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Addressing Social Inequality and Improper Water Distribution in Cities: A Case Study of Karachi, Pakistan

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Abstract: Inhabited by almost 20 million people, Karachi, also known as the "city of lights", houses almost 60 percent of the industries in Pakistan and is considered as the financial and industrial center of the country. The city contributes almost 12–15 percent to the gross domestic product (GDP), showing its significance in Pakistan's economy. Unfortunately, with the increase in population, the city is facing a serious shortage of water supply. The current allocation of water among the city's districts is not equitable, which has caused water scarcity and even riots in some areas. Surface water and ground water are the two primary sources of water supply in the city. The water supply provided by Karachi Water and Sewerage Board (KWSB) is approximately 650 million gallons per day (MGD) against a demand of 480–866 million gallons per day (MGD), resulting in a serious shortfall. Keeping a holistic view in mind, this paper focuses specifically on proposing measures to address the gap in proposing concrete solutions to manage Karachi's increasing water woes. It also proposes a water allocation mechanism and uses Nash bargaining theory to address the inefficient and unequal water distribution. Results indicate that our suggested policies and water allocation mechanism have the potential to simultaneously resolve the supply–demand mismatch and water shortage problems of the city.

Keywords: social inequality; Karachi; Karachi water and sewerage board; Nash bargaining theory

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1. Introduction

Marginalization and exclusion patterns are present all over the world, with persisting and stark inequalities in water access. Progress made in the sanitation and water sector does not always benefit those people who need these services the most, especially in underdeveloped countries. The international human rights law demands that fundamental human rights principles of equality and non-discrimination must be met in letter and spirit, and should focus on the communities, groups, and individuals who do not fully enjoy their rights [1].

Policy makers, duty bearers, and experts should aim at realizing the rights of all the people, with a particular focus on the excluded and marginalized. Apart from meaningful, active, and free participation for all, the conflict mechanism resolution, access to remedy, and accountability mechanisms should also be in place [2]. These mechanisms should be appropriately implemented at the national level. In addition, a proper monitoring framework should be in place to track their progress [3].

Resilient, livable, and sustainable water-sensitive cities should be for everyone and not only for those who have the resources and capacity to access them [4]. However, nowadays, in modern urban contexts where social, material, economic, and cultural resources are varied between the communities, especially in underdeveloped countries, a question arises: how do we assure this accessibility?

Several studies conducted in underdeveloped and even developed nations have addressed and presented the challenges faced by them regarding inequalities for water supply access and urban water management. For example, various researchers have shown that in under-developed countries such as Zambia, Jordan, Bolivia, Ghana, India, and Uganda [5]; Cameroon [6]; Argentina, Columbia, and Brazil [7]; and even in a developed country such as China [8], the people living in backward areas and communities are more likely to face a shortage in the urban water supply compared to rich areas.

Inequality is aggravated by various socio-technical factors such as poor governance, non-existent or limited societal engagement, and the absence of proper water resource policies. Due to the factors mentioned above, water access in developing and underdeveloped countries is limited, and the input opportunities in the decision-making processes are also limited for the socially marginalized and urban poor groups [5,7].

It may be noted that the link between domestic water use and inequality in the water distribution is not only confined to the dimensions of urban water resources, but extends across various other domains of resource provision. For example, even in the developed countries of Australia, the UK, and the USA, studies show that the disadvantaged and the poor population are more likely to experience deteriorated amenities, fuel poverty, intensified heat exposure, and improper access to welfare and health facilities compared to the advantaged population [5,9–11].

Water allocation in cities is undertaken based on the population of the areas. The increase in population causes an imbalance between the available water resources and its consumption [12], and, as a result, the poor and disadvantaged population is likely to experience more water shortages than the advantaged population [10], causing discontent among the stakeholders. Therefore, the most important criterion for water resource allocation is equity [13]. In turn, this indicates that a system should be established that ensures equity in the allocation of water among the stakeholders. When the water demands exceed the available water, many problems occur. Water conflict is one such problem, and the main reason for such a conflict is the unsuitable model used to allocate water resources [14].

Various problems of scarce resource allocation can be solved using game theory and the Nash bargaining method. The Nash bargaining solution can satisfy desired properties such as flexibility, invariance under changes in scale, unanimity, and Pareto optimality. Several authors [15–20] used the Nash bargaining solution to manage and allocate scarce resources. In addition, Mehta and Webb. et al [21,22] established that water resources are under immense pressure due to an increase in competing uses, which cause different resource stress dynamics in different regions. The competing uses can be domestic consumption, urban demand, industrial demand, and use in food production processes. The European Commission (2012) also stated that the pressure on freshwater resources is increasing due to the change in population and increasing consumption patterns [23]. It is predicted that the countries such as India and China may face severe water deficits by 2030, and by 2050, there will be a 55 percent increase in the global water demand [21]. Some studies state that water scarcity is primarily due to the bad governance and mismanagement of the water sector, followed by a lack of economic investment and the development of new water resources [24,25]. According to Hussein [26], there is a single dominant discourse of water scarcity composed of two narratives: water insufficiency and water mismanagement. The former is related to water scarcity, whereas the latter refers to improper management and distribution of water resources.

Urban communities, particularly in underdeveloped countries such as Pakistan, are vulnerable to future demand for water, energy, and food [27–29]. This vulnerability is further exacerbated by an increase in population and climate change. A solution is therefore needed to address these issues. This is the century of cities, and more than 50 percent of the world's population lives in cities. This number is expected to reach 68 percent by

2050 [30]. As a result, the demand for food, energy, and water is increasing, leading to concerns about crossing critical thresholds of capacity at all scales. Due to the increase in population, climate change, and deteriorating infrastructures in cities, there is a growing awareness of risks to the sustainability of food, energy, and water (FEW) in cities [31].

Optimization of the water resources can be a feasible solution for equitable water allocation. To solve such complex problems, evolutionary algorithms can be used [32–34]. Water allocation in the Sefidrud Basin was undertaken using an optimization model by Roozbahani et al. [35]. Allocation of scarce water in the Central Desert basin, Iran, was done by Habibi Davijani et al. [36]. They used a particle swarm optimization algorithm to minimize the cost function. To prevent water conflict in the Urmia Lake basin, Iran, Bozorg-Haddad et al. [12] applied bankruptcy games optimization to determine allocation policies. These optimization models addressed the supply–demand gap in various areas. Finally, an optimal water resource allocation model was developed by Wang et al. [37] in the Haihe River basin, which addressed the water scarcity issue under climate change conditions.

Karachi, the largest city in Pakistan, is currently facing a serious water shortage. The water supply in the city is inequitable and irregular. Some areas of Karachi are receiving more water than others, whereas some are receiving too little to meet their needs [38]. This improper allocation of water has led to several disputes in the city. In June 2002, two ethno-political parties staged a rally against water shortages, which turned violent after police fired at the protestors, killing two and leaving six injured [39]. The protestors set vehicles on fire and ransacked property. The tension eased later when additional water supplies were brought in from the river Indus, the critical source of water for Karachi and the rest of the province [39]. Recently, on 20th September 2021, Jamaat-i-Islami, a strong political party of Karachi, staged a sit-in and demonstrated outside the offices of the Karachi Water and Sewerage Board (KWSB) in protest over the problem of water shortage in the metropolis [40]. If not adequately addressed, this issue of improper water allocation may lead to serious disputes and violence in the future.

This paper aims to explore the relationship between domestic water provision and inequality in the context of Karachi, the largest city in Pakistan. It also shows the impact the social inequality has on the people living in different areas of Karachi and suggests a Nash bargaining solution for equitable water distribution among the different sectors of the city.

2. Materials and Methods

Water allocation among different competing stakeholders is a typical case of a bankruptcy problem in which the demand of all the stakeholders exceeds the total available water resources. In accordance with the definition above, this problem is formulated as: (N, E, c, x^-). Here $N = [1, 2, 3, \ldots, n]$ is a finite set of agents. These agents can be administrative units within the city or riparian countries within a transboundary river basin that are competing for limited water resources. E is the limited available water resources reserve, which is not sufficient to satisfy the need of the stakeholders, whereas c_i is the total amount of water claimed by the riparian units, and $i \in N$. x^- is the amount of water allocated to the stakeholder. Let us assume that the total amount of water available in the territory of the stakeholder, i is a_i; therefore, the total available water resources within the city are $E = \sum_{i=1}^{n} a_i$. Conflicts arise among the water users, and the existing distribution mechanisms fail when their total demand exceeds the available water resource reserves. During such a water-scarce situation, optimization techniques are helpful to allocate limited water resources. These techniques help to buffer the conflicts and prevent the collapse of the water supply system. Let us assume that x^- is the amount of water allocated to the agent I; three conditions of bankruptcy must be met, as detailed by Equations (1)–(3):

$$\sum_{i=1}^{n} x_i = E \tag{1}$$

Equation (1) is called Pareto efficiency and requires that the aggregate value of available water resources should be exactly distributed among the competing agents.

$$x_i^- \geq c_i \tag{2}$$

Equation (2) is called claim boundedness, and it helps prevent resource overuse, which may cause the tragedy of the commons.

$$x_i^- \geq 0 \tag{3}$$

Equation (3) ensures non-negativity.

2.1. Asymmetric Nash Bargaining Solution

Building on earlier works [16,17,20,41,42], the Nash bargaining solution concept is proposed for the allocation of water among the six districts of Karachi.

In this study, the asymmetric Nash bargaining theory is combined with the bankruptcy concept and applied to the city of Karachi for the allocation of water among the districts when the supply–demand gap exists. While applying this methodology, the disagreement allocation points (m_1, m_2, m_3, … , m_n) and the bargaining weights ($w_i = w_1, w_2, w_3, \ldots, w_n$) of the riparian units are also considered to ensure equity and self-enforceability in a closed and bounded space. In addition to having a unique solution, such an optimization solution also satisfies a set of desirable properties. The solution maximizes the area between the Pareto-optimal frontier (x-) and the disagreement point (m_i).

The Nash equilibrium point can determine the disagreement points, the minimum benefit of each riparian unit, the maximum and the minimum point, and other methods. In this case, the vector of disagreement points (d_1, d_2, … d_i, … , d_n) is defined as the benefits of minimum water allocation to the riparian units. This represents the minimum benefits that the riparian units can accept. It is, therefore, necessary that the individual rationality requirements are reflected before the cooperation of the followers so that the maximal and minimal solutions are satisfied. For each riparian unit, the disagreement point formula is defined by Equation (4):

$$d_i = u_i(m_i) \tag{4}$$

In order to solve the problem of minimal water allocation to each riparian unit, the bankruptcy theory can be used when the total available water is less than the total water demands. The minimal water allocation formula for each riparian unit is given by Equation (5):

$$m_i = max\left(0,\ E - \sum_{k \neq i} c_i\right) \tag{5}$$

Subject to:

$$E < C \tag{6}$$

The minimum water allocation to any riparian unit, especially to those with smaller claims, may become zero if the above method of bankruptcy theory is used for the minimum water allocation. However, each riparian unit will demand a minimum amount of water λi in the process of water resource allocation. Using the above theory of bankruptcy, the minimum water allocation may be less than the minimum water requirement of each riparian unit, λi. Therefore, in order to avoid the case of unreasonable minimum water allocation by bankruptcy theory, we propose Equation (8), which determines the minimum water allocation and considers the minimum requirement for each riparian unit:

$$I_i = max(\lambda_i,\ E - \sum_{k \neq i} c_i) \tag{7}$$

where λ_i is the minimum water requirement of each stakeholder or claimant, which is taken as forty percent of the stakeholder's claim in this study. E is the total amount of water available and c_i is the claim of each riparian unit.

For the optimization problem, the respective water claims of the riparian units serve as the upper bound core. According to Harsanyi [43], the optimization problem for the allocation of water under the bankruptcy scenario is given by Equation (8):

$$Maximize\ N^w = \left(x_1^- - \left(E - \sum_{i \in N/\{1\}} c_i\right)\right)^{w_1} \left(x_2^- - \left(E - \sum_{i \in N/\{2\}} c_i\right)\right)^{w_2} \left(x_3^- - \left(E - \sum_{i \in N/\{3\}} c_i\right)\right)^{w_3} \ldots \left(x_n^- - \left(E - \sum_{i \in N/\{n\}} c_i\right)\right)^{w_n} \quad (8)$$

The above model is constrained by feasibility and individual rationality. The claims and the disagreement points serve as the upper and the lower bounds, respectively. Therefore, the river sharing optimization problem for the districts of Karachi can be formulated as stated in Equation (9):

$$Maximize\ N^w = \left(x_{KC}^- - \left(E - \sum_{i \in N/\{KC\}} c_i\right)\right)^{w_{KC}} . \left(x_{KE}^- - \left(E - \sum_{i \in N/\{KE\}} c_i\right)\right)^{w_{KE}} . \left(x_{KS}^- - \left(E - \sum_{i \in N/\{KS\}} c_i\right)\right)^{w_{KS}} . \left(x_{KW}^- - \left(E - \sum_{i \in N/\{KW\}} c_i\right)\right)^{w_{KW}} . \left(x_{KoR}^- - \left(E - \sum_{i \in N/\{KoR\}} c_i\right)\right)^{w_{KoR}} . \left(x_{ML}^- - \left(E - \sum_{i \in N/\{ML\}} c_i\right)\right)^{w_{ML}} \quad (9)$$

In the above equation,

$$\sum_{i=1}^{n} w_i = 1$$

Moreover, in Equation (9),
x_{KC}^- is the optimized water allocation for Karachi Central District.
I_{KC} is the lower core bound for Karachi Central District.
x_{KE}^- is the optimized water allocation for Karachi East District.
I_{KE} is the lower core bound for Karachi East District.
x_{KS}^- is the optimized water allocation for Karachi South District.
I_{KS} is the lower core bound for Karachi South District.
x_{KW}^- is the optimized water allocation for Karachi West District.
I_{KW} is the lower core bound for Karachi West District.
x_{KoR}^- is the optimized water allocation for Korangi District.
I_{KoR} is the lower core bound for Korangi District.
x_{ML}^- is the optimized water allocation for Malir District.
I_{ML} is the lower core bound for Malir District.
N^w is the weighted Nash objective function which should be maximized.
The following constraints are to be set for this allocation model.

1. The allocation of water to each district should be more than or equal to its lower core bound (Equation (10)):
$$x_i^- \leq m_i\ ,\ i = 1,\ 2, \ldots, n \quad (10)$$
2. The water allocation to each district should be more than its lower core bound and less than its claim (Equation (11))
$$m_i \leq x_i^- \leq c_i \quad (11)$$

3. The total water allocation for all the districts should be equal to or less than the total available water (Equation (12)):

$$\sum_{i=1}^{n} x_i^- \leq E \tag{12}$$

2.2. Water Allocation Using of Nash Bargaining Theory

Determination of bargaining weights

It is very important that the water resources should be efficiently allocated due to the intense competition of water resources. Several authors have showed that the allocation of water should be based on sustainability and equity principles [44,45]. The optimization model in Equation (10) is applied to allocate water among the six districts of Karachi. In this study, two cases of bargaining weights were applied in all the scenarios (these four scenarios have been discussed in detail in the next section). Firstly, all the bargaining weights were assumed to be equal. Secondly, the bargaining weights of the districts were taken according to their population density. It is assumed that higher population density of any district will lead to more complex water supply networks, and hence their leakages will be greater. Therefore, these districts will be given preference in terms of water allocation. According to various reports and interviews conducted by the officials of the Karachi Water and Sanitation Board (KWSB), 15 percent of the water supply is wasted due to technical leakages [38,46]; therefore, it was important to consider the effect of leakages in the water allocation. The population densities of the provinces and their respective bargaining weights are shown in Table 1.

Table 1. Population densities and bargaining weights of all districts of Karachi.

District	Population Density	Bargaining Weight
Karachi Central	43,064	0.40
Karachi East	20,686	0.19
Karachi South	14,502	0.14
Karachi West	4206	0.04
Korangi	23,866	0.22
Malir	891	0.01

3. Case Study

3.1. Description of the Study Area

Located on the coast of the Arabian Sea, the city of Karachi lies in the extreme south of Pakistan. It has a total area of approximately 3530 square kilometers. As per the latest census of 2017, the population of Karachi is approximately 16 million, making it one of the largest metropolitan cities in the world [33]. Due to the migration of the people from rural to urban areas in search of better livelihoods, the population of Karachi is increasing rapidly. This additional increase in population has put pressure on all the available resources and utilities of the city, including water. As a result, groundwater extraction has also increased [33]. In 2001, the number of households in Karachi was about 2.1 million, which increased to 3.9 million in 2020. Of the 3.9 million households, almost 75 percent lie in the category of low-income and poor groups, while the remaining 25 percent constitute middle- and high-income groups.

As shown in Figure 1, Karachi serves as a major port to the Arabian Sea. It is a major contributor to Pakistan's economy, comprising approximately 30 percent of its manufacturing sector and 20 percent of the gross domestic product (GDP). The city also has a large informal economy which is not reflected in the GDP estimates [47]. Much of the increase in Karachi's population is attributed to the mass migration of various ethnic groups and the influx of refugees from conflicts in nearby countries such as Bangladesh and Afghanistan [47].

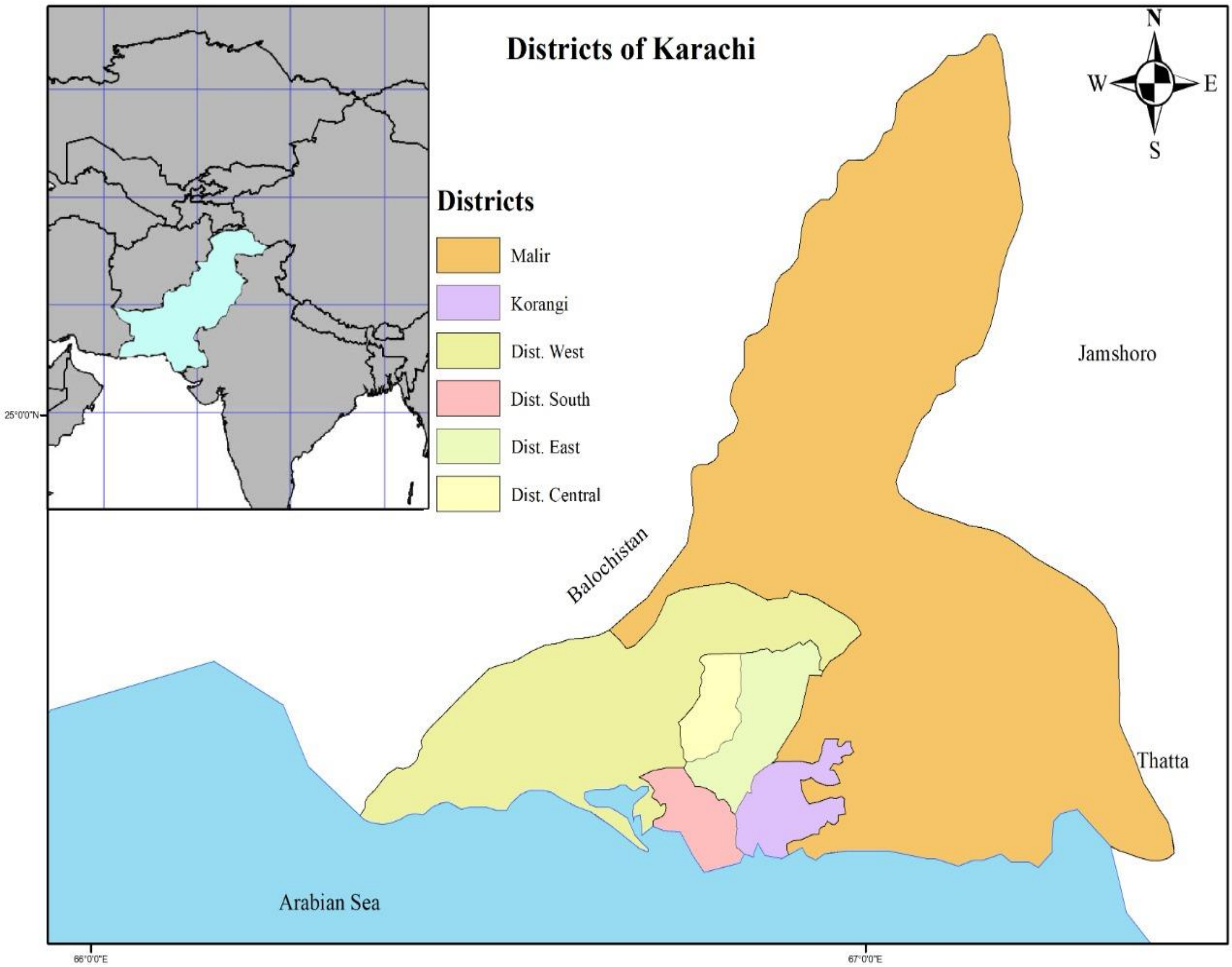

Figure 1. Districts of Karachi.

3.2. Water Sources and Its Availability in Karachi and Current Water Distribution

Primarily, there are two sources of water supply in Karachi: the Indus River, which supplies 645 million gallons per day (MGD), and Hub dam, which supplies 50 MGD. However, the supply of Hub dam depends on the rain. Therefore, its supply fluctuates between 30–75 MGD. As a result, the total water supply to Karachi is almost 690–680 MGD. Of this, 30 MGD are supplied to Port Qasim and Steel Mills; therefore, the city is left with approximately 650 MGD of water [34]. As per the Karachi Water and Sanitation Board (KWSB), the maximum and minimum per capita water demand are 54 gallons per capita per day (GPCD) and 30 gallons per capita per day (GPCD), respectively. Table 2 shows the maximum and minimum water requirements for all the districts of Karachi. These districts are also shown in Figure 1.

Table 2. Population and water requirements for various districts.

Name of Division	Status	Population as per Latest Census	Water Requirement @ 54 GPCD (In MGD)	Water Requirement @ 30 GPCD (In MGD)
Karachi Central	District	2,971,382	161	89
Karachi East	District	2,875,315	155	86
Karachi South	District	1,769,230	96	53
Karachi West	District	3,907,065	211	117
Korangi	District	2,577,556	139	77
Malir	District	1,924,346	104	58
Total	Division	16,024,894	866	480

In addition to equitable allocation of water using optimization techniques, metering of bulk supply is essential. This will assist in checking the siphoning and ensuring that towns receive their share. Once the water reaches the towns, its distribution can be handled by Tehsil Municipal Administrations (TMAs) and Union Councils (UCs) and be linked to recovery of water taxes within towns. The siphoning and technical leakages within towns can then be handled. Quotas to towns can be revised considering the current population and its needs, unlike the present quota.

As per February 2008, in a report published by the Karachi Water and Sewerage Board (KWSB) [48], it had a water quota of 417.65 MGD, for the water supply to the towns, the Cantonment, and DHA areas. However, the actual supply reaching the towns was only about 293 MGD. Seven towns—Orangi, Gadap, Baldia, Jamshed, Site, North Karachi, and Gulshan—were receiving 30–57 per cent of their quota and others were receiving about 60–100 per cent. Cantonment was receiving 100 per cent, whereas DHA was receiving 133 per cent, as shown in Table 3. These values clearly show that water allocation among the towns is not equitable. This improper water allocation continues today.

Table 3. Water supply in various towns of Karachi as per KWSB report 2007 [48].

Sr. No	Town	Water Requirement (Million Gallon per Day) (MGD)	Actual Received	
			(MGD)	% Quota
1	Lyari	14	12	85
2	Saddar	32	30	93
3	Kemari	10	8	80
4	Jamshed	30	14	46
5	Gulshan	35	20	57
6	Shah Faisal	12	9	75
7	Malir	20	12	60
8	Landhi	16	20	125
9	Korangi	24	21	87
10	Bin Qasim	14	14	100
11	Gulberg	22	17	77
12	North Nazimabad	20	14	70
13	Liaqatabad	18	18	100
14	North Karachi	35	20	57
15	Orangi	40	12	30
16	Baldia	20	8	40
17	Site	18	10	55
18	Gadap	8	3	37
19	Cantonment	22	22	100
20	DHA	6	9	133
	Total	416	293	

3.3. Current Domestic Water Requirements for Karachi City and Water Deficit

Karachi's main urban water management organization is the Karachi water and sewerage board (KWSB), but its services are not up to the mark [49]. Due to inequitable and irregular water supply, the performance of the KWSB is often questioned [46]. Water is supplied to Karachi through a bulk conveyance system comprising a complex network of canals, conduits, siphons, multi-stage pumping, and filtration. The present supply to Karachi from Indus and Hub sources is approximately 650 million gallons per day (MGD) or 2925 mL/day. The maximum and minimum per capita water demands are 54 and 30 GPCD, respectively; for a population of 16.4 million this equates to 866 and 480 MGD, respectively, as shown in Table 2. In addition, 100 MGD additional water is required after each interval of 5 years to bridge the demand and supply gap [38,46]. The gap between the actual supply and the availability is siphoned from the bulk distribution and sold through tanker supplies.

In addition to water shortage, there is another serious problem of water losses during transmission. As per a report published by the WWF [50], the water supply system of Karachi is almost 40 to 45 years old, and an estimated 35 percent of the water (amounting to 227.5 MGD) is lost during transmission. As a result, the water availability decreases to 422.5 MDG. Only 60 percent of the houses are connected to a water supply network and water is available for between 2 and 4 h each day, to as low as 2 h for each two-day period. This mostly occurs in low-income areas. In order to fulfil the demand supply gap, the already deprived population is forced to buy water from unregulated water hydrants.

3.4. Proposed Scenarios

In order to eliminate injustice in the water allocation, this study proposed the following four scenarios. Equitable allocation of water for all these scenarios is performed using the Nash bargaining solution. These scenarios area are also shown in Table 4.

3.4.1. Scenario-1: Total Water Availability = 650 MGD and Water Requirement @ 54 GPCD

In this scenario, it is assumed that the total water availability is 650 MGD, whereas the total water requirement of all the 6 towns @ 54 GPCD amounts to 866 MGD. The total shortfall, therefore, is 226 MGD.

3.4.2. Scenario-2: Total Water Availability = 650 MGD and Water Requirement @ 30 GPCD

In this scenario, it is assumed that the total water availability is 650 MGD, whereas the total water requirement of all the 6 towns @ 30 GPCD amounts to 480 MGD. Therefore, in this case, there is no shortfall.

3.4.3. Scenario-3: Total Water Availability = 422.5 MGD and Water Requirement @ 54 GPCD

In this scenario, it is assumed that the total water availability is 422.4 MGD, considering the line losses. The total water requirement of all the 6 towns @ 54 GPCD amounts to 866 MGD. The total shortfall, therefore, is 443 MGD.

3.4.4. Scenario-4: Total Water Availability = 422.5 MGD and Water Requirement @ 30 GPCD

In this scenario, it is once again assumed that the total water availability is 422.4 MGD, considering the line losses. The total water requirement of all the 6 towns @ 30 GPCD amounts to 480 MGD. The total shortfall, therefore, is 57.5 MGD.

From the above scenarios, it can be seen that, with the exception of scenario 2, shortfall exists in all scenarios. The next target is to reallocate the water in these scenarios (scenarios 1, 3, and 4) to ensure equitable water among the districts of Karachi. The minimum water requirements (disagreement points) for all the districts are also shown in Table 5.

Table 4. Water availability, requirements and deficits under different scenarios.

Reference Scenarios	Water Availability (MGD)	Water Requirements (MGD)		Shortfall (Total) (MGD)
Scenario-1	650 MGD	Karachi Central (KC)	= 161	226
		Karachi East (KE)	= 155	
		Karachi South (KS)	= 96	
		Karachi West (KW)	= 211	
		Korangi (KoR)	= 139	
		Malir (ML)	= 104	
		Total	= 866	
Scenario-2	650 MGD	Karachi Central (KC)	= 89	No Shortfall
		Karachi East (KE)	= 86	
		Karachi South (KS)	= 53	
		Karachi West (KW)	= 117	
		Korangi (KoR)	= 77	
		Malir (ML)	= 58	
		Total	= 480	
Scenario-3	422.5 MGD	Karachi Central (KC)	= 161	443.5
		Karachi East (KE)	= 155	
		Karachi South (KS)	= 96	
		Karachi West (KW)	= 211	
		Korangi (KoR)	= 139	
		Malir (ML)	= 104	
		Total	= 866	
Scenario-4	422.5 MDG	Karachi Central (KC)	= 89	57.5
		Karachi East (KE)	= 86	
		Karachi South (KS)	= 53	
		Karachi West (KW)	= 117	
		Korangi (KoR)	= 77	
		Malir (ML)	= 58	
		Total	= 480	

Table 5. Minimum water requirements for all districts.

Total Water Availability: 650 MG Total Water Availability after Losses: 422.5 MGD				
Name of Division	**Water Requirement @ 54 GPCD (In MGD)**	**Water Requirement @ 30 GPCD (In MGD)**	**Minimum Water Requirement for 54 GPCD (40 % of Claim)**	**Minimum Water Requirement for 30 GPCD (40 % of Claim)**
Karachi Central	161	89	64	36
Karachi East	155	86	62	34
Karachi South	96	53	38	15
Karachi West	211	117	84	34
Korangi	139	77	56	22
Malir	104	58	42	17
Total	866	480		

4. Results and Discussion

Table 6 shows the allocation of water among the six districts of Karachi by applying the Nash bargaining theory under three different scenarios, using homogenous and heterogenous weights. In the first scenario, the total water availability is 650 MDG, whereas the water requirements for all the districts amounts to 866 MDG. The water shortage, therefore, is 226 MDG. The bargaining weights of the districts are taken according to their population density. It is assumed that higher population density of any district will lead to more complex water supply networks, and hence more leakages. Therefore, those districts having greater population density are given preference in terms of water allocation. Figure 2 shows the results of scenario 1 under homogenous and heterogenous weights. Similar results for scenarios 3 and 4 are depicted in Figures 3 and 4, respectively.

Table 6. Results for all scenarios using homogenous and heterogenous weights.

Scenarios	District	Allocation (Using Equal Weights)	Allocation (Using Bargaining Weights)	Allocation as Percentage of the claim (Using Equal Weights)	Allocation as Percentage of the Claim (Using Bargaining Weights)
Scenario 1	Karachi Central	115	161	71%	100%
	Karachi East	113	136	73%	88%
	Karachi South	89	90	93%	94%
	Karachi West	135	99	64%	47%
	Korangi	107	138	77%	99%
	Malir	93	27	89%	26%
Scenario 3	Karachi Central	77	95	48%	59%
	Karachi East	75	75	48%	48%
	Karachi South	51	49	53%	51%
	Karachi West	97	94	46%	45%
	Korangi	69	74	50%	53%
	Malir	55	35	53%	34%
Scenario 4	Karachi Central	80	161	50%	100%
	Karachi East	78	62	50%	40%
	Karachi South	59	43	61%	45%
	Karachi West	78	62	37%	29%
	Korangi	66	50	47%	36%
	Malir	61	45	59%	43%

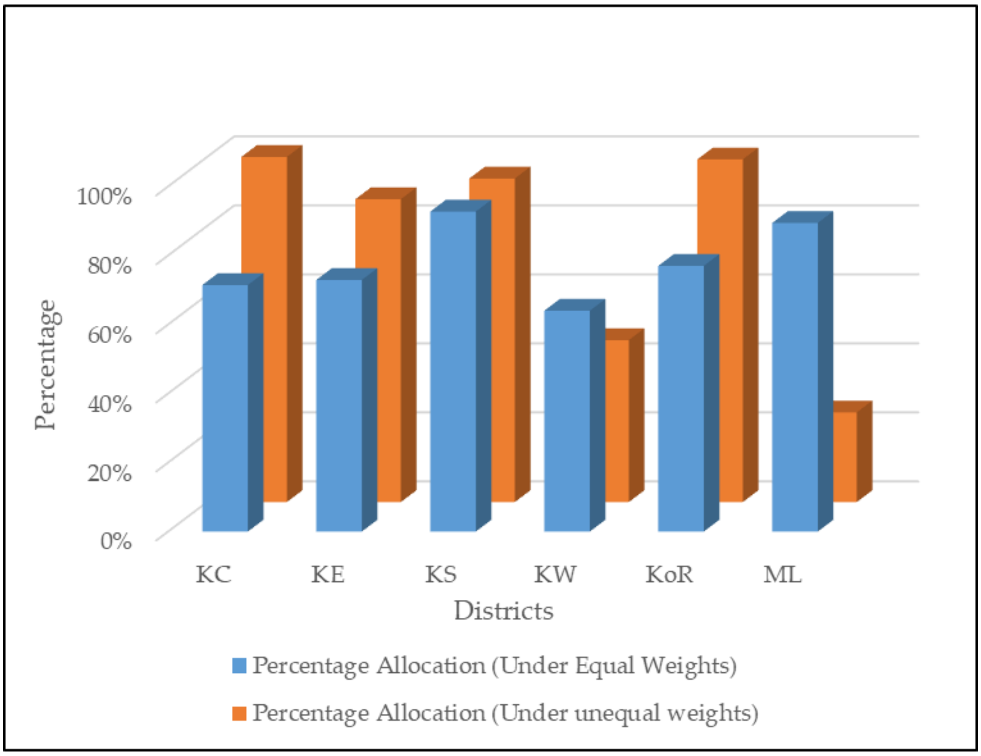

Figure 2. Water allocation under homogenous and heterogenous weights (scenario 1).

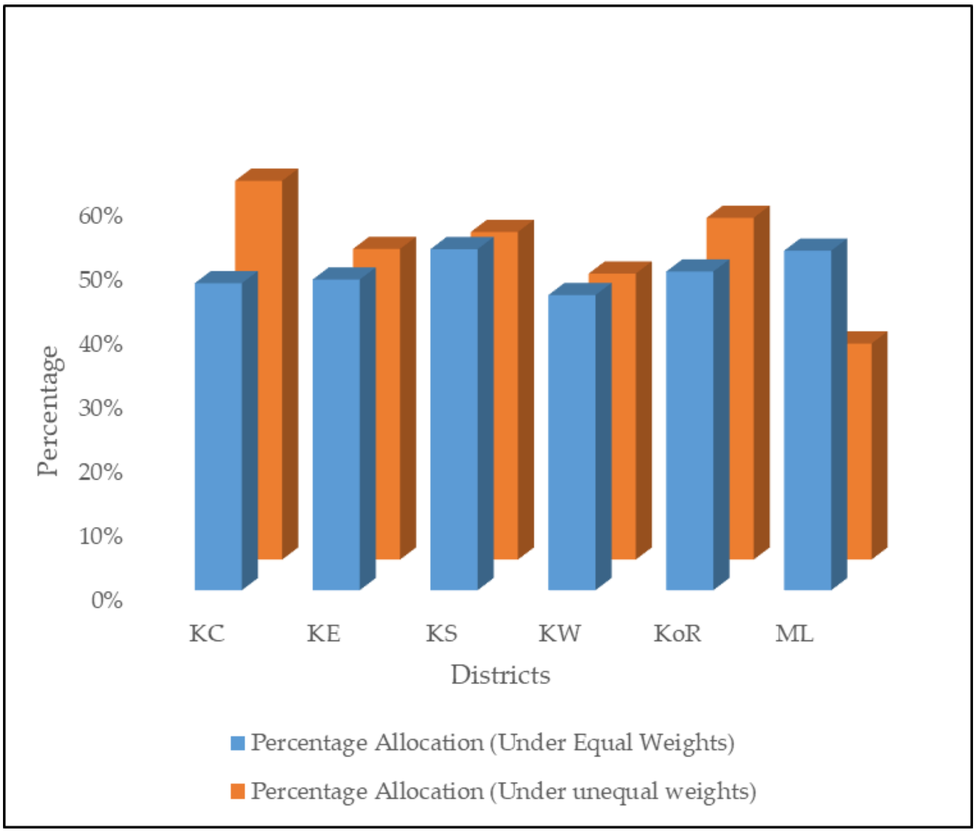

Figure 3. Water allocation under homogenous and heterogenous weights (scenario 3).

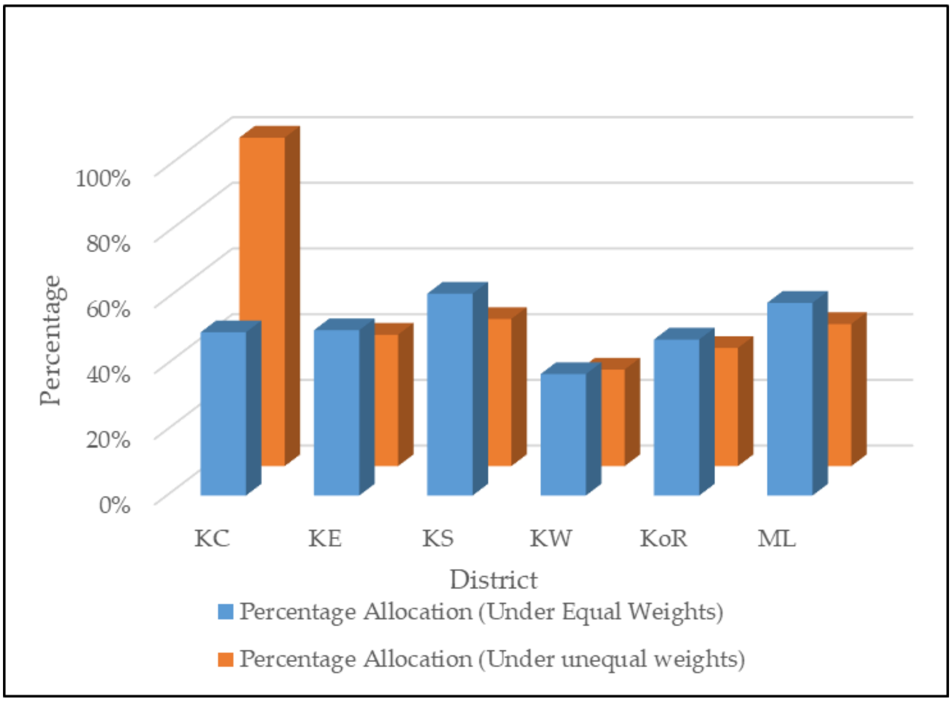

Figure 4. Water allocation under homogenous and heterogenous weights (scenario 4).

It can be seen from Figures 2–4 that the allocation of water using the Nash bargaining solution under homogeneous weights yields different results than the water allocation under heterogenous weights. Allocation of water under heterogenous weights is more appropriate for districts having greater population density. Similarly, water allocation is reduced for the districts having lower population density. For example, in scenario 3, Karachi Central receives 48 percent of its water demand under homogenous weights, whereas its allocation is increased to 59 percent under heterogenous weights. This is due to the fact that the population density of Karachi Central is highest among the six districts of Karachi; therefore, its allocation is increased under heterogenous weights. Similarly, for the same scenario, the allocation of water for Malir district is reduced from 53% under homogenous weights to 34% under heterogenous weight. This is due to the fact that Malir district has the lowest population density among all the districts of Karachi and hence its allocation is reduced under heterogenous weights.

These three different scenarios, under the homogenous and heterogenous weights, are used as example scenarios. These scenarios open the possibilities for discussion among the district administrations of Karachi and the KWSB about the consequences and implications for individual districts, in addition to the other water-scarce cities of the world. Other factors can also be applied using different bargaining weights, and issues of equity and sustainability may be discussed with facts. Questions such as the payment of water tariffs can also be examined in resolving the supply–demand gap.

5. Conclusions

A city with a population approaching 20 million, Karachi is facing numerous challenges due to its rapid urbanization and population growth. Water scarcity is one of these challenges. Located in the arid climate region, the scarcity of water is considered a serious problem of the city as the pattern of rainfall in this region is highly erratic. Decision makers should holistically address the water sector by considering the important factors such as population growth, rapid urbanization, and climate change. Best practices and regulations should be implemented at the local government level for the better management of water resources, which are already becoming scarce. New development in the periphery of the city must be consistent with the available water resources; otherwise, the future residents of the city will face a serious challenge related to water supply. The Nash bargaining solution under homogenous (equal) weights, in this study, does not consider other factors such as water use efficiency and non-payment of water tariff. Therefore, in order to expand the scope of the conversation, one may explore other scenarios, including the effects of changing population, growing population, and water tariffs. We hope this proposed framework for water allocation will find more innovative applications for other populated cities experiencing water shortages across the world.

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