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Application of Game Theory in Water Supply Management in Rajkot City

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Abstract- *Water resources are essential elements for the existence of human beings and all other species. In India per capita surface water availability in the years 1991 and 2001 were 2309 m^3 and 1902 m^3 and these are projected to reduce to 1401 m^3 and 1191 m^3 by the years 2025 and 2050 respectively. In India, the major challenge is to manage its increasing water demand and tackling its water losses through leakage and non-revenue water. Managing water demand usually involves some conflicts which may occur among the different stakeholders. The present water demand for the Rajkot City is 270 MLD while Rajkot Municipal Corporation can continues supply water to the city of 245 MLD considering all water supply sources available in Rajkot city. So, there is 25 MLD gap between water demand and water supply in the Rajkot city. It is expected to increase to 111 MLD and 192 MLD by 2035 and 2050 respectively. The water demand-supply gap in Rajkot city is expected to almost double by 2050. This gap is continuing increasing day by day as population increases. This calls for the identification of proper sources of water supply, their conservation and optimal utilization. The overall objective of this study is to develop a methodology to provide optimal solution for water supply in Rajkot city.*

In the present study, a five user water distribution model is formulated for Rajkot City. The game theoretic approach is utilized in analyzing water conflicts between different users i.e. industrial (k=1), Unaccounted (k=2), Institutional (k=3), domestic (k=4) and Public (k=5) for the optimal supply of freshwater to different users from different water sources i.e. Ajii-I (ak), Narmada (nk), Nyari-I (nyk), Bhadar(bk), Nyari-II (nyk*) to fill the gap between water demand and water supply in the Rajkot city. Their common objective is to minimize water shortage or to maximize water supply. However, the water supply is limited which results in a conflict between these users. Game theory is an appropriate approach to simulate and resolve such conflicts. Non-symmetric Nash bargaining solution is used to develop an environment for the conservation of water and optimized the weighted Nash product to obtain the actual solutions. From the study, it is concluded that there is no water distribution strategy which satisfies the need of domestic users with current water distribution system. Water pricing policy would be one of the solutions to provide incentive to the users and promote efficient and equitable use of water for different users.*

Keywords—*Game Theory, Water Resource Management, Water Distribution, Water Supply*

INTRODUCTION:

Water resources are essential elements for the existence of human beings and all other species.[1] The water distribution on earth shows that of all the water that exists, 97.5 percent is saltwater. Only 2.5% of the water on our planet is fresh water that can be used for human needs. [2] Liquid surface freshwater sources such as rivers and lakes only constitute about 22,300 cubic miles (93,100 cubic kilometers), which is about 0.0067 % of total water, yet rivers are the source of most of the water people use.[3] Global fresh water demand has tripled since the 1950s, but the supply of fresh water has been declining. The global population is projected to increase to about 9 billion by 2050. [4] In India per capita surface water availability in the years 1991 and 2001 were 2309 $m^3$and 1902 m^3 and these are projected to reduce to 1401 m^3 and 1191 m^3 by the years 2025 and 2050 respectively. [5] During the last few decades, freshwater scarcity is becoming a threat to society for sustainable development and creates water conflict between different users with contradictory or conflicting interests, goals and strategies.

When water is provided to the community, it must be clean, safe, adequate in quantity and easily accessible to consumers. As per IS 1172-1993, minimum per capita demand of 135 liter should be provided for LIG and economically weaker section (EWS) in small towns. Moreover domestic requirement, there are various types of water demands in a city i.e. institutional, industrial, unaccounted and public use. Domestic water is no longer a free commodity. The expense and effort involved to make it available at a particular location in a particular form and at definite time make it an "economic commodity". It has to be produced and supplied to the consumers in a desirable quality based on their demand, of course at a "price".

Rajkot is one of the largest city in the state of Gujarat and has been the largest city in Saurashtra region. It is located on the bank of Aji River. It falls within the arid zone, and the monsoon is very erratic, confronting the city with frequently occurring water scarcities. Geologically, the city is located on hard basaltic rocky strata having small confined aquifer that yields poor water in quantity as well as quality. The Rajkot Municipal Corporation is able to provide inequitable and intermittent supply for an average of 20 minutes per day. As per census 2011, Rajkot City's population is 1323363 and spread area of 104.86 km^2. Due to the vibrant economy, the Rajkot city has witnessed the high growth rate of 28.24% in the last decade and faces the infrastructure challenges that any rapidly growing city in India would face. Apart from the above, some parts of the city including newly developed areas and which have now been included within the extended municipal limits, are not supplied with protected and safe water supply. This poses constant danger and hazard to health of community. Groundwater in Rajkot is not considered to be sustainable water source due to the lower water table and associated risks of fluoride and nitrate. The present water demand for the Rajkot City is 270 MLD while Rajkot Municipal Corporation can continues supply water to the city of 245 MLD considering all water supply sources available in Rajkot city. So, there is 25 MLD gap between water demand and water supply in the Rajkot city. It is expected to increase to 111 MLD and 192 MLD by 2035 and 2050 respectively. The water demand-supply gap in Rajkot city is expected to almost double by 2050. This gap is continuing increasing day by day as population increases. To meet the water demand, Most of the water for the city comes from the Narmada Canal which is hundreds of kilometers away through the Saurashtra Narmada Avtaran Irrigation Yojana (Sauni Yojana). It is estimated that every liter of water requires 6 W of energy to make it to Rajkot which is highly unsustainable. The major challenge for the city is to manage its increasing water demand and tackling its water losses through leakage and non-revenue water. Managing water demand usually involves some conflicts which may occur among the different stakeholders.

Game theory is a method, which is used in competitive or cooperative position to find optimal choices that will lead to desired outcome. In every game at least two players will be involved in who will gait to maximize their own benefits with regard to opponent's decision. [6]However, achieving a win-win situation is the most desirable one for every player, but sometimes, players' decisions lead to the worse and critical conditions for all involved stakeholders. These water conflicts can occur during the use of water resources because any stakeholder involved in the project may act on behalf of them whereas in game theory approach benefits of whole stakeholders are considered. Game theory is an appropriate approach to simulate and resolve such conflicts. The overall objective of this study is to develop a methodology to provide optimal solution for water supply in Rajkot city.

LITERATURE REVIEW:

Hamidreza Dehghan Manshadi et al. (2015) developed new methodology for sustainable development in an inter-basin water transfer in central part of Iran, from the Solakan to the Rafsanjan basins water allocation management with resolving conflict based on cooperative games and virtual water concept for quantity-quality assessment of water transfer projects to satisfy both economic and environmental objectives and needs.[7] Manzar and Mahjouri (2013) used fall back bargaining approach to solve the waste load allocation problem between wastewater dischargers and environment protection agency at Zarjub river in the northern part of Iran. [8] Elmdoust and Kerachian (2012) developed perfect Bayesian equilibrium (PBE) approach for modeling the bargaining among dischargers using N-person iterated signaling games for Zarjub river quality management in Iran. [9] Nikoo et al. (2012) developed a methodology based on interval optimization and cooperative game theory for optimal operation of an inter-basin water transfer from the Karoon river basin in south-west to Rafsanjan plain in central part of Iran considering efficiency, equity and sustainability criteria. [10] Daylami et al. (2011) developed cooperative water quality management approach for efficient river water quality management. In this approach, a sub-model embedded to a Genetic Algorithm optimization model was designed to simulate water quality of the Zarjub river system located in the northern part of Iran based on the modified Streeter and Phelps quality relations. Regarding the treatment levels of effluent dischargers, the optimization model minimizes the total waste treatment cost of the system. [11] Mahjouri and Ardestani (2011) developed cooperative and non-cooperative methodologies for large scale water allocation problem in southern Iran. They compared the results of two approaches based on the total obtained economic benefit and the role of cooperation in utilizing a shared water resource. Results showed the importance of acting cooperatively to achieve maximum revenue in utilizing a surface water resource while the river water quality and quantity issues are addressed. [12] Nikoo et al. (2011) used a new game theoretic approach by combining a two-person nonzero –sum game, a multi-objective genetic algorithm and cooperative for trading pollution discharge permits in Zarjub river. [[13] Salazar et al. (2010) used non-symmetric Nash bargaining approach to generate adequate water distribution network to fulfill domestic, industrial and agricultural water demands as a three-person linear in which the users are the players, the water supplied amounts from five water sources are strategies, and the total water supplies are the payoffs. He concluded that for all water distribution scenarios there is no water distribution strategy that satisfies the domestic demand with current system. Therefore investments and further developments are needed in combination with more efficient water usage by the three sectors in the near future to secure the satisfaction of domestic users. He also recommended that a market driven water pricing policy would also give an incentive to the users for more efficient usage of water. [14] Deidda et al. (2009) proposed an approach starts with the hydrologic and economic characterization that allocates costs among water users with a cooperative game theory approach based on a fully integrated river basin model with monthly time steps at Turia river basin located in the Valencia and Teruel districts, Spain. [15] Lari et al. (2009) developed conflict-resolution methodology for conjunctive water allocation problem of surface and groundwater resources using Non-dominated Sorting Genetic Algorithm II (NSGA-II) and Young Conflict – Resolution Theory (YCRT) in Tehran metropolitan area of Iran. They linked NSGA-II optimization model with simulation model to develop Pareto fronts among objectives. The best solutions on the Pareto fronts are then selected using YCRT. [16] Niksokhan et al. (2008) studied Non-dominated Sorting Genetic Algorithm-II (NSGA-II) for developing pollutant discharge permit trading in Zarub River in the northern part of Iran considering the conflict of interest of involving decision-makers and the stakeholders. In this methodology, a trade-off curve between objectives is developed, then the best non-dominated solution on the tradeoff curve is defined using the Young Conflict Resolution Theory (YCRT) and finally an optimization model provides the trading discharge permit policies. [17] Schreider et al. (2007) used game theoretic approach for modeling the strategies of phosphorus application by farmers of the Glenelg-Hopkins Basin in Western Victoria. [18] Raquel et al. (2007) applied game theory to find out the optimal solution between two conflicting objectives among 12 alternative groundwater extraction scenarios at Alto Rio Lerma Irrigation District in Mexico, where economic benefits from agricultural production should be balanced with associated negative environmental impacts include continued diminishment of groundwater quality, and declining groundwater levels in the basin, which can damage surface water systems that support environmental habitats. [19] Wang et al. (2003) proposed a game theoretic approach to solve water allocation problem in two steps i.e. initial allocation of water rights to water users or stakeholders based on existing water rights systems or agreements and reallocation of water to achieve efficient use of water through water transfer. [20] Supalla et al (2002) used sequential auction with repeated bidding under game theory to solve the water resource management problem for the Middle Platte River ecosystem at three states Colorado, Nebraska, and Wyoming. The results suggest that the use of auction mechanism can improve the prospects for reaching a multi-state agreement on who will supply in stream flow water, if the auction is structured to discourage misrepresentation of costs and if political compensation is allowed. [21] Bogardi and Szidarvovszky (1976) applied oligopoly game theory approach in deterioration of water quality, irrigation system, water quality management or several areas of complex water resource decision making. [22]

METHODOLOGY:

i. **Game Theoretic Approach:** Game theory is a mathematical framework for analyzing the strategies of each decision maker or player to maximize each player's chance of winning, and to predict possible outcomes of the game. The complexity of water resource conflict can be analyzed using game theory to explore the variety of potential outcomes resulting from the various strategies used by the players of the game. A game involves a set of players or decision makers, that each having a number of options (strategies) which they can use based on their preferences for particular outcomes. A strategy for water resources management using game theory includes defining the players for conflicting areas, optimization of water quantity for each player in order to maximize his payoff and finally optimize water quality so that every player can maximize his payoff.

ii. **Model Framework:**

A model is a generalization of the real world system. It is not the real world but merely constructed to help us better analyze and understand the real world problem. Game theory is a set of analytical tools designed to model interdependent situations, in which the rational behavior of one player affects not only his or her own gains and losses but also those of others.

Mathematically, five users are competing for the water: Industrial (k=1), Unaccounted (k=2), Institutional (k=3), domestic (k=4) and Public (k=5). Their common objective is to minimize water shortage or to maximize water supply. However, the water supply is limited which results in a conflict between these users. Let k = 1, 2, 3, 4, 5 be the index of the users, for each of them the decision variables are:

1. Ajii-I (a_k)
2. Narmada (n_k)
3. Nyari-I (ny_k)
4. Bhadar (b_k*)
5. Nyari-II (ny_k*)

Every user i.e. Industrial, Unaccounted for Water (UFW), Institutional, Domestic and Public wants to maximize its water supply, $a_k + n_k + b_k + ny_k + {}^*ny_k$, which is the equivalent as minimizing shortage.

There are two general limitations for each user. The supplied water amount cannot exceed demand D_k, it is the k user's demand. The calculation of the minimal amount required by each user can be denoted as D_k^{min}. The users have two common constraints. The complete water quantity cannot go beyond demand:

$$a_k + n_k + b_k^* + ny_k + ny_k^* \le D_k \tag{1}$$

Each user has to obtain a minimum required quantity of water i.e. D_{mink}:

$$a_k + n_k + b_k^* + ny_k + ny_k^* \ge D_k^{min} \tag{2}$$

In addition to these constraints, each user has its own conditions.

Industrial users (k = 1) have two special constraints. Let A_N Minimum quantity of Narmada water that is used by industry and A_{Ny} Maximum quantity of Nyari-I water that is used by industry

$$\frac{n_1 + ny_1^*}{a_1 + n_1 + ny_1 + b_1^* + ny_1^*} \ge A_N \tag{3}$$

$$\frac{ny_1}{a_1 + n_1 + ny_1 + b_1^* + ny_1^*} \ge A_{Ny} \tag{4}$$

It can be written as:

$$A_N a_1 + (A_N - 1)n_1 + A_N ny_1 + A_N b_1^* + (A_N - 1)\, ny_1^* \leq 0 \quad (5)$$

and

$$-A_{Ny} a_1 - A_{Ny} n_1 + \left(1 - A_{Ny}\right) ny_1 - A_{Ny} b_1^* - A_{Ny} ny_1^* \leq 0 \quad (6)$$

Unaccounted for water (UAF) users (k = 2) have one additional constraint. Let A_u Maximum proportion of Nyari-I's water that can be used for unaccounted purposes. Then this constraint can be written as follows:

$$\frac{ny_2}{a_2 + n_2 + ny_2 + b_2^* + ny_2^*} \leq A_u \quad (7)$$

$$-A_u a_2 - A_u n_2 + (1 - A_u) ny_2 - A_u b_2^* - A_u ny_2^* \leq 0 \quad (8)$$

Institutional users (k = 3) have one additional constraint is used. Let A_I, maximum proportion of the Narmada and Nyari-II water that can be used for institutional purposes. Then this constraint can be written as follows:

$$\frac{n_3 + ny_3^*}{a_3 + n_3 + ny_3 + b_3^* + ny_3^*} \geq A_I \quad (9)$$

$$A_I a_3 + (A_I - 1)n_3 + A_I ny_3 + A_I b_3^* + (A_I - 1)\, ny_3^* \leq 0 \quad (10)$$

Domestic users (k = 4) have one additional constraint is used. Let $A_{d,}$ maximum proportion of Nyari-I's water that can be used for domestic purposes. Then this constraint can be written as follows:

$$\frac{ny_4}{a_4 + n_4 + ny_4 + b_4^* + ny_4^*} \leq A_d \quad (11)$$

i.e.

$$-A_d a_4 - A_d n_4 + (1 - A_d) ny_4 - A_d b_4^* - A_d ny_4^* \leq 0 \quad (12)$$

Public users (k = 5) have one additional constraint is used. Let $A_{P,}$ maximum proportion of Nyari-I's water that can be used for public purposes. Then this constraint can be written as follows:

$$\frac{ny_5}{a_5 + n_5 + ny_5 + b_5^* + ny_5^*} \leq A_P \quad (13)$$

$$-A_P a_5 - A_P n_5 + (1 - A_P) ny_5 - A_P b_5^* - A_P ny_5^* \leq 0 \quad (14)$$

The total water availability of all sources can be represented by the additional constraints:

$$a_1 + a_2 + a_3 + a_4 + a_5 = S_a \quad (15)$$

$$n_1 + n_2 + n_3 + n_4 + n_5 = S_n \quad (16)$$

$$ny_1 + ny_2 + ny_3 + ny_4 + ny_5 = S_{ny} \quad (17)$$

$$b_1^* + b_2^* + b_3^* + b_4^* + b_5^* \leq S_b^* \quad (18)$$

$$ny_1^* + ny_2^* + ny_3^* + ny_4^* + ny_5^* \leq S_{ny}^* \quad (19)$$

As it was stated previously, each user wants to minimize its water shortage which is equivalent to maximize the total quantity of water supply:

$$\text{Maximum} \quad a_k + n_k + b_k^* + ny_k + ny_k^*, \quad \text{for } k = 1, 2, 3, 4, 5 \quad (20)$$

This problem can be considered as a five-person game, in which the water users are the players, the strategy of player k is the decision vector$p_k = (a_k, n_k, b_k^*, ny_k, ny_k^*)$. If $p = (p_1, p_2, p_3, p_4, p_5)$ is the simultaneous strategy vector of the three players, then it has to satisfy conditions. The payoff function of player k is given by equation below. Observe that all constraints and payoff functions are linear. Hence the dilemma can be rewritten in the form of the matrix as follows:

$$\begin{gathered} \text{Maximum} \quad z_k^T p_k \quad (k=1, 2, 3, 4, 5) \\ \text{Subject to} \quad p \geq 0 \\ Xp \leq y, \end{gathered} \quad (21)$$

Where, $z_k^T = (1,1,1,1,1)$ and the elements of vector y and matrix X are resolved by the constraints. In addition, we also require that

$$w_1 + w_2 + w_3 + w_4 + w_5 = 1 \quad (22)$$

Then the non-symmetric Nash bargaining solution can be obtained as the optimal solution of the following nonlinear optimization problem:

$$\text{Maximize} \quad (z_k^T p1 - D_1^{min})^{w1}(z_k^T p2 - D_2^{min})^{w2}(z_k^T p3 - D_3^{min})^{w3}(z_k^T p4 - D_4^{min})^{w4}(z_k^T p5 - D_5^{min})^{w5} \quad (23)$$
$$\text{Subject to} \quad p \geq 0$$
$$Xp \leq y$$

All the players are treated equally which is supposed by the symmetry axiom, but it is not possible if the players have dissimilar significance factors. The non-symmetric Nash bargaining solution is the only solution which satisfies all other axioms, so it is a natural extension of the conventional theory of Nash. In the general formulation of the non-symmetric Nash bargaining solution, it is generally required that the cost of every payoff function is at least the corresponding "status quo" value. The Nash bargaining approach is a classic method for utility division. Two players sequentially and infinitely propose a new offer until both players accept or disagree with the offer. An optimal division of additional benefits can be obtained through the Nash bargaining game. There are two assumptions about the game of water allocation with respect to the water demand management plan. First, the game is a game of complete information. This means that all the information for each player is treated as common knowledge; such as water demand and benefit functions. In other words, the game is played from the perspective of the water manager. Second, differences exist over the bargaining power of players, and the differences will affect the player's share. Therefore, the asymmetric Nash bargaining approach is utilized in analyzing this game.

RESULT & DISCUSSION:

In the result analysis, Rajkot city water demand data was used for the analysis of water distribution. The water demand for industrial user is 35 MLD (=D_1), Unaccounted user is 49.23 MLD (=D_2), Institutional use is 12.31 MLD (=D_3), Domestic user is 176 MLD (=D_4), and Public user is 5.23 MLD (=D_5). However a minimum water demand for industrial user is 32.148 MLD (=D_1^{min}), and minimum water demand for institutional user is 9.420 MLD (=D_3^{min}).

Table-I: Water Distribution from Different Sources in Rajkot (MLD)

	Ajii-I	Narmada	Bhadar	Nyari-II	Nyari-I	Total
Domestic	6.162	99.922	46.000	11.000	11.412	174.496
Institutional	1.656	6.010	0.000	0.000	1.769	9.435
Industrial	10.447	11.005	0.000	0.000	10.696	32.148
Unaccounted	7.815	8.683	0.000	0.000	7.129	23.627
Public	0.920	3.380	0.000	0.000	0.994	5.294
Total	27.0	129.0	46.0	11.0	32.0	245.0

The current water distribution in the Rajkot city is listed in Table-I. According to Table-1, the total available water in Nyari-I is 32 MLD, Nyari-II is 11 MLD, Ajii-I is 27 MLD, Bhadar is 46 MLD and Narmada canal is 129 MLD.

Table II. Propose Results for w1 = 1, w2=0, w3 = 0, w4=0, w5=0

	Industrial	Unaccounted	Institutional	Domestic	Public	Total
Ajii-I	0.000	0.000	0.000	7.000	0.000	7.000
Narmada	21.000	29.400	1.950	52.950	0.050	105.350
Nyari-I	11.550	16.170	1.880	6.840	0.005	36.445
Bhadar	2.100	2.940	2.920	34.500	0.010	42.470
Nyari-II	0.350	0.490	2.670	7.150	0.000	10.660
Total	35.000	49.000	9.420	108.440	0.065	201.990
Dkmin	32.148	23.627	9.420	90.000	0.050	
Dk	35.000	49.000	12.310	174.496	5.000	

Table III. Propose Results for w1 = 0, w2=1, w3 = 0, w4=0, w5=0

	Industrial	Unaccounted	Institutional	Domestic	Public	Total
Ajii-I	0.000	0.000	0.000	7.000	0.000	7.000
Narmada	20.300	28.420	1.950	51.950	0.050	102.670
Nyari-I	11.550	16.170	1.880	6.840	0.004	36.444
Bhadar	2.100	2.940	2.920	34.500	0.010	42.470
Nyari-II	1.050	1.470	2.670	7.150	0.001	12.341
Total	35.000	49.000	9.420	107.440	0.065	200.990
Dkmin	32.148	23.627	9.420	90.000	0.050	
Dk	35.000	49.000	12.310	174.496	5.000	

Table IV: Propose Results for w1=0, w2=0, w3=1, w4=0, w5=0

	Industrial	Unaccounted	Institutional	Domestic	Public	Total
Ajii-I	0.000	0.000	1.698	3.327	0.040	5.066
Narmada	17.500	26.460	2.730	52.950	0.50	99.690
Nyari-I	10.500	16.170	3.770	6.390	0.004	36.834
Bhadar	2.555	3.577	3.010	33.110	0.000	42.252
Nyari-II	3.850	2.793	1.880	6.930	0.000	15.453
Total	34.405	49.000	13.088	102.707	0.094	199.389
Dkmin	32.148	23.627	9.420	90.000	0.050	
Dk	35.000	49.000	12.310	174.496	5.000	

Table V: Propose Results for w1=0, w2=0, w3=0, w4=1, w5=0

	Industrial	Unaccounted	Institutional	Domestic	Public	Total
Ajii-I	0.000	0.000	1.415	3.081	0.000	4.496
Narmada	18.900	26.460	2.170	53.458	0.005	100.993
Nyari-I	11.550	16.170	2.359	6.505	0.001	36.585
Bhadar	2.555	3.577	3.019	32.660	0.000	41.811
Nyari-II	1.995	2.695	3.114	7.260	0.000	15.064
Total	35.000	48.902	12.077	102.964	0.006	198.955
Dkmin	32.148	23.627	9.420	90.000	0.050	
Dk	35.000	49.000	12.310	174.496	5.000	

Table VI: Propose Results for w1=0, w2=0, w3=0, w4=0, w5=1

	Industrial	Unaccounted	Institutional	Domestic	Public	Total
Ajii-I	0.000	0.000	0.000	7.000	0.000	7.000
Narmada	14.000	19.600	5.378	61.952	0.050	100.980
Nyari-I	10.500	9.800	1.887	6.619	0.001	28.807
Bhadar	7.000	0.588	1.321	41.860	0.004	50.773
Nyari-II	0.003	0.005	0.660	10.120	0.000	10.788
Total	31.503	29.993	9.246	127.551	0.055	198.000
Dkmin	32.148	23.627	9.420	90.000	0.050	
Dk	35.000	49.000	12.310	174.496	5.000	

The existing water demand-supply gap can be overcome by adopting several initiatives like encourage recycling and reuse of water, rainwater harvesting, restore and rejuvenate lakes and formulate a comprehensive strategy for sustainable use of water. In the Rajkot city water distribution system is quite old and already needs remodeling. The expected losses in the distribution system may be round about 35%-25%. Hence, actual effective supply is less. Remodeling of distribution system will reduce the losses. It will save quantity of water brought from the long distance. It will also increase the level of satisfaction to the consumers. The increased level of satisfaction, it is expected that consumers will be willing to pay for the services. Urban water supply can be controlled and regulated by installing water-meters in households and consumers may be asked to pay a 'price' for the water they have consumed, since the majority of consumers in urban communities are able and willing to pay.

CONCLUSION:

Freshwater demand for a city is increasing day by day and creating a wide gap between water demand and water supply. Municipality tries to fulfill the needs of the various users and provide fresh water to them for various purposes. In the present study, a five user water distribution model is formulated for Rajkot City. Rajkot Municipal Corporation is providing freshwater to five users i.e. industrial, unaccounted, institutional, domestic and public. All users are competing to each other to maximizing their supplied amount of freshwater from five water sources i.e. Ajii, Narmada, Nyari-I, Bhadar, and Nyari-II. Each user has a minimum amount of water that has to be supplied in order to operate or survive; however, their demands are much higher. Non-symmetric Nash bargaining solution is used to develop an environment for the conservation of water and optimized the weighted Nash product to obtain the actual solutions. From the study, it is concluded that there is no water distribution strategy which satisfies the need of domestic users with current water distribution system. Rajkot Municipal Corporation although claims to have equitable water supply to all areas, irrespective of variables such as local topography, distance of consumer from water distribution stations (WDS), pressure at consumer end and likewise. The existing water demand-supply gap can be overcome by adopting several initiatives like encourage recycling and reuse of water, rainwater harvesting, restore and rejuvenate lakes, design a complete solution to use tertiary treatment of water and formulate a comprehensive strategy for sustainable use of water. Water pricing policy would be one of the solutions to provide incentive to the users and promote efficient and equitable use of water for different users.

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