ESTIMATION OF WATER DEMAND USING GIS AND WEAP MODEL: A CASE OF KISUMU CITY, KENYA

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Abstract

Increased population of Kisumu City in Kenya has resulted into increased demand and competition for water and the related facilities causing water scarcity. The Kisumu water supply system, managed by Kisumu Water and Sewerage Company (KIWASCO), has a current net supply capacity of 5,400m^3/day against a net demand of 26,880m^3/day. Efficient and effective planning and management of the water supply system is therefore necessary to ensure better services. This requires a comprehensive database on water demand and its future projections. In this study, GIS is used to determine water demand based on the 1999 population census and water use data. Future water demand projections from 1999 to 2030 are generated using Water Evaluation and Planning (WEAP) model under different scenarios. With a vibrant industrial and commercial development as well as improved water supply, the annual water demand for Kisumu City is estimated at about 9.1 million m^3 in 1999 with a projected value of about 18.8 million m^3 in 2030. However, with limited industrial and commercial development as well as non-improved water supply, the annual water demand ranges from 9.1 million m^3 in 1999 to 12.8 million m^3 in 2030. This information is necessary for the current and future planning, design, improvement and management of the City's water supply.

Key words: water demand, projections, scenarios, weap, GIS

1. INTRODUCTION

Kenya is classified as a water scarce country and the situation is getting worse by day. With a population of about 35 million people, the country faces formidable fresh water planning and management challenges especially in urban and peri-urban areas. As in all other countries in Africa, the fast pace in urbanization is contributing to an increasing number of high densely populated settlements in urban centres. More than half of the urban population lives in such settlements where population growth rate reaches 10% and even more [12]. Kisumu City, which is one of the fastest growing urban centres in Kenya, is no exception. It has water scarcity problems, which could be attributed to inequitable water distribution, poorly performing utilities, pollution of water resources, lack of access to water infrastructure, poor management and maintenance of existing infrastructure and poor governance/water policies. The existing water supply system has limited capacity and has deteriorated over the years [7]. It cannot meet the water demand of the ever increasing population.

This study estimates the overall water demand within Kisumu City and its projections over the years from 1999 to 2030. The water demand for the initial year is formulated in a GIS environment and the projections modelled and evaluated in Water Planning and Evaluation Model (WEAP) under different scenarios. The findings of the study are necessary in evaluating the performance of the existing water supply sources in meeting the present and future water demands. It can also be used to solve the City's water problems by identifying effective planning and management strategies.

Water demand evaluation is focussed on domestic and non-domestic water demands as separate variables and finally summed up to give the total water demand. Domestic water demand includes water supplied to houses for sanitary, culinary, drinking, bathing and other purposes, while the non-domestic water demand includes water used by public institutions, commercial and industrial centres [21].

While attempting to develop a household water demand function, a number of demand variables were considered, carefully reviewed and reduced to; price of water, income, number of persons in the household, electricity bill, number of water faucets inside the house and average number of interruptions in service per month [11]. Nauges (2004) has also shown that, a 10% increase of the water price (over several periods) leads to a decrease in residential water use of 5.5%. This shows the impact of water price on domestic demand [13]. In examining these parameters for the case of Kisumu City, it is noted that domestic water use is not currently being majorly influenced by any of the cost related parameters e.g. water price, given the high level of water scarcity and poor water connectivity. The water price within the City varies from Ksh. 1.50/= to Ksh. 20.00/= (0.3 US dollars) for 25 litres of water regardless of quality most of the times [2]. This study therefore estimates domestic water demand as a function of population, population growth rates, living categorization (estates and income levels), level of water connectivity and per capita water use.

The non-domestic water demand used in this study is based on the JICA Report [10] which gives the water demands as per the sub-locations and a 15 year projection with the assumption of a vibrant industrial and commercial growth. In this study the distribution of non-domestic water demand within the specific sub-locations is based on proportional distribution by area as documented by Walski et al., (2007) [23]. Delineation and area calculations can be accomplished by use of GIS packages [1].

Water Evaluation and Planning Model (WEAP)

Water Evaluation and Planning (WEAP) Model was developed to give water professionals access to appropriate tools for water resources planning [16]. It has been used in Volta Basin, Ghana to analyze and understand the impact of climate change on water resources, agriculture and environment, and to evaluate adaptation strategies to address basin-wide water allocations that protect the environment, improve food production, and enhance industrial capacity [1]. It has been enhanced and used in water resources planning cases in the United States by Hydrologic Engineering Center (HEC), the CalFed Bay-Delta Program, the US Bureau of Reclamation, the US Fish and Wildlife Service and the Metropolitan Water District of Southern California [15]. In the Aral Sea, it was used to simulate current water balances and evaluate water management strategies [17]. In South Africa, it was applied to the Steelpoort sub-basin of the Olifants and used to build a model allowing for the simulation and analysis of various water allocation scenarios and scenarios of users' behavior [5]. In the River Njoro watershed, Kenya, it was used as a decision support tool for local stakeholders and communities in addressing shared water issues [8]. In Naivasha, Kenya, it was used for the development of an integrated water resource management model to understand the situation in the whole catchment and identify where problems exist and the weakness that affect the catchment and their improvement [3]. Other places where WEAP has been used include; Middle East involving Israelis and Palestinians, New Hampshire at the Contoocook River as part of the Merrimack River Initiative, Texas in U.S. for supply augmentation through an inter-basin transfer, Southeast U.S. for integrated assessment of the Apalachicola-Chattahoochee-Flint River Basin, Korea for water planning to examine the long-term reliability of the Korean water supply, India and Nepal for capacity building, China for the development of the Beijing Environmental Master Plan Application System (BEMPAS) for the Beijing Municipal Environmental Planning Bureau and Central Asia to develop and evaluate adaptation strategies in the Syr arya Basin [6].

WEAP is preferred for use due to its flexibility as a water balance modeling tool [15], its scenario approach that allows easy representations of the scenarios [17], its compatibility with other models e.g. GIS and hydrological models [1] and the ease of use and its user friendly interfaces (5). Its node oriented approach is used by many other water planning models including; ZWAM-Zayandeh Rud Water Allocation Model [19], Calvin [4,9] and South Florida Water Management Model [20]. This study therefore uses WEAP due to its advantages and its capability of being enhanced to develop a water resources planning model for Kisumu City.

2. METHODOLOGY

Study area

Kisumu City is the third largest city in Kenya and the provincial headquarters of Nyanza Province which is one of the eight provinces is Kenya. It is located on the eastern shores of Lake Victoria at the tip of Winam Gulf as shown in Figure 1.

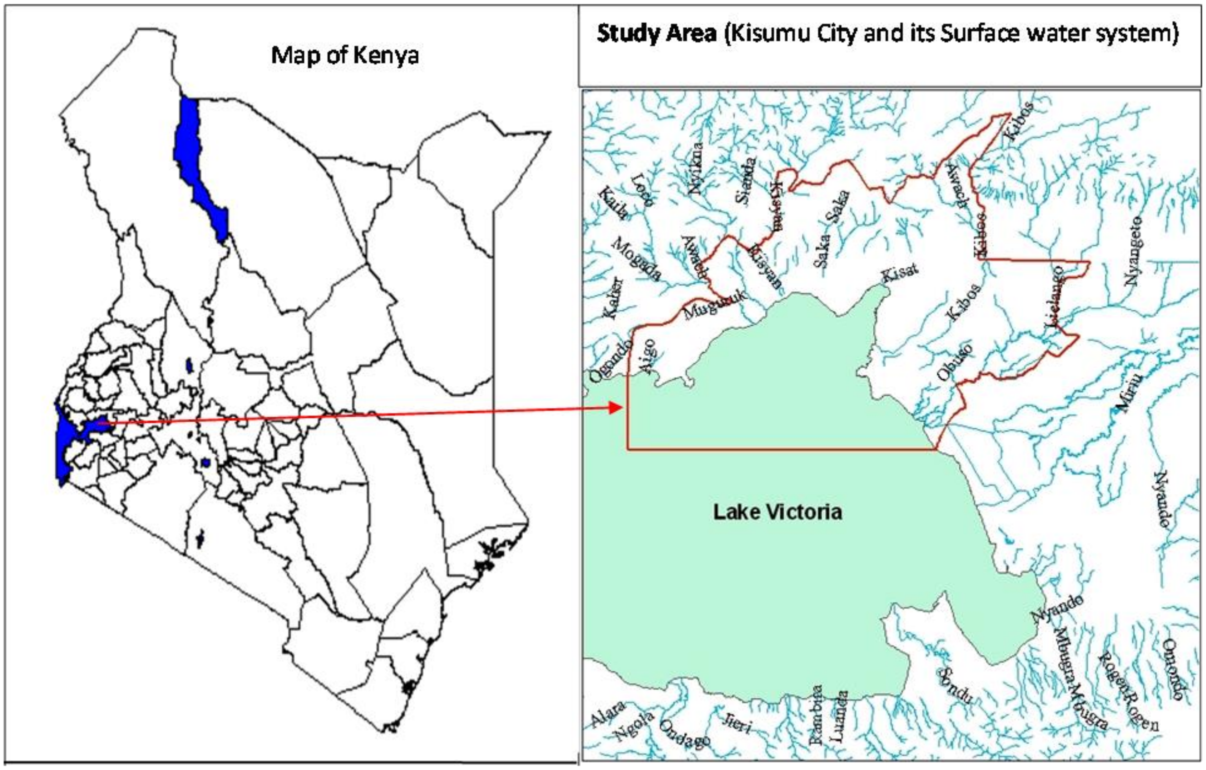

Figure 1: Map of the study area

As stipulated by the National Water Act 2002 [18], the water services within Kisumu City are formally provided by Kisumu Water and Sewerage Company (KIWASCO) and supervised by Lake Victoria South Water Services Board (LVSWSB). Kisumu City's population has grown from less than 50,000 inhabitants in 1969 to 320,000 in 1999 as per the 1999 National Population Census.

GIS data processing

Topographical maps of 1:50000 for Kisumu City region and its catchments were obtained from the survey of Kenya and scanned. The maps covered Kisumu West, Kisumu East and Kaimosi areas. Their scanned images were overlaid in ArcGIS for georeferencing. A detailed quick bird satellite image with an accuracy of about 1m for a section of the City (mainly the congested urban and peri-urban City areas) was obtained from the UN-Habitat. This was registered on to the overlaid images to show clearly the details of the features that appeared congested and crowded on the topographic maps. The features required for the study were then digitized and processed accordingly. These included the basic map features such as the residential estates, road network, river network and the railway lines. Other features used for analysis were obtained as described in the subsequent sections.

Derivation of demand zones from enumeration areas

Enumeration areas are smallest unit areas that are covered during population census. The areas are drawn on maps and are traced along census tracts which mostly follow existing roads and estate boundaries. They link the population data to specific localities within the region. In this study, maps showing the enumeration areas and population data based on 1999 National Census data were obtained and digitized as polygons in ArcGIS and the population data entered in the corresponding attribute table. The areas were then edited and merged into 86 zones based on a number of factors including; residential estates, road network and living categorization (urban, peri-urban and rural), and used as demand zones for this study as shown in Figure 2.

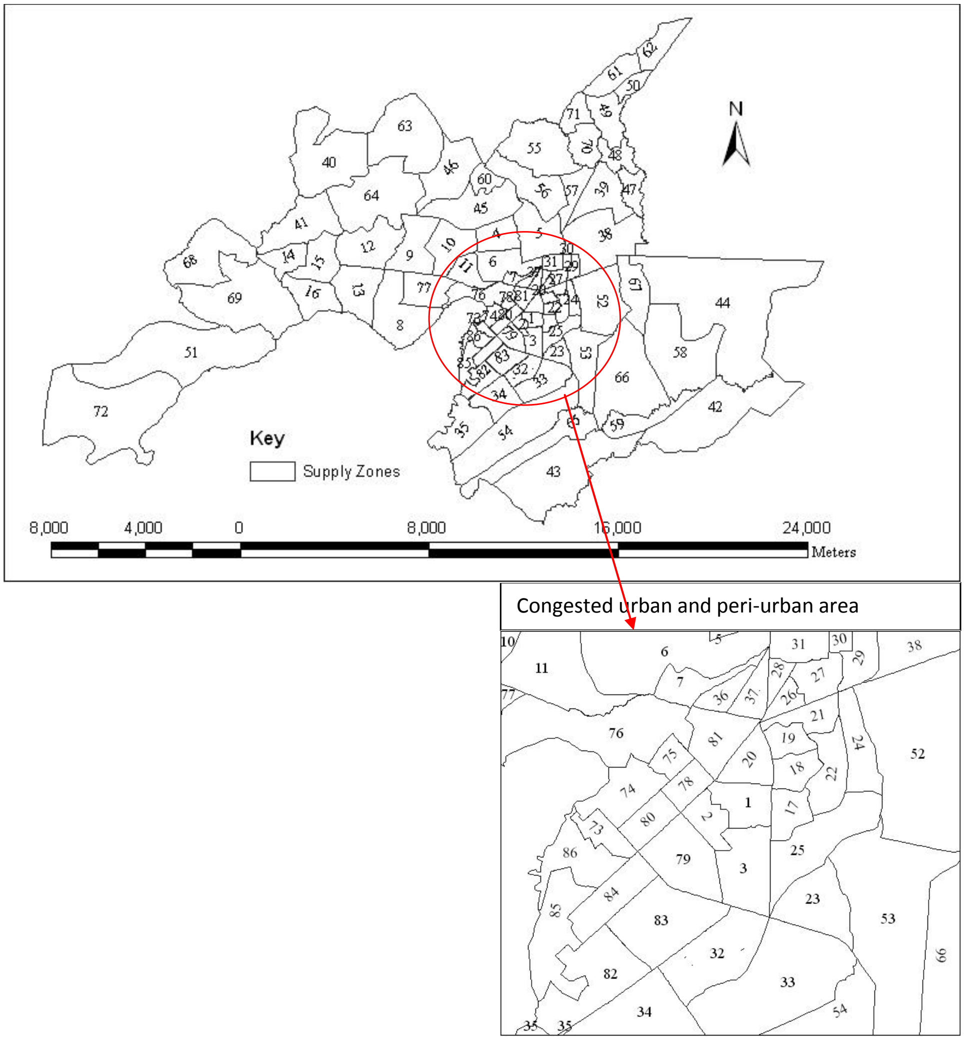

Figure 2: Water demand zones

The population growth rates used for future projections were the average of inter-census growth rates for the individual demand zones based on the 1969, 1979, 1989 and 1999 census [7]. The water supply method and per capita water use for Kisumu City were derived from JICA (1998) report (See Tables 1 and 2) [10]. The details for some selected demand zones are shown in Table 3.

Table 1: Per capita water consumption for Kisumu City

User Category		Urban Area (lcd)	Peri- Urban (lcd)	Rural Area (lcd)
Individual Connection	High income	200	120	120
	Medium income	120	60	60
	Low income	60	50	50
Communal Taps	High income	20	20	20
	Medium income	20	20	20
	Low income	20	20	15

Source: [10].

Table 2: Water Supply Method for Kisumu City

URBAN AREA				
	Income Level (1999 to 2006) (%)	Method of supply and proportion %	1999 to 2006 (%)	Improvements after 15yrs and Beyond (%)
High Income Level	15%	Individual Taps	15	20
Medium Income Level	35%	Individual Taps	35	30
Low Income Level	50%	Individual Taps	35	50
		Common Taps	15	0
PERI-URBAN				
	Income Level (1999 to 2006) (%)	Method of supply %	1999 to 2006 (%)	Improvements after 15yrs and Beyond (%)
High Income Level	10%	Individual Taps	9	10
		Common Taps	1	0
Medium Income Level	25%	Individual Taps	20	32
		Common Taps	5	8
Low Income Level	65%	Individual Taps	26	30
		Common Taps	39	20

Source: [10]

Table 3: Population and growth rates for selected demand zones

Zone No.	Demand Zone	AREA (m^2)	POP_1999 (Persons)	MEAN EL (M)	Mean Growth Rate %
1	P Kaloleni1	500499	4035	1173	1.25
10	P KogonyA4	3192188	2599	1220	2.5
17	P ManyattaA1	369236	8583	1161	1.5
24	P ManyattaB2	589707	4355	1160	1.5
31	P Migosi6	578804	531	1177	1.25
38	P Wathorego1	6533587	4072	1175	2.5
58	R Mayenya1	8669804	2702	1150	1.5
66	R Nyalunya2	9278118	5450	1144	1.5
72	R Osiri	15110307	5898	1191	1.5
73	U Bandari1	318700	1569	1170	0.75
76	U Bandari4	2007013	735	1145	1.25
77	U Bandari5	2679669	475	1155	1.25
78	U Kaloleni4	306512	1259	1181	1.25
84	U Southern Milimani3	673424	1473	1181	0.75

NB: The initial letter under demand zone represents the living area. P-Peri urban,R-Rural and U-Urban.

Modelling water demand in WEAP

Modelling in WEAP requires several steps. These include; defining the time frame, spatial boundary, system components and configuration of the problem, the current account, alternative sets of future assumptions, and scenario development and their evaluation. The initial task is to define the quantities of water demand. It mainly depends on the current year which is the starting year for the simulation and it represents the water demand situation as it currently exists [16].

For this study the current account was 1999 because of the 1999 National census data which gives accurate data on domestic water use and the JICA (1998) report that documents other water uses [10]. The last year of the model is 2030. This covers the year 2015 to assess the achievements with regard to Millennium Development Goals [22] and the year 2030 to evaluate future conditions beyond 2015 and inconformity with Government of Kenya Development Plan under vision 2030 [14]. The trend for simulation is modeled in WEAP and was defined for each component separately in each of the 86 demand zones.

Demand analysis and calculations in WEAP

Demand analysis in WEAP is a disaggregated, end-use based approach for modeling the requirements for water consumption in an area. Economic, demographic and water-use information are used to construct alternative scenarios that examine how total and disaggregated consumption of water evolve over time in all sectors of the economy. The levels of final demand drive all demand calculations in WEAP [16].

Kisumu City is viewed as a structure, which consists of sectors including domestic, industry, commercial and public. These sectors are defined in absolute terms for each demand zone e.g. population for domestic use and total production units for other water uses (with assumption of 1 production unit requires 1m^3 of water). Each demand zone was divided into activity levels depending on sectors; domestic and other water uses, living standard; high income, middle income and low income, connectivity; individual water connection and communal tap and other water uses; industrial, commercial and public use. The activity levels are described in proportionate terms. Figure 3 demonstrates the hierarchical structure used by WEAP for a typical demand site U Bandari 1.

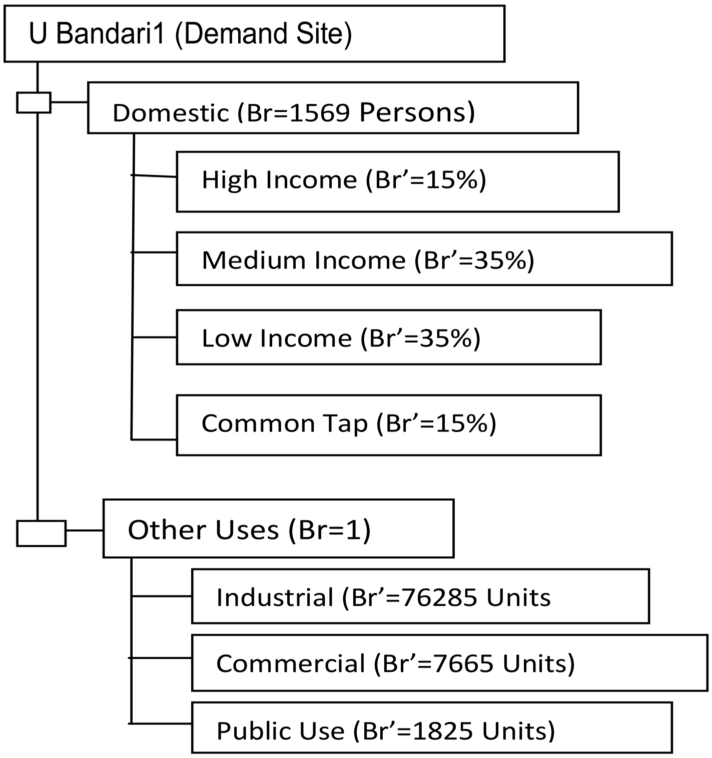

Figure 3: Typical hierarchical structure for a demand zone

Demand at a demand zone is then calculated by multiplying the activity levels and the water use rates of each activity. Each activity level and water use rates are individually projected into the future using a simple exponential growth rates (e.g. population growth rates for domestic water use) and interpolation functions (for other water uses). Annual water consumption is calculated by multiplying the total level of activity by a water use rate. A demand site's (*DS*) demand for water is calculated as sum of the demands for all the demand site's bottom-level branches (*Br*). A bottom-level branch is one that has no branches below it.

$$AnnualDemand_{DS} = \sum_{Br}(TotalActivityLevel_{Br} \times WaterUseRate_{Br}) \quad (1)$$

where, *Br* is the bottom-level branch, Br' is the parent of *Br, Br''* is the grandparent of *Br.*

The total activity level for a bottom-level branch is the product of the activity levels in all branches from the bottom branch back up to the demand site branch

$$TotalAcivityLevel_{Br} = (ActivityLevel_{Br} \times ActivityLevel_{Br'} \times ActivityLevel_{Br''} \times ....) \quad (2)$$

The activity level for a branch and the water use rate (per capita water use) for a bottom-level branch, are entered as data.

Scenario development

The parameters considered for scenario development include; population and its growth rate, water supply method, per capita water consumption and variation in other water uses. They are varied for each scenario as discussed below. The population for the current account, 1999, is based on the 1999 National Census information and is apportioned as per the demand zones. Water supply method, which indicates the level of water connectivity, is based on the Water Supply Master Plan for Kisumu City [10] as shown in Table 2. Each demand zone is classified as urban, peri-urban or rural and further sub-divided to reflect the income levels. The appropriate per capita water consumption is determined from Table 1. The estimates in the current account for other water uses are based on the Water Demand and Supply Planning for the Kisumu City [10]. It gives water use for each sub location which is distributed proportionally for each demand site.

Reference scenario-1 is based on the current account. Average population growth rates based on the inter-censual growth rates and the category in which the areas fall are used to estimate the future population. These rates are documented in the final report for the feasibility study on "Improving Water Supply and Sanitation Services in Kisumu City" [7]. All other parameters with regard to other water uses, water supply method and per capita consumption remain the same as in the current account. This means there are no improvements on the water supply system. Other water uses have also been assumed to be constant suggesting negligible expansion in the industrial, commercial or public sectors.

For Reference scenario-2, all the parameters are the same as in the Reference scenario-1 except that, “Other Water Uses” increases as indicated in the JICA Report [10]. Scenario-1 is based on the Reference scenario-2 with the water supply method varied as indicated in Table 2. Table 4 shows the summary of the demand scenarios.

Table 4: Summary of water demand scenarios

Scenarios	**Domestic Demand**	**Other Water Demand**	**Water Supply method**
Reference Scenario-1	Increase as per population growth rates.	Constant at present status.	Constant at present status.
Reference Scenario-2	Increase as per population growth rates.	Vary as per JICA Report, 1998 starting 2006.	Constant at present status.
Scenario-1	Increase as per population growth rates.	Vary as per JICA Report, 1998 starting 2006.	Varies as per Kisumu City Master Plan to required targets in 15 years from 2006.

3. RESULTS AND DISCUSSIONS

Water demand was projected using WEAP Model from 1999 to 2030. The total annual water demand for different scenarios for all the demand zones are shown in Figure 4

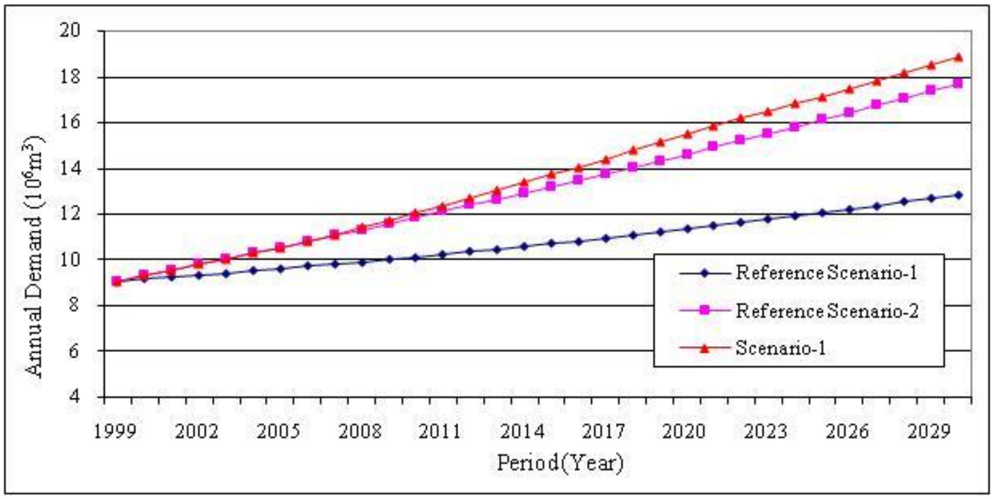

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Figure 4: Water demand projection

Figure 4 shows the variation of water demand with regard to the different scenarios. Reference scenario-1 shows the lowest water demand. It assumes that the present City's water situation is maintained. The water demand therefore only increases due to population growth reaching 12.8 million m^3 by 2030. In reference scenario-2, increase in water demand for other water uses has resulted into a significant increase in water demand of 17.7 million m^3 by the year 2030. This shows the impact of commercial and industrial sectors if they are to be vibrant in the future.

Scenario-1 gives the highest demand throughout the years. It is expected that the increase in water supply will prompt the improvement of the water supply method by encouraging individual water connectivity. This will result into an increase in per capita water use hence the overall increase in water demand. Therefore, a further increase in water demand from 17.7 million m^3 to 18.8 million m^3 in the year 2030 is realized. If water supply is improved to expected levels, the curve for Scenario-1 represents the most realistic trend.

Water demand projections were also examined with respect to water uses i.e. domestic and other water uses and presented in Figures 5a-c. Further analysis was similarly done to reflect the location of the demand as per the living areas i.e. urban, peri-urban and rural areas and results shown in Figures 5d-f.

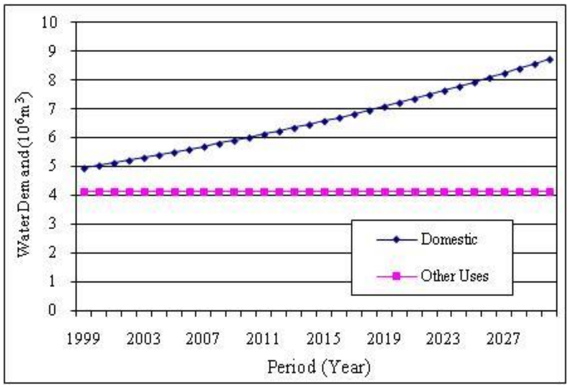

Figure 5a: Reference scenario-1

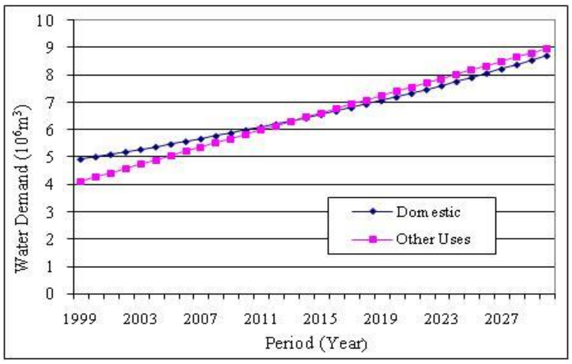

Figure 5b: Reference scenario-2

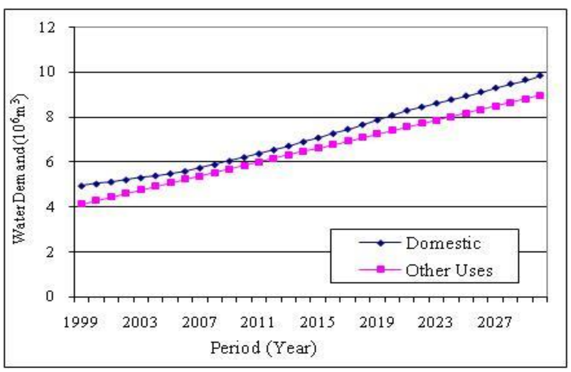

Figure 5c: Scenario-1

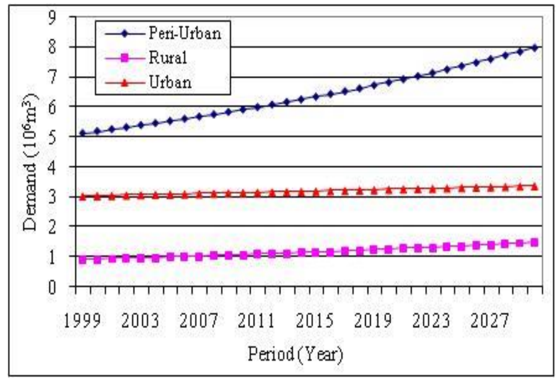

Figure 5d: Reference scenario-1

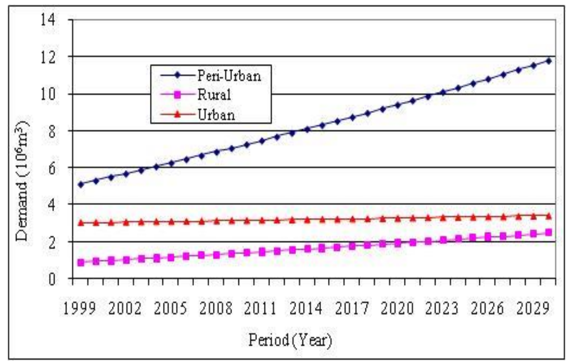

Figure 5e: Reference scenario-2

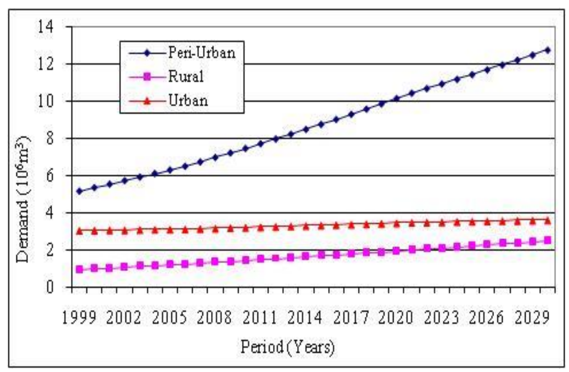

Figure 5f: Scenario-1

Figure 6a-f: Water demand as per the water uses and the living areas

As can be seen in Figures 5a and 5c, domestic water demand is more than that for other water uses. In Figure 5b other water uses bypasses domestic water demand. This situation is reversed in Scenario-1 when the water supply method is improved as planned.

A comparison of water demand with regard to urban, peri-urban and rural areas in all the scenarios show that water demand in peri-urban areas is the highest and is even more than both the urban and rural demands combined. It rises very steeply from 1999 to 2030. Rural water demand is the lowest in all the scenarios. Both rural and urban water demands vary relatively gently from 1999 to 2030 (See Figures 5d-f).

In summary the water demand for Kisumu City, if all parameters change as expected, is reflected by Scenario-1 and it indicates that its annual values vary from 9.1 million m^3 in 1999 to 18.8 million m^3 in 2030. The other scenarios are also possibilities hence the need for their consideration. The water demand in peri-urban areas shall continue to dominate throughout the interval.

4. CONCLUSION AND RECOMMENDATIONS

In this study, water demands are increasing, due to the increased growth of human activities. Complex conflicts between competing users, between stakeholders along common source of water, and between economic growth itself and environmental conservation are therefore expected. Integrated approach in the utilization and management of the scarce water resources to meet the ever-increasing competing water demand is therefore critical.

The present water demand for the city is constricted because of the persistent water scarcity within the city over the years. Water scarcity affects settlement patterns, water supply method, and growth in commercial and industrial sectors, hence the per capita water use. However, Scenario 1 presents a more realistic demand situation and future projection. It shows that annual water demand varies from 9.1 million m^3 in 1999 to 18.8 million m^3 in 2030. This is because it incorporates population growth rate, expansion in public, industrial and commercial sectors as well as improved water supply method as more water is available. The other scenarios are also possibilities hence the need for their consideration. The water demand in peri-urban areas is also found to dominate throughout the period considered.

Water Evaluation and Planning (WEAP) model used in this study, is flexible and it allowed the representation of the City's water demand and future projections as adequately as data was available. Many scenarios representing different management and future development options can be evaluated and compared.

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