Domestic Water Demand Forecasting and Management Under Changing Socio-Economic Scenario

Asif M. Bhatti [1] and Seigo Nasu [2]
[1] Assistant Professor, Kochi University of Technology, Kochi, Japan.
[2] Professor, Director, MoT Department, Kochi University of Technology, Kochi, Japan.

***ABSTRACT*:** Water is one of the basic human need and imperative for sustaining quality of life on the earth. However, its unbalanced and unmanaged use makes it scarce. In Pakistan, about 96% of its available water is being used for agriculture and the remaining 4% for domestic, industrial and other purposes. Per capita water availability has decreased from 5260 m^3 in 1951 to 1050 m^3 by the year 2010, placing Pakistan in the category of a high water stress country. Presently, about 70 percent of the total population in the country has access to safe drinking water. The domestic water use in selected cities of Pakistan was comprehensively examined. The per capita water consumption varies significantly from 30 liter per capita per day (l/c/day) to 350 liter per capita per day. The poor are particularly vulnerable when water is either unclean or in short supply. In urban areas, rainwater and ground water is used for municipal supplies to meet domestic requirements. The water demand fluctuates with the seasons of the year, the days of the week, and the hours of the day. A good understanding of domestic water usage patterns and trends is essential to bridge the gap between present and future domestic water supply and demand. The present paper surveys the domestic water use in different parts of Lahore, Faisalabad and Rawalpindi, where water supply and demand is estimated and forecasted under changing socio-economic scenarios. The policy-relevant variables, mainly econometric problems and water prices are systematically considered and their effect on water demand was appraised. The study concludes that better management coupled with effective policy, awareness, efficient structures, institutional strengthening and professional skills is vital to enhance the sustainability of the system.

KEYWORDS: *Water scarcity, domestic water demand, Forecast Model, Policy*

1. INTRODUCTION

Water is essential in sustaining quality of life on earth. The sustainability of socially sensitive good such as water depends on effective and efficient use of available water resources. The extensive use of water has increased globally and the efficacy of supply side measure is questionable. Owing to drastic increase in population, technological advancement and economic growth; the demand for water supplies is continuously increasing. Numerous researchers has emphasized on water demand management rather than only the supply side management.

Water demand management is defined as a "policy that stresses making better use of existing supplies, rather than developing new ones" [1]. The water demand management in relation to water supply enables to estimate that how much the increase in demand for water could be met by effective and efficient use of existing water supplies. By definition, the term "domestic water demand", is usually taken to mean the amount of water required for various domestic uses. Whereas the phrase "water demand management" refers to the various methods by which water demand and may be limited [2]. Deverill, 2001 defined water demand management as a practical strategy that improves the equitable, efficient and sustainable use of water [3]. Water demand management is a set of techniques - whether technical, economic, administrative, financial or social - that add resilience to water systems to permit them to cope with shortage [4]. An operational definition of water demand management with five components proposed by the same author [4] is as follow; (i) reducing the quantity or quality of water required to accomplish a specific task; (ii) adjusting the nature of the task so it can be accomplished with less water or lower quality water; (iii) reducing losses in movement from source through use to disposal; (iv) shifting time of use to off-peak periods; and (v) increasing the ability of the system to operate during droughts. Water resources management is a political and socio-economic issue as well as a scientific, technological and engineering concern [5]. However, difficulties mainly arise from the integration of social perspectives with the technical elements. In the framework of water

demand management, the comprehensive analysis of water demand by keeping in view the population growth, socio-economic values and water pricing etc. is an essential component in designing water demand curve. It is vital to understand that how demand is formulated, which factors determine it, how the water demand responds to social and econometric variables, and how future demand will be shaped. The present paper surveys the consumption patterns for domestic water use in relation to income, price and other water demand shifting variables in selected mega cities of Pakistan and suggests framework for better use of existing water supplies.

2. OBJECTIVE

The prime objective of the present research work is to collect the water usages data of household and to identify pattern and trends in relation to socio-economic and econometric variables. The paper comprehensively describes the present situation, issues and water quality of domestic water supply in Pakistan and selected megacities. The domestic water demand forecast model is developed for Pakistan and selected cities to formulate the future water policy. Finally, suggestions were made for sustainable water demand management to cope with water scarcity.

3. BACKGROUND

Pakistan is the sixth largest country in the world by population with 2.48% of the world total population [6]. The total population increases from 34 million in 1951 to 170 Million by the year 2010. The proportion of urban population increased from 17% in 1951 to 36% by 2010 with urban population of 58 million and population density of more than 209 persons per square kilometer. Rapid urbanization and high population growth rate directly impact the water demand for domestic, industrial and agricultural sectors. In Pakistan, about 96 percent of its available water is being used for agriculture, 2 percent for industrial and the remaining 2 percent is used by the domestic sector. Approximately 35 percent of domestic water supply is unaccounted for water. Pakistan is on the verge of becoming a water deficit country and was ranked a water deficit country according to the "supply side" criteria developed by John Waterbury and Malin Falkenmark. The criteria ranked countries according to "Annual renewable fresh water resources" and defined 17, 00 as the level of water supply above which shortage will be local or intermittent. As the renewable water supply falls below 1,000 m^3/capita/year, water scarcity begins to occur [7] [8]. The supply side criterion is based on a country's annual water resources without reference to present and future demand or needs for water. The delineation of present water demand and supply issues, policies and future water demand forecast will help to manage the water efficiently and effectively.

3.1 Domestic water supply and demand related Issues

Access to safe and adequate potable water supply is a basic human right. In Pakistan, groundwater is the main source for drinking water. However, the cities of Karachi and Hyderabad depend on surface water as a drinking source. The part of the supply to Islamabad and Rawalpindi is also met with surface water. Domestic water supply and demand is not uniform in different cities of Pakistan and varies significantly based on location, climatic change, house characteristics, and socio-economic variables. Indeed, residential water demand is often found to be a positive function of the number of individuals in the family, the size of the house, the number of water-using appliances, and household income [9][10]. Drinking water demand is increasing rapidly while the options for new development of water resources are limited. In Pakistan, the municipal infrastructure is in poor shape. Underfunding by the government and low revenue collection over the decades has weakened the capacity of municipal governments to fund, build, and maintain infrastructure [11]. Pakistan's water quality ranks as 80th out of 122 nations [12]. In Punjab province, the bacterial contamination was found in 49 % of collected water samples. The major contribution to supply within the home comes from private hand and/or motor pumps, which provide improved drinking water supply for 71 % of the households of Punjab [13]. In rural areas the provision of pipe water supply is low and most of the rural population depends on handpump. However, in most of the cases, the quality of groundwater is not good. The majority of the population in the country is relying on unsafe and polluted drinking water. The poor are particularly vulnerable and spend large part of their income on buying water for survival. Pakistan Council of Research in Water Resources has carried out extensive water quality monitoring program and reported that the bacterial contamination in 2005-2006 is ranged from 45 to 50 percent in Islamabad, Rawalpindi, Lahore and Faisalabad [14]. Major issues facing by the domestic water supply sector are; i) Inadequate, inequitable and inefficient

distribution on water resources, ii) No clear policy and guidelines for operation and maintenance of municipal infrastructure, iii) High capital investment with low or no rate of return, iv) Drastic depletion of groundwater table, v) High ratio of unaccounted for water and low revenue collection efficiency, vi) About 80% unmetered water supply connections in mega cites, vii) Lack of water awareness as an economic good viii) Lack of citizens interest and involvement in water related projects, ix) Confusion of social, technical, environmental and political aims, and x) Lack of an integrated approach and legal framework.

3.2 Study Area: Domestic water supply in selected mega cities

The study area of two metropolitan cities Faisalabad and Rawalpindi and one mega city Lahore is selected. All the three cities are located in the Punjab province of Pakistan. Lahore in the capital of Punjab Province and the second largest city of Pakistan. The Rawalpindi city is the fourth largest city of Pakistan and mainly relies on groundwater. Faisalabad is the third largest city. It is certainly located in the flat alluvial plain of Punjab province. The groundwater is the major source of water for domestic purpose. The increased and unregulated private exploitation of groundwater for domestic consumption have led to a decline in the water table and deteriorating the groundwater quality.

4. METHODOLOGY

Domestic water demand management is to make water available for people without compromising the sustainability of the system. For sustainable operation and equitable distribution, it is imperative to forecast the water demand by taking into account the social and technical aspects of water. The population forecast model of the country and the three urban areas was developed as follow;

$$Pop_i = Pop_0(1+GR_1)\,(1+GR_2)\,\ldots\ldots(1+GR_i)$$

Where Pop_i is the population in the *ith* year, Pop_0 is the initial population GR_i is the growth rate of population in the *ith* year. The population growth rate of the country depends on crude birth rate (birth per 1000 persons), crude death rate, immigration to the country and migration from the country. However, to forecast the urban population, the expansion of the urban area is an important component. The population forecast model was developed for four scenarios: low birth rate, medium birth rate, high birth and constant birthrate with reference to the current population statistics. The detail of the population model is illustrated on website of Pakistan Institute of Population Studies.

Domestic water demand include the amount of water used by households for different activities in house as well as outside including drinking, cooking, bathing, washing, water use for kitchen, laundry, and gardening etc. The relevant information regarding water demand and supply, water tariff, water supply facilities, water table, water quality and quantity, operational cost, and revenue collection were collected from water and sanitation authorities in respective cities.

To support the research work, a preliminary questionnaire survey was also carried out. In each city, about 80~100 household were surveyed. The criteria taken in to account were living standard and household economic class. The houses were surveyed from lower income class to high income class depending on area of residence and monthly household income. The collected data is compared with the other reports and surveys already done by the concerned authorities and ministries and found in good agreement. However, the accuracy and reliability of the collected data is questionable and demand for extensive survey.

4.1 Scenario Analysis

The rationale of the scenario analysis is to elucidate the impact of different water demands and socio-economic variables on future water supply and demand.

Income group classification: For the purpose of water demand analysis, the income groups are broadly classified in to three income groups. The low income group with an average income of US$ 100/household/month, the medium income group with an average income of US$ 225 /household/month and high income group with an average income of US$ 600/ household /month and above [15] [16].

Water demand Scenario: On the basis of the collected data, the country's total water demand is further divided into four categories: water demand of mega cities, metropolitan cities, towns and rural areas. To develop urban water demand forecast model, the medium growth rate is considered for further analysis. The water demand in urban areas is further categorized as the water demand by high income group, water demand by medium income group and water demand by low income group. To

forecast the future water demand, three scenarios were considered as follow:

i): ***Constant water demand***: This scenario is based on the assumption that the domestic water demand will follow the same trend and will not change in the coming years.

ii): ***High Water Demand***: It is assumed that the positive change in socio-economic pattern and living standard will lead to change in domestic water demand and the domestic water demand will increase in the future.

iii): ***Low Water Demand***: The awareness of water as an economical good, well developed water pricing policy, rules and regulations, and the technological development will cause low water demand in the future.

The per capita domestic water demand of respective income group is estimated as follow;

$$WD_i = WD_0\,(1+ WDgr_1)\,(1+ WDgr_2)\ldots\,(1+ WDgr_i)$$

Where WD_i is the per capita domestic water demand in the *ith* year, WD_0 is the initial per capita domestic water demand and $WDgr_i$ the growth rate of per capita domestic water demand in the *ith* year [17]. The total domestic water demand TWD_i in the *ith* year is estimated as follow;

$$TWD_i = WD_i * Pop_i$$

5. RESULTS AND DISCUSSION

Based on the analyses, the population and the water demand for domestic sector for the next twenty years were forecasted. It was observed that under the constant birth rate scenario, the population of the country will rise to 216 million and 272 million by the year 2020 and 2030 respectively. Under the low birth rate and high birth rate scenarios the population will be about 232 and 260 million respectively by the year 2030. However, under the middle birth rate scenario the population of the country will touch the figure of 245 million by the year 2030. The previous population data trends showed that the realistic approach is to consider the medium birth rate scenario for further analysis. The graphical representation of the projected population is shown in figure 1. The drastic increase in urbanization with the growth rate of nearly 3% was noticed in the previous year. With the same growth rate, the urban population will be equal to the rural by the year 2030 (figure 2). The domestic water demand of Pakistan under scenarios of constant water demand as in base year 2010, low water demand and high water demand was forecasted as given in Table 1. Under the constant water demand scenario, the domestic water demand will be 1.3 times and 1.6 times more than the base year 2010 by the year 2020 and 2030 respectively. The water demand management is vital to cope with growing domestic water demand in Pakistan.

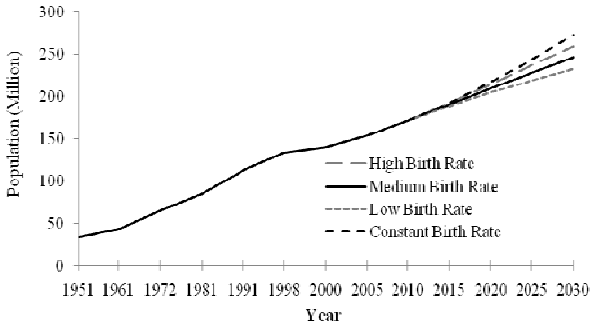

Figure 1: Population forecast under different birth rate scenarios

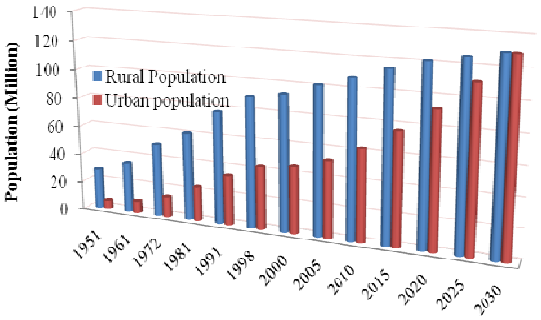

Figure 2: Urban and Rural population forecast under medium birth rate scenario

Table 1: Domestic water demand forecast of Pakistan

Year	Domestic water demand (BCM)		
	Low Water demand	Constant water demand	High water demand
2010	8.42	8.42	8.42
2015	8.95	9.57	10.94
2020	9.32	10.79	13.80
2025	9.48	12.04	16.97
2030	9.38	13.27	20.35

The present water situation in the Punjab province was comprehensively examined. It was observed that 86 % of urban population depends on water supply scheme/tap water and electric motor (0.5 -1 hp) as a major source of drinking water. The majority of rural population use hand pump and electric motors for

groundwater abstraction. The main source of drinking water is listed in table 2. In urban areas, 51% households have drinking water access within the premises or collect drinking water at the distance of 0-100 meter. Only 18% of the households have to collect water at the distance of 1 Km or more. In rural areas, 36% households have drinking water availability within the premises or at the distance of 0-100 meter. In rural areas fetching water for cooking and drinking, mostly by women, involves lot of time and distance. In some cases, the water collection source is more than 2 or 3 km.

Tab1e 2: Main source of drinking water in Punjab Province, Pakistan [13]

Source	Main source of drinking water (%)		
	Punjab	Urban	Rural
Tap Water	28	51	18
Hand pump	33	11	44
Motor pump	35	35	35
Dug well	1	1	2
Other	3	3	2

The water demand forecast model of the study area was developed. All the three cites showed similar kind of trends with regard to housing characteristics and water demand. An average household had six members with a balanced gender ratio of 50:50. In the city of Lahore around 98% of the household have water access within the premises. Groundwater is the major sources of drinking water. The quality of groundwater is generally not good and bacterial contamination was found in 59% of the collected water samples. Majority of population (70%) don't adopt any treatment method before drinking the water. Where as 30% citizens use water treatment methods such as boiling and water filtering. A small portion of the population use mineral/bottled water for drinking. The majority of population is at the mercy of Water and Sanitation Authorities and drink the supplied water without treatment. In Rawalpindi about 89% of the household have water access within the premises. Groundwater and surface water is the main sources of drinking water. The quality of groundwater is poor and only 25% of the collected water samples were found fit for drinking purpose. Around 75% population drinks water from the source without any treatment. Around 14 % households boil water before drinking and the remaining use other treatment methods for safe water. The portion of the population using mineral/bottled water is small; however, rapid increase has been seen in the past years. In industrial city of Faisalabad about 83% of the household have water access within the premises with groundwater as the main sources of drinking water. The quality of groundwater varies within the city and 42 % of the collected water samples were found fit for drinking purpose [16]. More than 90% of the population doesn't use any treatment method for drinking water. Around 20 % of population relies on mineral/bottled water as a drinking source. The economic feasibility of the mineral water is another issues and only high income group may use bottled water for drinking purpose. Moreover, the government has installed water treatment filters in different cities and in different parts of same cites to provide the safe water to the population. The collected data during the preliminary household survey showed that 28% of the water is used for bath and shower. The percentage of daily household water use in different activities is graphically reported in figure 3. A high range of variation was observed in each activity. The average use for drinking water is 2 liter/capita/day. The per capita water use for bath/shower range from 15 ~ 150 liters/capita/day and for toilet the range is 5 ~ 60 liters/capita/day. The water use range for cooking purpose is 5- 45 liter/capita/day. The water demand of high income group is generally twice than the low income group.

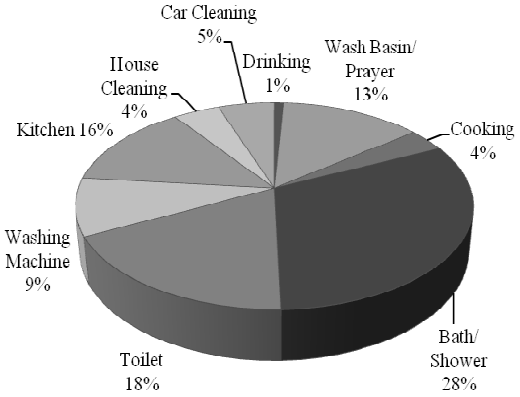

Figure 3: Daily household water use in different activities (%)

The water supply indicator of the Lahore, Rawalpindi, Faisalabad, Dehli/India, Shanghai/China and highly developed city Osaka/Japan were tabulated as shown in table 3. The water supply per day is only 8 hours in Rawalpindi as compared to 18 hours in Lahore and 24 hours in Osaka Japan. One of the major issues is high value of unaccounted for water in Lahore, Rawalpindi and Faisalabad. Nearly one third of the water is unaccounted for water and revenue collection efficiency is low (70%).

Table 3: Water Supply Indicators in the research study area [18] [16]

Indicators	Lahore	Rawalpindi	Faisalabad	Dehli/ India	Shanghai/ China	Osaka/ Japan
Per day hours of water Supply (hour/day)	18	8	8	6	24	24
Water production (m^3/capita/day)	0.34	0.28	0.28	0.3	0.47	0.53
Water Supply Coverage (% of total population)	87	85	75	69	100	100
Unaccounted for water (%)	34	40	40	53	17	7
Revenue Collection efficiency (%)	75	70	50	70	93.5	95
Consumption/capita (Liter/c/day)	270	210	200	110	251	263
No. of Staff per 1000 connection	12	11	10	19.9	5.7	1.7

The staff per thousand connections is 1.7 persons in Osaka as compared to 10 to 12 persons in study area. Most the water connections are unmetered with flat rates based on the covered area. The metered connections are less than 25 percent of total water connections causing unequal distribution of the available water resources. The number of person per domestic connection is 6 to 6.23 as compared to developed country with only 2.3 persons per domestic connection.

The population forecast model and water demand forecast model was developed for the three cities under consideration. The year 2010 is taken as base year and the population and water demand for the years 2015, 2020, 2025 and 2030 were forecasted. The current population 6.4 million of Lahore city will become 8.6 and 11.5 million by the year 2020 and 2030 respectively. Under the constant water demand scenario, the domestic water demand of urbanized city Lahore will be 1.3 times and 1.6 times more than the base year 2010 by the year 2020 and 2030. The present water demand of 1.6 MCM (million cubic meter)/day will be nearly 3 MCM/day by the year 2030 as depicted in figure 4. The present population of Rawalpindi city is 1.9 million and this figure will rise to 2.5 and 3.3 million by the years 2020 and 2030 respectively as shown in figure 5.

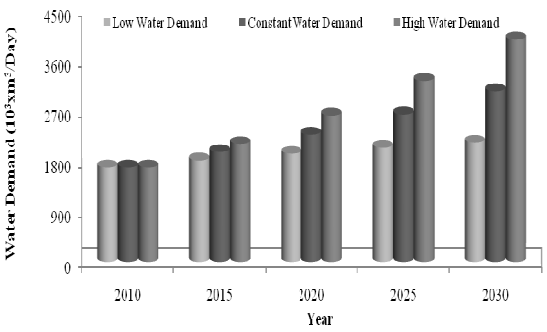

Figure 4: Water demand forecast under different scenarios: Lahore City

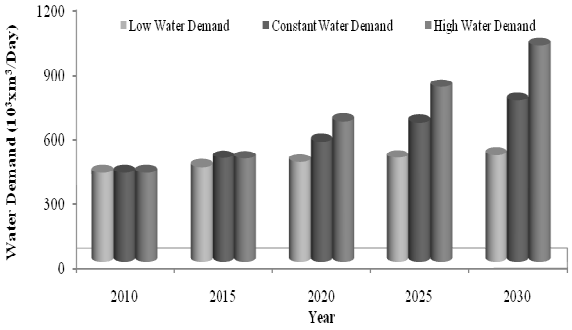

Figure 5: Water demand forecast under different scenarios: Rawalpindi City

Under the constant water demand scenario, the current domestic water demand of 4.2 MCM/day will be around 7.5 MCM/day by the year 2030. In case of Faisalabad city, the population of the city will increase to 3.9 million by the year 2010 and 5.2 million by the year 2030. With the constant water demand scenario, the city needs 8.3 MCM/day and 11.2 MCM/day by the year 2020 and 2030 respectively as represented in figure 6. For sustainable water supply and demand management, the cities have to adopt proper policy and techniques to cope with water scarcity and to ensure the water availability for the survival of entire population.

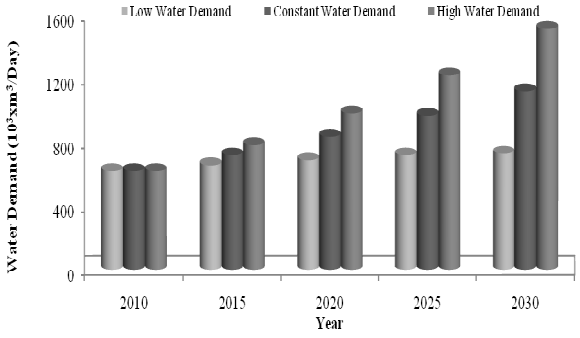

Figure 6: Water demand forecast under different scenarios: Faisalabad City

The gap between water supply and demand is ranged between 20-35 lpcd in three cities. The model results showed that the gap between the water availability and demand is widening. Without appropriate planning and demand management the booming water scarcity will impede the domestic water sector. The per capita expenditure on drinking water from piped water or groundwater without treatment is ranged from US$ o.1 to USS$ 0.35. Only small portion of the households treated their drinking water at home depending on their awareness regarding water quality and health. In case of bottled water the per capita expenditure ranged from US$ 8 to USS$ 10. The correlation of the water demand with water price varies significantly depending on social and econometric factors.

The change in water price will effect the poor and its impact on water demand will not be noteworthy. The water demand seems to be inelastic with respect to change in price. Middle income class is willing to pay more for reliable water quality and quantity. The high income class use water as much they want regardless of the water price that is less than 1 percent of monthly income. The behavior change will be key for sustainable water demand management. The policy-relevant variables, mainly income and water prices should systematically considered and their effects on water demand has to be appraised in the formulation of short term and long term water policy. The correlation of water demand, income and water price is demonstrated in figure 7.

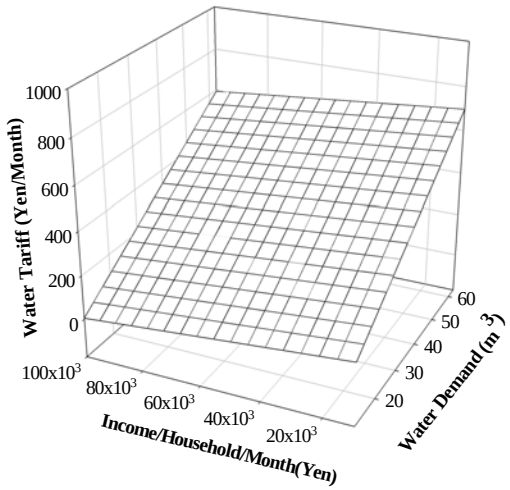

Figure 7: The income, water demand and water tariff relationship

Water demand (m^3)
*= 0.08 *Water Tariff + 0.0001 Income/month + 0.35*

The increase in water demand induced by increase in income need to be managed wisely. The other economic instruments have little potential to influence water use. The success of water supply and demand management depend on effective and efficient utilization of the scarce water resources at both the individual and collective level.

6. CONCLUSION

The domestic water demand is function of econometric variables, assess to knowledge, housing characteristics, accessibility to the water source, economic class, water quality, climate and hydrology, water pricing and water policy. In order to cope with domestic water needs of rapidly growing population, an efficient, economic and environmentally acceptable integrated approach is needed to arrive at sustainable solutions. There is dire need to evolve workable methods and approaches to synchronize the demand and supply gap. It is dire need to create knowledge to be shared among different disciplines. To improve water supply in urban areas, the installation of water meters need to be encouraged. Building a new social framework including community participation at all level of water management is necessary. The community participation in water pricing policies, incentives for efficient use, affordability by low-income users and other vulnerable groups, water awareness especially among the women and children are prime factors for success of any domestic water project. The Government of Pakistan should acknowledge a water crisis and start to collect sufficient and reliable data. The extraction of groundwater should be regulated and more efficiently monitored. The shift in policy from surface water for agriculture to surface water for domestic purpose and provision of water to provision of safe, adequate, equitable, sustainable and affordable water services is crucial for healthy and prosperous Pakistan.

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