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# Ways to Define the Most Sustainable Actions for Water Shortage Prevention in Mega Cities, Especially in Developing Countries

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***Abstract*—**Climate change, industrial bloom, population growth and mismanagement are the most important factors that lead to water shortages around the world. Water shortages often lead to forced immigration, war, and thirst and hunger, especially in developing countries. One of the simplest solutions to solve the water shortage issues around the world is transferring water from one watershed to another; however it may not be a suitable solution. Water managers around the world use supply and demand management methods to decrease the incidence of water shortage in a sustainable manner. But as a matter of economic constraints, they must define a method to select the best possible action to reduce and limit water shortages. The following paper recognizes different kinds of criteria to select the best possible policy for reducing water shortage in mega cities by examining a comprehensive literature review.

***Keywords*—**Criteria, management, shortage, sustainable, water.

## I. Introduction

WITHOUT improvement in water management, the urban water demand will increase and water resources will diminish [1]. A joint report of WHO and UNICEF emphasizes that in 2008, more than 2.6 million people do not have access to clean water and approximately 900 million people do not have access to appropriate drinkable water resources [2]. As a matter of climate change and population growth, water resources in many countries around the world are under a stress and managers should do their best to decrease water losses [3].

As a result of economic growth, water consumption around the world is expected to increase from 4500 billion cubic meters to 6900 billion cubic meters until 2030. This amount of water represents 40% more than present sustainable water resources currently available. At the present time, more than 50% of all water shortages occur in developing countries. Unsustainable water demand can increase the usage of underground water sources, increased costs and reduced levels of social and economic activities [4].

In arid and semi-arid regions of the world, especially in mega cities, limitation of water resources can increase water demand, and the lack of a planned program for consumption can create problems for the provision of water [5].

Water transfer from distant basins can increase immigration, which creates a population concentration, which can increase per capital consumption and also incidents of water shortage. The evaluation of the methods of water distribution is an important factor for the sustainable provision of water [6].

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## II. Method

In the following paper, a comprehensive review of all possible actions to reduce water shortage, especially in developing countries like Iran, was conducted. Those actions have a wide spectrum from provision activities to demand management, and from tariff management to controlling the birth rate and migration to cities. The best possible method to evaluate those activities is to divide them into smaller groups and then evaluate the effectiveness of each group. In the following paper, these activities are divided into two groups of supply and consumption management.

### *A. Supply Management*

Supply management can be divided into two subgroups, procurement management and distribution management.

#### 1. Procurement Management

Based on previous studies, the most important activities related to Procurement management are listed below:

- Investment in coastal areas, mangroves, lagoons, lakes and rivers that can bring 440%, 540%, 2640% and 1550% profit to water companies, respectively.
- Investment in waste water treatment that can decrease water usage by around 42% [7].

Storing rain water, desalination and utilization of water conservation methods can be very useful actions as an alternative to building new dams which require a huge amount of investment [8].

#### 2. Distribution Management

Distribution management can be divided into three sub-groups that are Distribution pipes, Tariff management and Non-Revenue Water (NRW) Management.

##### i. Management of Distribution Pipes

One of the best methods to decrease water disasters in mega cities is maintenance and replacement of the pipe distribution network [9]. When the number of pipe bursts reach to around 15-30 leaks per 100 miles, the pipe should be replaced [10]. Moreover, 0.5% per year can be introduced as an appropriate rate for replacing water distribution pipes [11].

The maintenance technologies of water pipes can be divided into three subgroups entitled structural, nonstructural and semi structural methods.

Cement mortar, epoxy cover and painting could increase the effective age of a pipe for 20-25 years [12], while the use of cathode protection could increase the life of a pipe for 40 years, and the installation of sacrificial anodes, which can lead to a 50% decrease in pipe deterioration [13], are among the most important nonstructural activities.

ii. Tariff Management

Water tariff management is an effective solution to decrease water demand. There are two tariff systems entitled Increasing Block Tariff (IBT) and Two-Part tariff system [7]. It is obvious that the amount of decrease in water demand as a result of tariff management is related to price elasticity.

iii.Management of Non-Revenue Water

The reduction of non-revenue water, costs approximately one third of building new water production units [14]. Managing non-revenue water is one of the main components of demand management. The amount of non-revenue water globally is 25% to 50% of the total amount of water which can be derived from water resources. Non-revenue water can be divided into two main parts, entitled physical and commercial/ superficial losses [9].

Globally, the daily amount of physical (actual losses or leakage [9]) losses is estimated at 415 million cubic meters, which includes losses due to leakage in transmission, distribution and tributary pipes [15]. The superficial losses are divided into four categories entitled meter destruction, calculation error, water theft and non-registered meters, which is approximately 25% of the total of non-revenue water [16].

*B. Consumption Management*

Consumption management activities not only decrease the stress on water resources but are less costly than new water procurement projects, such as transferring water from one water basin to another, installation of new dams, etc. These activities also decrease the costs of wastewater management [6], [17].

Increasing consumption efficiency, immigration controls, public awareness, pressure management, meter management, inspection, leakage management, allotment (which can increase accidents for 24 and 20% in time and after allotment respectively), water reuse, using water efficient instruments and management of non-revenue water are the most important activities of consumption management.

The results of a comprehensive survey of previous studies, which assessed the average and standard deviation of water conservation, have been presented in Table I. In most cases, the standard deviation is more than three, which means there is no correlation between the data.

The data that are not in range have been deleted.

As can be seen in Table I, water reuse, water allotment, installation of water meter, awareness and decreasing the consumption out of the home, respectively, have the most effect on decreasing of water consumption. Moreover, using air water mixture faucets, high efficiency toilet (which consumes 32% of total urban consumption [19], [55], [61], [21] high efficiency showers(which consumes 19.37% of total urban consumption [19], [56]-[61], [70], as well as high efficiency dishwashers and washing machines(which consumes 15% of total water consumption [19], [56], [60] are the least effective devices to decrease urban water consumption.

In different studies, the effectiveness of applying more than one activity to reduce water usage has been evaluated. In Table II, the results of such an evaluation have been proposed.

## III. Methods of Selection the Best Possible Actions, Especially in Developing Countries

As previously mentioned, water companies can undertake a variety of activities to reduce water shortages in mega cities from exposition management to consumption management, and reducing non-revenue water, but because of limited budgets and also multiple objectives, like satisfaction of customers, minimizing social hazards, human health, environmental protection, increasing the quality of water distribution and etc., water companies must find appropriate ways to reach all of the objectives in an optimized manner. As a result, in many cases, the optimization of one goal does not necessarily lead to the optimization of another, and therefore, the inter-dependency of all processes, need to be optimized as much as possible. There are several optimization method, however, the dynamic modeling of provision and distribution water to identify engineering and non-engineering activities is the most valid and effective method.

In many previous studies, the capabilities of water systems in Jordan, Nevada and Tehran have been evaluated using Stella and Vensim software [99]-[101]. In these studies, internal effects of different activities in the provision and distribution of water and their feedback have been evaluated at various time intervals in a dynamic manner. The advantages of using these modeling software systems is that the user can graphically find out the internal dependency of parameters and also can track the changes of different variables in different time zones.

In other studies, multi criteria analysis was used as an effective tool to integrate urban water management [91]. Multi criteria analysis is a tool to solve problems that have multi dimensions [92]. The most useful methods in multi criteria decision making are ELECTRE, PROMETHEE, REGIME, NAIDE, Goal Programming, Compromise Programming, Analytic Hierarchy Process (AHP) and fuzzy theory [93], [94].

The results of different studies [92], [95]-[97], [1] show that, compromise programming can be used in both engineering planning and also in decision-making analysis [99]. In this method, the selected solution is the closest one to the ideal condition and the furthest one from the worst situation.

Selection of an appropriate criteria and the weight of each criterion compared to other criteria, is one of the main steps in the multi criteria decision-making process. The cost of water provision, the cost of conservation activities, the amount of water provisioned, social hazards, water leakage, social satisfaction, water companies income, the amount of water conserved, reliability of water sources, and access to water resources are the most important criteria that have been considered in different water related studies [1], [91], [92].

TABLE I
THE EFFECTIVENESS OF DIFFERENT ACTIVITIES TO REDUCE WATER CONSUMPTION IN MEGA CITIES

| Activity | Decrease in Consumption (%) | Standard Deviation | Modified Decrease in Consumption (%) | Modified Standard Deviation |
|---|---|---|---|---|
| **Awareness** | 15.73 [18]-[22], [7] | 8.59 | 16 | 1.73 |
| **Pressure management** | 17.4 [26], [25] ,[24], [23] | 19.3 | 4.17 | 2.3 |
| **Meter management** | 26.33 [25], [27]-[36] | 15.06 | 20.62 | 1.76 |
| **Inspection and leakage management** | 7.9 [37]-[42], [25], [19] | 65.69 | 2.8 | 0 |
| **Allotment and consumption limitation** | 26.17 [43]-[50], [19], [18] | 16.85 | 21.28 | 2.9 |
| **Water reuse** | 58.4 [51]-[54], [19], [25] | 38.87 | 24 | 2.84 |
| **High efficiency toilets** | 8.86 [66]-[69] [44], [19], [63], [62], [32], [25], [38], [37] | 25.88 | 2.9 | 2.34 |
| **High efficiency showers** | 6.2 [25], [73], [44], [72], [67], [69], [19], [55], [71] | 26.54 | 2.3 | 2.54 |
| **High efficiency washing machine** | 5.17 [19], [74]-[78], [63]-[65], [36], [25] | 18.17 | 5.7 | 2.25 |
| **High efficiency dishwasher** | 0.6(for four family member) [78] | 4.73 | 4.1 | 0.7 |
| **Hot water circulation (four points of use)** | 6.8 [77], [79], [25] | | | |
| **Insulation of hot water pipe** [70] | 3 | | | |
| **High efficiency faucet** [82], [70], [39], [38], [33] [25], [19] – Toilet, shower and dishwasher sink | 0.8 | | | |
| Air and water mixture faucet | 0.7 | | | |
| Thermostatic mixture faucet | 2.9 | | | |
| Infrared faucet | 4.7 | | | |
| **Decreasing urban water consumption outside home(which is 64% of total urban water consumption [56]-[60], [80], [21]** | 20.99 [81]-[85], [53], [52], [19], [25] | 21.55 | 15.36 | 1.73 |

TABLE II
THE EFFECTIVENESS OF APPLYING MORE THAN TWO ACTIVITIES TO REDUCE WATER CONSUMPTION IN MEGA CITIES

| Activity | Percentage of decreased consumption | Source |
|---|---|---|
| Limitation of water consumption + high efficiency toilets + water pricing (Australia) | 35 | [98], [56] |
| Pricing policy + using high efficiency devices + educational campaign (Indonesia) | 30 | [18] |
| Establishment of consumption management committee + advertisement + water consumption limitation + public education + high efficiency devices + water pricing (Melbourne, Australia) | 30 | [18] |
| Swapping regular toilets with high efficient ones + high efficiency baths + dishwashers and washing machines | 38.3 | [19] |
| Swapping regular toilets with high efficient ones + high efficiency dishwashers + decreasing the leakage index | 40 | [19] |
| Decreasing the volume of toilet flushes + using water and air mixture faucets + high efficiency baths (United States, Australia and Britain) | 9-12 | [42], [86] |
| Using high efficient water consumption devices instead of less efficient ones | 50-35 | [42], [86] |
| Using high efficient toilets, washing machines, baths and faucets (Tampa Florida) | 49.7 | [87], [42] |
| Water consumption limitation + educational programs for reducing water consumption (Queensland, Australia) | 50 | [42], [88] |
| Installation of high efficient devices and modification of piping system (Western United States and Australia) | 50 | [21], [86] |
| Adjustment of water flow from faucets + using high efficiency toilets (Spain) | 30 | [21], [89] |
| Installation of high efficiency water usage devices | 4.34 | [24] |
| Installation of high efficiency water devices (Tehran) | 20 | [90] |

Typically, developing countries have lower income levels and more people who are susceptible to the hazards of water shortage. The two main criteria in developing countries have to be cost- of provision and conservation activities- and social hazards. Moreover, the weight of the cost and social hazard criterion should be as high as possible in developing countries. To address the selected criteria, it seems that tariff management, management of NRW and consumption management are the most important activities which can be carried out by developing countries to reduce water shortages.

## IV. CONCLUSION

Based on a comprehensive literature review, this paper presents the different activities related to the provision and demand management of water in mega cities such as awareness, pressure management, inspection and leakage management, allotment and consumption limitation, water reuse, using high efficient toilets, baths, faucets, washing machines, dishwashers, internal hot water circulation, insulation of hot water pipes and decreasing outside home water usage. Then, by considering the outcome of different conservative activities around the world, the effect of such activities is proposed as a percentage of total water usage. It has been found that water reuse and water allotment with 24% and 21.28%, respectively, are the most effective activities; while air and water mixture faucets, at 0.7%, are the least effective action for reducing water consumption.

In the next stage, dynamic analyses and multi criteria decision making have been proposed as the best methods for the selection of effective ways of managing water shortage in mega cities, especially in developing countries.

In the final section of the paper, multiple criteria for selecting the best possible activities to reduce water shortages, especially in developing countries has been introduced. It has been mentioned that activities such as tariff management, consumption management and management of Non-Revenue Water are the most important activities that developing countries can implement to reduce water shortages.

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