore, the huge amount of electricity saved would emit about 35–505 tons of carbon dioxide and its equivalent gases. Considering the Dhaka city, the proposed pricing model would benefit the environment more as it reduces electricity consumption by 3710–56160 MWH per year, which would further decrease the greenhouse gas emissions by up to 37630 tons per year. Hence, the proposed pricing model satisfies the 'environmental integrity' theme of IWRM through its substantial positive impact on the environment in terms of both conserving groundwater resources and reducing greenhouse gas emissions.

Table 5. Impact of proposed water-pricing model on environment.

Indicators	Tejgaon Residential Area		Dhaka City	
	1st Pricing Block	2nd Pricing Block	1st Pricing Block	2nd Pricing Block
Amount of water saved	0.22 Mm^3/year	4 Mm^3/year	17 Mm^3/year	255 Mm^3/year
Amount of energy saved from reduced extraction of water	50 MWH/year	750 MWH/year	3710 MWH/year	56,160 MWH/year
Amount of CO_2e emission saved from the reduced amount of energy production	35 tons/year	505 tons/year	2485 tons/year	37,630 tons/year

The findings show that large water users (formal residents) are using water capriciously because the existing water expenses comprise only 1% of their average income. The slum dwellers, on the other hand, pay approximately 17% more for water, forcing them to use insufficient water due to their low affordability. The proposed water-pricing model would benefit the slum dwellers in two ways: diminishing the economic burden of water and providing enough water for assuring hygiene. As the proposed price would be almost 17 (1st block) and 10 (2nd block) times lower than the existing water prices in the slum, one slum dweller can save about BDT 336-352 per month even if he/she uses 50 L of water in a day. Furthermore, the additional burden of spending BDT 210 per month on treatment for water shortage related diseases is reduced. Regarding the provision of sufficient water, even for those having comparatively low income, the dwellers of the Baganbari slum (a slum with a legal water connection) use, on average, about two times more water (40 lpcd) than those of the Tejgaon slum (Table 6). The quantity of water consumption of the Baganbari slum dwellers meets the basic access standard (20 lpcd) of WHO [127], which indicates that the lower first block price of the proposed pricing model can assist the slum dwellers in attaining the basic water access. In addition, the two-tiered pricing further leads to a cross-subsidy system in that the large consumers subsidize the small consumers, who are usually the low-income households. Whenever water consumption is maintained in the first block, a household can reduce its water bill by about 67%. On the contrary, when water consumption involves both the first and second blocks, the percent rise in the water bill is higher as a penalization for high consumption.

Table 6. Comparison of water issues in two slums with and without legal water connections.

Existing Water Issues	Baganbari Slum	Tejgaon Slum
Type of water supply	Legal connection from DWASA	Illegal connection from private vendors
Water price (BDT/m^3)	14.46	250
Average HH income (BDT)	5600	6440
Average income spent on water (%)	1.3	8.0
Average water consumption (lpcd)	40	18

The proposed IBT model fulfills multiple objectives, such as groundwater conservation, the cost recovery of water supply and the reduction of price burden of water for low-income residents, and thus satisfies the three core principles of IWRM. However, the implementation of an IBT-tariff structure is quite challenging. One of the most important challenges is the necessity to quantify individual household use and household size to allocate use to the relevant block and allow customers to be billed at rates pertinent to their use levels. The lack of effective water metering in the Dhaka city is thus an obvious barrier to the implementation of the proposed water tariff. In this case, the solution can be drawn from the Israel metering practice, where standard water meters are mandated by law for all the wells, water producers, and consumers in the country. Such metering and IBT have formed the basis of demand management by reducing the water usage by 26% [125]. Moreover, non-metered users can also be encouraged to install meters in their households either by provision of a loan for sharing the meter installation cost or levying an additional fee to discourage their practice. In addition, in Dhaka city, DWASA provides legal water connections to the slums through NGOs, which sometimes become unsustainable after accomplishment of the NGO project. In this case, supplying water directly through the community management group can be more effective. The standard meter installation and monitoring of community management group would need a huge investment, but it can be recovered from the additional revenue earned following the implementation of the proposed water pricing.

5. Conclusions

Water pricing is more effective at managing scarce resources than non-pricing policy tools due to the price-demand elasticity, which creates a great scope for managing the water demand in the Dhaka city. The current water supply system in the city provides a continuous domestic water at a low price (BDT 14.46 per m^3), which in turn underrates the true value of water, and results in an overuse of scarce groundwater resources. Thus, the prevailing system is leading to a rapid depletion of this important environmental resource. On the contrary, the slum dwellers are being deprived of basic water needs because of the high price (BDT 250 per m^3) arising from illegal channels of water supply. The combination of a high water price and low income has led to suffering in the life of the slum dwellers, such as less water use (by 11 times), water-shortage related diseases (66%), unhealthy bathing practice (58%), unhygienic sanitation (82%), and gender inequalities. To improve the conditions, this study has developed a domestic water-pricing model following an IBT-pricing structure with the use limit of 50 lpcd in the first block. The suggested unit price of water in the first block covers the unit extraction cost (BDT 15.18), while that in the second block includes the cost of resource degradation externalities (BDT 25.37). As externalities, the study considered the increased energy consumption due to groundwater depletion, damage costs due to the dryness of tubewells, the carbon footprint of water, and treatment costs. Incorporating the cost of externalities, the price of water is estimated to be about 75% higher than the existing price in the second block.

The proposed water-pricing model satisfies the core principles of IWRM by earning an additional revenue of 5% to 75% (economic efficiency); reducing water usage up to 27%; lessening energy consumption by up to 56,160 MWH; lessening greenhouse gas emissions by 37,630 tons per year (environmental integrity); and allowing cross subsidies from large users to small users (social equity). This is a solid demonstration of operationalization of the IWRM concept using environmental economics. The IWRM concept was critiqued in the past due to the absence of an operational framework. This case study breaks that implementation barrier. Since people are already using filtration devices, bottled water, jar water, water vending machines, water lorries, etc., which are far more expensive than the unit price suggested in the proposed model, there is a great potential for practical deployment of the model. It will be a win-win situation for the service provider, water user and the environment. Real initiatives are now needed from the government to pilot the proposed model. The model would be very useful to the policy and decision-makers for optimal water allocation in the domestic sector for the present and future. However, the conclusions drawn from the study are constrained by the limited primary and secondary data collected from a specific area of Dhaka city. Hence, there is potential for further refinement of the model with more data from other areas of the city as the externalities vary from area to area. The model can be applied to other cities in the developing countries, particularly in South Asia. Similar pricing models can also be developed for other water uses, such as industrial, commercial and agricultural uses.

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