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Research Article

Spatial Quantification of Domestic Water Consumption in Rehankot, Dir Town, Khyber Pakhtunkhwa Province-Pakistan

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Abstract: This paper is an effort to quantify and map the water supply system and the spatial distribution of domestic water consumption pattern in the Rehankot- a densely populated area in Dir Town. Perennial River, Springs and Kareez are the main sources of water supply in the area. Public water supply schemes have been developed to collect, and distribute potable water to the community. To assess the water consumption patterns a questionnaire based household survey was conducted using random sampling techniques. Global position system (GPS) was also used to spatially locate the sampling units. Kernal Density Estimation (KDE) was applied to visualize population densities and ordinary Kriging has been used to visualize the spatial trend of domestic water consumption per day. Average daily water consumption has been quantified for different income groups and of different family sizes. High income groups and large families consumption was high. The total water consumption of large, medium and small families was found 912, 526 and 282 liters (*l*) per day (d) respectively. Whereas, per capita consumption was found very high within medium size families is 70 liters consumption (*l*c/d) and almost same in small and large size families as 57 and 55 *l*c/d respectively. Similarly based on income distribution pattern the total water consumption was found directly proportional to their income levels. The overall average per capita consumption was found as 61 *l*/c/d which are still 9 litres less than the standard consumption value. This study highlights the problems regarding the existing water supply system in the area and the variability of consumption patterns regarding family size and income distribution.

Keywords: Domestic water, Consumption, Spatial Quantification, Mapping, GPS, GIS.

1. INTRODUCTION

This study is undertaken to quantify domestic water consumption and map high to low consumption areas using geo-statistical technique. The amount of water supplied for domestic purposes is not sufficient and residents are facing problems throughout the year particularly in summer season. Therefore, this attempt has been made to highlight the spatial distribution of domestic water consumption. Domestic water supply and safe drinking water is one of the fundamental human rights [1-4]. However, years of national and international efforts have not overcome the problem of clean drinking water supply yet. Worldwide, 783 million people do not have access to clean drinking water [5]. Accordingly, more than 3 million people have lost their lives and 2.4 billion suffered numerous form of water borne diseases associated to poor water quality [6]. The United Nations has projected that almost half of the world population will face water stress by the year 2050 [7]. Water stress is the condition when annual water availability per capita ranges from 1000m^3 to 1700m^3 while water scarcity is the condition in which water availability remains less than 1000m^3 [8]. The factors generating water stresses include unprecedented increase in demand for agriculture, domestic water, industrial usage, energy generation, changes in consumption patterns of consumption, and unaccounted water [9]. The

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standard daily water requirement for a person is 50 litres irrespective of individual economic status [10]. The per capita water availability and consumption vary from place to place and even within different income brackets. The water supply system includes: - water pumping, and its supply through main, secondary and tertiary pipelines, and finally to the end users [11]. The main determinants of water supply system are sufficient amounts of water and efficient network that make water available for 24 hours for the end users [12].

Domestic water consumption is a function of socioeconomic and climatic conditions, and public water policies and strategies [13-14]. It is the amount of water supplied for indoor and outdoor household purposes, whereas demand indicates the amount of water estimated to be required [15-16]. The minimum estimated water requirement per person per day is 7.5l in home for drinking and preparing food, and the requirement for personal hygiene is at least 50*l*/capita/day including personal hygiene, food hygiene, domestic cleaning, and laundry needs [17]. In developed countries domestic water use ranges from 100 to 180*l*/capita [18-19]. The main objective of this research is the spatial quantification of domestic water consumption in Dir Town.

2. MATERIALS AND METHODS

2.1 Study Area

The district of Upper Dir is situated in the North-west of Pakistan and about 180km from the capital city of Islamabad. The Upper Dir extends from 35º 04' to 35º 46' N-latitude and 71º 32' to 72º 22' E-longitude with a total geographical area of 3,699 sq.km [20]. The total population of the district was enumerated as 575 thousand as in 1998 with an increase of 58.7 percent since 1981. The average annual growth rate was 2.8 percent during this period and population density of 156 persons/sq.km. The estimated population till 2017 was estimated as 0.88 million [21]. The elevation of study area varies from 5577 meters above mean sea level in the north to 844meters in the south. River Panjkora fed by rain and melt water, is the main source of water consumption. The annual rainfall in the area varies from 823 to 2149m [22, 23]. The studied community is Rehankot- situated in Dir Urban- the old settlement with high population density in the entire district. The estimated population of the target area is 19810 persons with 2830 households. The average family size is about 7 persons [24]. For domestic consumption, public water supply schemes have engineered by Tehsil Municipal Authority (TMA), district Upper Dir on perennial Dir River in Panakot, 12km upstream of the study area (Fig. 1). The storage and purification tanks are in Panakot in the proximity of river.

2.2 Data Collection and Analysis

This micro-level study on water consumption pattern has been conducted in Rehankot community of Dir Town in KP Province. Primary data was collected from field using questionnaire based households (HH) survey and Global Position System (GPS) survey, and secondary data from concerned government departments.

A detailed structured questionnaire was designed to conduct surveys in the target community using random sampling techniques. A total of 96 households were interviewed. They were asked questions regarding members of the family, monthly income in PKR, and daily water consumption in litres (l) suggested by Edwards and Martin [25]. GPS survey was also conducted to acquire the location of sampling units in the form of latitude and longitude. Similarly, GPS survey was also conducted to map water supply pipelines by acquiring two ground control points (GCP) for straight section, three points for curves and one point for bend at right angle. Data was prepared and standardized using MS- excel and then imported into ArcGIS 9.3.

Data regarding population, households, water supply and pipe diameter (in inches) was collected from the Tehsil Municipal Authority (TMA), District Upper Dir. The municipal boundary of Rehankot was collected from TMA office. Satellite image of the target area was downloaded from open source Google earth at premium resolution. ArcGIS 9.3 was used for digitization of image as a base layer to develop land use map.

The monthly HH income was classified into three categories, namely; low income having <35,000 PKR (150PKR = 1US$, 2019); medium

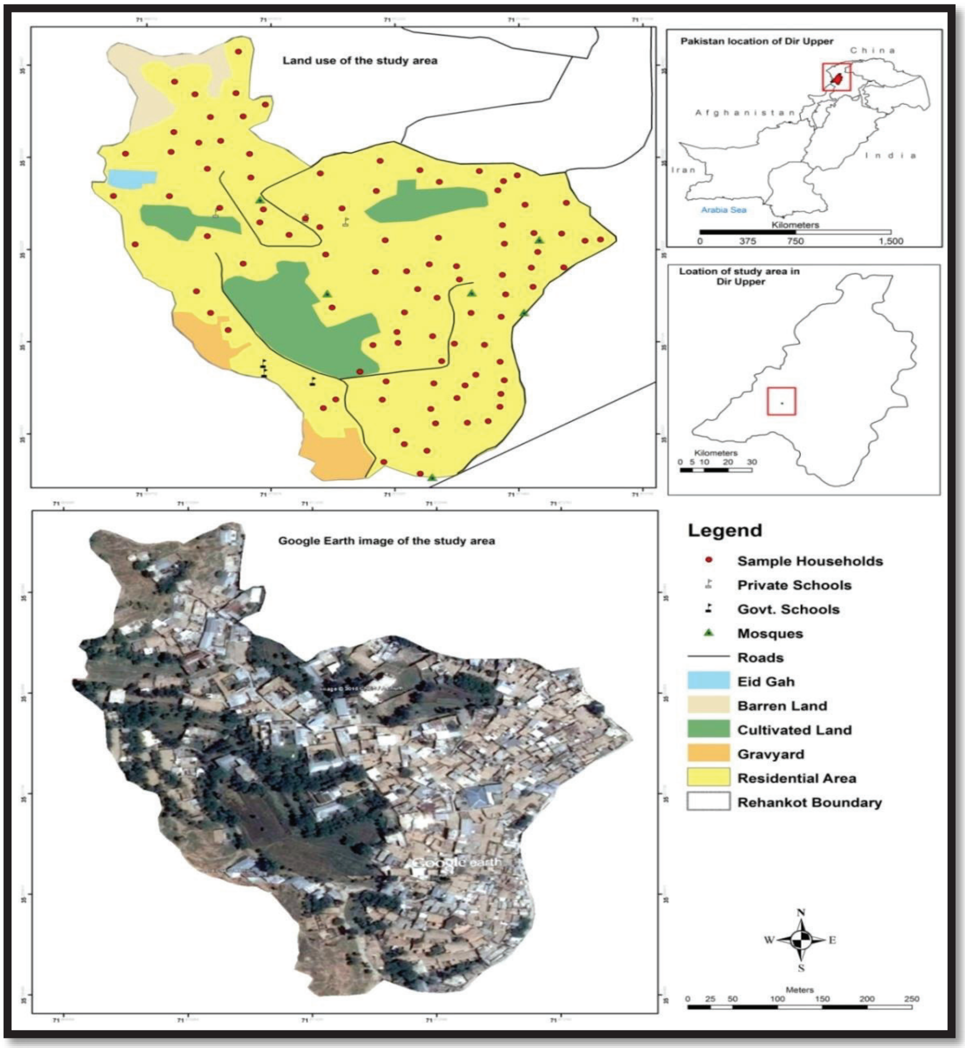

Fig. 1. The Study area of Rehankot, Upper Dir, KP Province, Pakistan (Source of Land use: Google Earth image)

income from 35,000 to 70000 PKR; and, high income having >70,000 PKR. These income classes were used to determine variation in domestic water consumption among various segments of the community. Similarly, family size was also classified into three categories, namely; small family having <5 persons; medium family from 5 to 10 persons and large family with >10 persons. The daily water consumption was also classified into three categories, namely; low consumption has <500 *l*/day; medium consumption from 500 to 800 *l*/day; and, high consumption having >800 *l*/day.

Likewise, the frequency distribution was performed to make monthly income and family size classes of the surveyed households. The average domestic water consumption per day for each income and family size class was calculated using the following formula:

$$\mathbf{C = \sum N/n}$$

Where "C" is the average water consumption per household/day, "N" numerical value of each observation and "n" is the number of observations. While average water consumption per person/day "c" was calculated using the following formula:

$$\mathbf{c = C \,/\, Fs}$$

Where "c" is the per capita water consumption, and "Fs" is the average family size.

The total consumption was calculated by using the following formula:

$$T = (p)x(c)$$

Where "T" is the total consumption in l/day, and "p" is the total population.

Each household location was digitized in ArcGIS environment and point layer was generated. Water consumption data was linked with the point layer and then Ordinary Kriging technique was applied to water consumption data to geo-visualize household water consumption in litres. Kernal Density Estimation (KDE) - a non-parametric method to estimate the probability density functions of a random variable was implemented using ArcGIS 9.3 to geo-visualize the spatial trend of family member per unit area (persons/m²). Land use land cover map of the study area is developed from Google Earth image in GIS environment.

3. RESULTS AND DISCUSSION

3.1 Socioeconomic Conditions of the Studied Population

Total population of the 96 surveyed households was counted as 843 persons. Family size has divided into three categories and the family included father, mother, their children, nephews, grandfather, and grandmother. Medium size family was around 65.6 percent, while small and large size families were 8.3 percent and 26 percent respectively (Table 1). Average family size of the surveyed households was 9 persons with a standard deviation of 5. Similarly, the monthly HH income was also classified into three groups out of which about 58.3 percent were low income with a monthly income of less than 35,000 PKR, around 22.9 percent were middle income having range of 35,000 to 70000 PKR, and about 18.8 percent belongs to high income group having more than 70,000 PKR (Table 2).

3.2 Water Consumption

The HH daily water consumption was classified into three categories out of which about 33.3 percent were low water consumption with a less than 500 *l*/day, around 50 percent were middle consumption having range of 500 to 800 *l*/day, and about 16.3 percent belongs to high consumption group having more than 800 *l*/day (Table 3).

The daily domestic water consumption has been quantified which varies among different income groups and family size groups. The average consumption of small family was 282 *l*/day, of medium size family was 526 *l*/day and of large family was 912 *l*/day (Table 4). At household level the water has been commonly used in bathing, washing of clothes, flushing, cooking, washing

Table 1. Frequency distribution of various family sizes of surveyed households

Family Size	Frequency	Percent	Valid Percent	Cumulative Percent
< 5	8	8.3	8.3	8.3
5 -10	63	65.6	65.6	74.0
> 10	25	26.0	26.0	100.0
Total	96	100.0	100.0	

Source: Field Survey July, 2016

Table 2. Frequency distribution of various income levels of surveyed households

Income levels	Frequency	Percent	Valid Percent	Cumulative Percent
<35,000	56	58.3	58.3	58.3
35,000 - 70,000	22	22.9	22.9	81.3
>70,000	18	18.8	18.8	100.0
Total	96	100.0	100.0	

Source: Field Survey July, 2016

utensils, cleaning of house, and for irrigation of plants and lawns. The residents are not using municipal water for drinking and the best sources of drinking water are Springs and Kareez.

Daily water consumption increased with the increase in household monthly income. HH low, medium and high monthly income has been consuming 463, 677 and 1054 *l*/day, respectively (Table 5). The TMA has designed Nairgah water supply scheme which has been providing 70 *l*/day per capita while the quantified average per capita water consumption is 61 *l*/day. The leakage from the distribution lines at various location affecting the supply of water. Analysis reveals that the estimated daily water consumption by the residents of the target area was 12084 *l*0l while TMA supply 567812 *l*. Average monthly income of the surveyed households was 43,000 with average domestic water consumption of 732 *l*/day. On other side based on family size, average domestic water consumption was 573 *l*/day and per person consumption was the 61 *l*/day. Water consumption level has been increased with increase of family size.

Physically, the target area has variation in elevation. The elevation ranges from 1379m to 1505m with change of 126m (Fig. 2). Water supply is basically the responsibility of TMA, Upper Dir. Water supply scheme with capacity of 50,000 gallons have been designed to store and distribute water in the target community. The water is supplied to the community twice a day at 8:00 am and 5:00 pm in a system of water supply pipelines with 4″, 3″ and 2″ diameter. During 24 hours 100,000 gallons (378541 *l*) of water is supplied to the target community. Water supply pipeline network is gravity based. The community is also fed by two private systems developed for mosques. One is Kareez system- a system of underground tunnels providing outlet to groundwater, and another one is Spring system proving water in 2″ pipe. Similarly, depending on the relief and geology the south and west of the study area has 5 springs and 3 springs are located in the north which has also been important source of drinking water. There is no plan to store water of these springs (Fig. 2). The risks associated with water supply are destructive flash floods, poor maintenance of damaged or broken pipes, loss of water, connections from main pipe

Table 3. Frequency distribution of various water consumption groups of surveyed households

Water Consumption	Frequency	Percent	Valid Percent	Cumulative Percent
< 500	32	33.3	33.3	33.3
500 - 800	48	50.0	50.0	83.3
> 800	16	16.7	16.7	100.0
Total	96	100.0	100.0	

Source: Field Survey July, 2016

Table 4. Average domestic water consumption by various family size households and per person

Family Size	Household consumption(*l*/day)	Per capita consumption(*l*/day)
Small	282	57
Medium	526	70
Large	912	55

Source: Field Survey July, 2016

Table 5. Average domestic water consumption by various income groups

Monthly Income (PKR)	Water consumption(*l*/day)
< 35,000	463
35,000 – 70,000	677
> 70000	1054

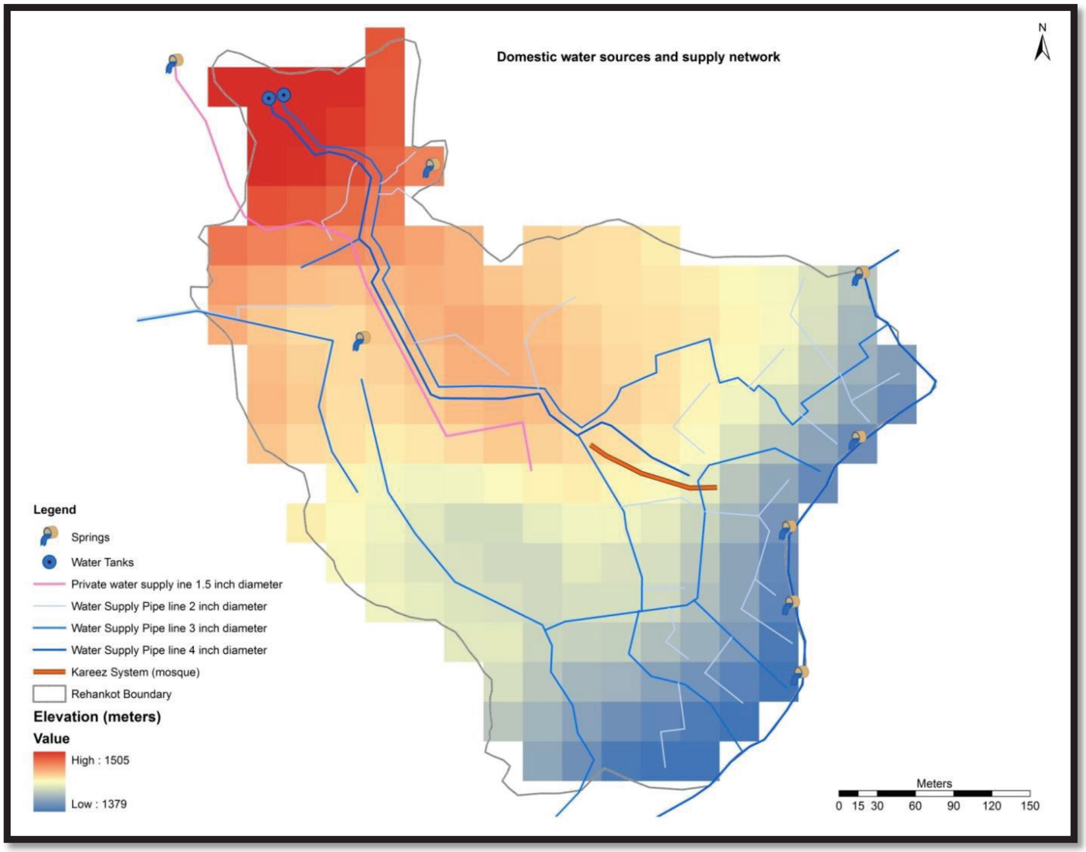

Fig. 2. Public and private water supply network and springs in Rehankot

in drains, unhygienic conditions of drains, blocked drains due to domestic solid water and unchecked water supply connections from main pipe.

Spatial variation has been observed in the consumption of domestic water. In the south and north consumption ranges from 300 to 350 *l*/day while in the centre of the study area consumption is maximum. The areas with maximum consumption have high income and large family size households (Fig. 3). The water consumption increases as household family size and monthly income increases. High income class and large families per day consumption is 1054 and 912 *l*/day respectively. Low income class and small families per day consumption is minimum. Similarly, per person consumption is 57, 70, and 55 *l*/day in small, medium and large families respectively. The head sources of water supply schemes are highly vulnerable because of non-resilient structure. Each year, flash flood remains the main causative factor of head source destruction 5-10 times and community remains without water for two to three days with lot of allied effects. Field survey indicates that the households having access to Springs or Kareez water are not using TMA water for drinking purposes.

The cross table analysis reveals that in low income group 30 and 26 HH were consuming water less than 500 *l*/day and 500 to 800 *l*/day respectively. In middle income group 17 HH was consuming water from 500 to 800 *l*/day, while most of the high income group were consuming more than 800 *l*/day (Table 6). Similarly, analysis further reveals that small families consuming less than 500 *l*/day. In medium size families most of the HH are consuming water from 500 to 800 *l*/day while large family's water consumption starts from 500 *l*/day (Table 7).

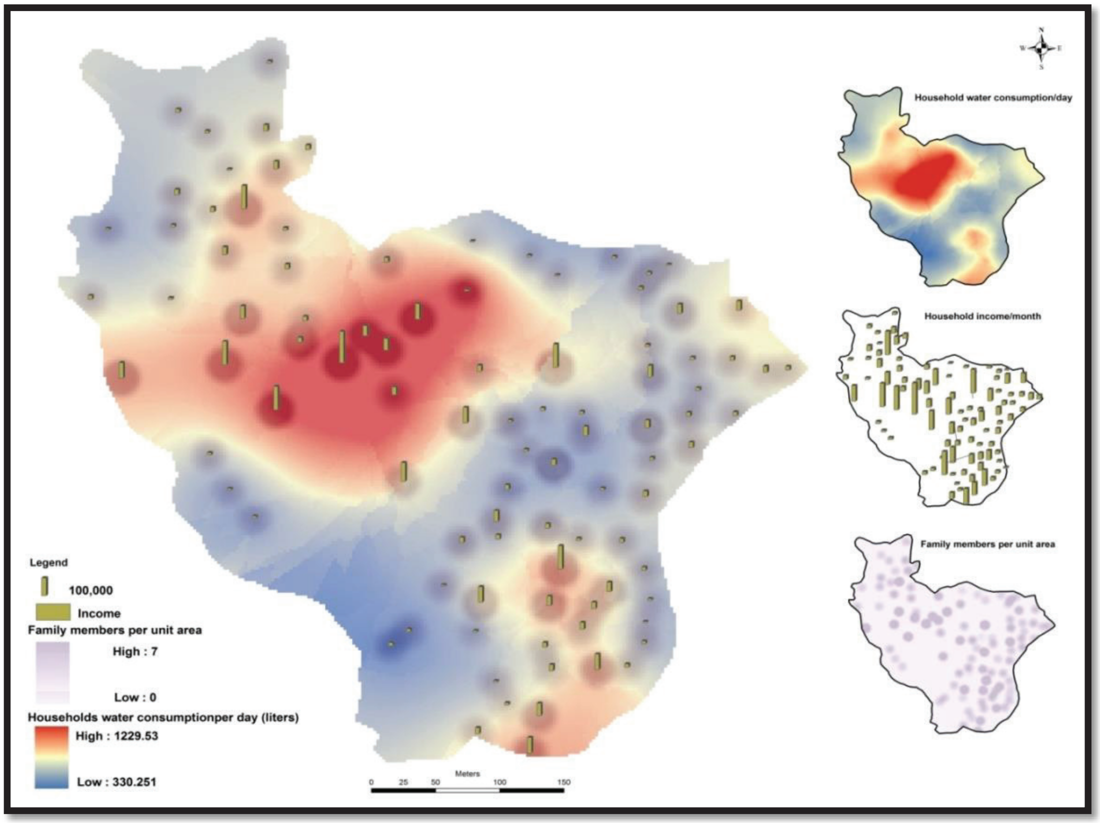

Fig. 3. Surveyed households water consumption, monthly income and family size

Table 6. Family income levels and water consumption cross tabulation

Income Levels	Water Consumption			Total
	< 500	500 - 800	> 800	
<35,000	30	26	0	56
35,000 - 70,000	2	17	3	22
>70,000	0	5	13	18
Total	32	48	16	96

Table 7. Family income levels and water consumption cross tabulation

Family Size	Water Consumption			
	< 500	500 - 800	> 800	Total
< 5	8	0	0	8
5 -10	24	37	2	63
> 10	0	11	14	25
Total	32	48	16	96

4. CONCLUSION

The study concludes that the water supply system in the study area is not evenly distributed in context of pipelines network and water provision. The community is also fed by Springs and traditional Kareez system. The consumption by household and per person also varies from place to place, income brackets, and family sizes. Household income and family size have direct relation with daily water consumption levels. Daily consumption of the high income group was more than low income group. Similarly Large and small families consumption was 912 *l*/day and 282 *l*/day, respectively. This paper also highlighted spatial distribution of supply network and consumption. The average per capita consumption is 61 *l*/day while TMA has been providing 70 *l*/day. It is further concluded that the water supply system needs improvements to reduce the losses from leakages and enhance the efficiency and capacity of existing water supply system. Similarly, the TMA water is not hygienic because of the lack of effective filter system at source. The proper filter system and flood resilient structures for water diversion and storage at source area are highly recommended. Capacity of the water supply system should be redesign on the basis of demands. The water supply system must be at certain distance from drains. Proper maintenance is also highly recommended because the leakage leads to loss of precious water. Water of the several springs is directly flowing into the drainage system without storing. The storage tanks for springs water is highly required. Similarly,

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