WATER DEMAND FORECAST AND MANAGEMENT MODELLING IN KATHMANDU VALLEY, NEPAL

Pratistha Pradhan[1]

Introduction

In many watersheds, the water demand for different sectors has been increasing steadily at a high rate, especially in urban areas throughout the world. The population in cities is rapidly increasing, which in turn increases the need for water. At the same time, expanding industrial activities demands the expansion of urban water supply services. The competition for water in agriculture is also increasing, since there is a need to increase production per unit area to feed the growing population.

According to 1995 data, total global water withdrawal comprised some 3 750 km^3/year, with actual consumption at around 2 270 km^3/year (61 percent of withdrawal). In future the total water demand is expected to grow 10-12 percent every 10 years. Water consumption will grow somewhat more slowly, with an increase of 1.26 times.

Agriculture consumes the maximum quantity of water (67 percent of total water withdrawal) and accounts for 86 percent of consumption in the global scenario. The global irrigated area was 254 million ha in 1995. By 2010 it is expected to grow to about 290 million ha and by 2025 up to 330 million ha. However in future, the proportion of water used for agriculture is likely to decrease slightly mainly at the expense of more intensive growth in other water demands such as industry and public water supply.

The problem is because water availability is not demand-elastic. The amount of water in the world is finite. The problem is not only due to the unavailability of water but also due to its inaccessibility, which makes it very expensive to be tapped. Again, water resources are threatened not only by increasing demand but also by diminishing water quality.

There are two possibilities to solve the problem of water supply. One is supply augmentation and the other is demand management. But the cost of developing new sources or expanding the existing sources is increasing as the most accessible water sources have been already tapped. Water demand management has been practised in many parts of the world and is the best alternative to using available resources in a sustainable manner.

Therefore, a reliable water demand forecast is mandatory for the planning and implementation of water demand management schemes. There are various factors influencing water demand and models can assist in understanding their effects, make predictions, and help to develop plans for management. Water demand management models can also help to assess the efficiency of various types of water conservation measures.

Water demand forecasting is especially useful for water utility of the water supply agencies to estimate the required amount of water in advance so that proper action can be undertaken to fulfill demand. Water demand management models also help to see the effect of the demand management measures on water demand.

[1] MSc. Thesis (Ref. No. WM-02-11), Asian Institute of Technology, Bangkok, Thailand. April 2003.
Examination Committee - Dr. M.S. Babel (Chair), Prof. A.D. Gupta (Co-Chair), Dr. Ole Mark, Dr. Michael A. Zoebisch

In Kathmandu, water scarcity is a daily problem. There is an immediate need for better water supply schemes and this implies the need for proper forecast of water demand beforehand. In Kathmandu, certain water demand management measures such as water pricing have been applied but they are inadequate and not well managed, so the problem is worsening day by day. Hence, in watersheds like the Kathmandu Valley there is an urgent need for proper water demand forecasting and management.

The traditional approach was to forecast water demand based upon the population and per capita requirement, which in general led to over-estimation. The modern approach is to use the econometric model including socio-economic and climatic variables.

At present, there are many water demand forecast models in the domestic sector but most of them are made for specific places and hence can only be used for that area. Moreover these models are not in a user-friendly form. Only a very little work has been done in the industrial sector and in management aspects of agricultural water demand. The IWR-MAIN software model considers many factors but it is complicated and demands sound technical background as well as proper training before use.

Hence, there is a need for a simple and user-friendly model that takes into account the practical factors affecting water demand for domestic, industrial, as well as agricultural sectors.

Study area

Nepal is a land-locked country between India and China with a total area of 3 811 81 km^2. The altitude of Nepal varies from 60 m to the world's highest peak at 7 878 metres above mean sea level (masl). It is broadly divided into the Terai in the south, mountains in the middle, and the Himalayan region in the north. Further classification is disaggregated into five development regions, 14 zones, and 75 districts. Inside districts there are urban centres and villages as smaller divisions. The total population of Nepal is about 20 million.

Kathmandu Valley was selected as the study area; it lies in the Middle Western development region and Bagmati zone. It includes three districts namely Kathmandu (395 km^2), Lalitpur (385 km^2), and Bhaktapur (119 km^2) (Figures 1 and 2). In Kathmandu Valley there are five urban centres: Kathmandu, Lalitpur, Bhaktapur, Madhyapur, and Kirtipur.

Figure 1. Map of Nepal showing the location of Kathmandu, Lalitpur, and Bhaktapur (map scale: 1: 5 000 000)

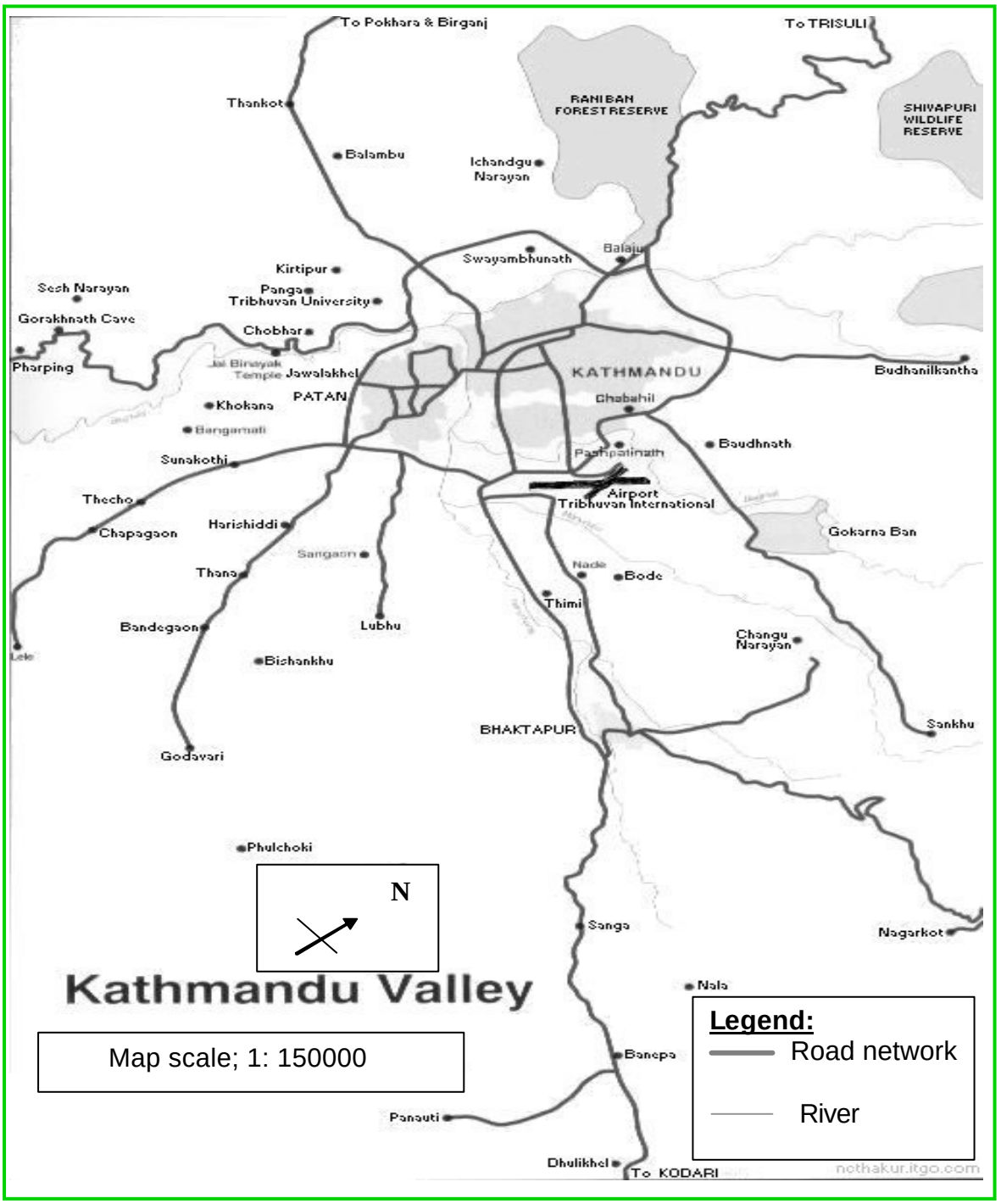

Figure 2. The main urban centres and the river system in Kathmandu Valley

Methodology

The general parameters affecting water demand in domestic, industrial, and agricultural sectors were first identified based on a literature survey. Model equations were formulated with the selected variables that were logical and important. A hypothesis for all the variables was made according to general acceptance with references to previous research. Finally a user interface for the water demand model in domestic, industrial, and agricultural sectors was developed using the Visual Basic 6.0 programme with Excel as back-up.

Domestic water demand model development

The dependent variables and independent variables may need to be changed. The decision to change the variables is taken by studying the nature of the partial plots.

The suggested model equations for domestic water demand forecasting are as follows:

$$Q = f\,(I, T, R, G, N, E, C, A, B, P)$$

Multivariate linear regression models in three different functional forms are used:

1) ***Linear model:***

$$Q = b_0 + b_1(Po) + b_2(N) + b_3(S) + b_4(T) + b_5(R) + b_6(G) + b_7(E) + b_8(D) + b_9(P)$$

2) ***Semi-log model:***

$$\ln Q = b_0 + b_1(Po) + b_2(N) + b_3(S) + b_4(T) + b_5(R) + b_6(G) + b_7(E) + b_8(D) + b_9(P)$$

3) ***Log-log model:***

$$\ln Q = \ln b_0 + b_1 * \ln(Po) + b_2 * \ln(N) + b_3 * \ln(S) + b_4 * \ln(T) + b_5 * \ln(R) + b_6 * \ln(G) + b_7 * \ln(E) + b_8 * \ln(D) + b_9 * \ln(P)$$

where,

b_0 and $\ln b_o$	=	Model intercept
Q	=	Total water use in MLD
Po	=	Population
N	=	Number of connections or number of households
S	=	Household size
T	=	Average monthly temperature (°C)
R	=	Total yearly rainfall (mm)
G	=	GDP at current market price (as a substitute of the income)
E	=	Ratio of population to number of university students
D	=	Ratio of population to number of doctors
P	=	Price of water
b_o	=	Model intercept
b_1, b_2, b_3-b_9	=	Coefficients

The hypothesis is that the residential water demand will increase along with the population, number of connections, temperature, and household size and will decrease with increase in rainfall, population to doctor ratio, and price of water.

The intercepts and coefficients are obtained from the calibration of the model using the past records of the variables at the 0.05 level, after the final model variable selection based upon statistical tests.

Industrial water demand model development

In this sector the model can give better results if it is used for different groups of industries separately depending upon their product type:

$$Q = f\ (N, C, IGDP, E, T, R, P)$$

$$Q = b_o + b_1 N + b_2 C + b_3(IGDP) + b_4 T + b_5 R + b_6 P$$

where,

Q	=	Yearly water use in the industrial sector (MLD)
N	=	Total number of industries
C	=	Total number of industrial connections
IGDP	=	Industrial gross domestic product
E	=	Number of employees
T	=	Average monthly temperature
R	=	Total yearly rainfall
P	=	Price of water
b_o	=	Model intercept
b_1-b_6	=	Coefficients of the parameters

The value of the model coefficient is obtained by using multivariate regression analysis as in the domestic model. Then using the coefficients obtained from the model along with the forecast values of the independent variables; the water demand for later years is forecast.

Agricultural water demand model

In the agricultural sector, the crop water requirement is calculated based on the rainfall and potential evapotranspiration. The option to include the leaching requirement is also provided in the model.

Volume of irrigation water required or field water supply = f (irrigated area, crop evapotranspiration, rainfall, irrigation efficiency, price of water, leaching requirement)

Net irrigation required in mm, $NIR = (ET_c - P_{eff})\ (1 + LR)$

Gross irrigation water requirement in mm, $IRWR = NIR / E_a$

Total volume of irrigation water in m^3, (Q) = IRWR * area of irrigation (A)

LR	=	Leaching requirement (decimal)
ET_c	=	Crop evapotranspiration
P_{eff}	=	Effective rainfall
E_a	=	Irrigation efficiency (0.6 to 0.7) (Source: FAO 56).

Effective rainfall (P_{eff}) is calculated according to the USDA Natural Resource Conservation Services (previously Soil Conservation Service) method:

For total rainfall < 250:

$$P_{eff} = (125 - 0.2 * \text{total rainfall}) * \text{total rainfall} / 125$$

and for total rainfall > 250:

$$P_{eff} = (125 + 0.1 * \text{total rainfall})$$

Then, the crop evapotranspiration is calculated using the adjusted crop coefficients (Kc) for a given crop, growth stage (use the standard values), and the climatic situation.

$$\text{Crop evapotranspiration } (ET_c) = f \text{ (temp, sunshine duration and intensity, wind velocity, and type of crop)}$$

$$ETc = ETo * Kc_{adjusted}$$

The potential evaporation (ET_o) is calculated using the Penman-Monteith equation as explained in FAO 56.

$$Eto = (0.408*\Delta*(Rn-G)+\gamma*(900/T+273)*u2*(es-ea))/(\Delta+\gamma*(1+0.34*u2))$$

ETo	=	Reference or potential ET mm/day
Rn	=	net radiation at the crop surface $MJ/m^2/day$
G	=	Soil heat flux density $MJ/m^2/day$
T	=	Air temperature at 2 m ht ^oC
u2	=	Wind speed at 2m ht m/s
es	=	Saturation vapour pressure kpa
ea	=	Actual vapour pressure kpa
es-ea	=	Saturation vapour pressure deficit kpa
Δ	=	Slope of vapour pressure curve kpa/^{o}C
γ	=	Psychometric constant kpa/ ^{o}C

The value of the crop coefficient (Kc) is taken from the standard table (see FAO 56) for the initial, mid-, and end-stage and is adjusted for the climatic condition, partial wetting, and mulching.

$$Kc_{adjusted} = \text{Max (Kc corrected for climate, Kc corrected for mulching, Kc corrected for intercropping)}$$

From the plot of K_c against time in days, Kc values for mid- and end-stages are obtained by interpolation. For all the crops on cultivated fields larger than 3-5 ha, the maximum Kc value is from 1.05 to 1.31. For the perennial crop, Kc is taken as constant throughout the year. The Kc is adjusted for the partial wetting factor by,

$$Kc_{ini} = f_w * Kc_{ini \text{ (from standard tables or figures)}}$$

where,
f_w= partial wetting factor and, Kc_{mid} or Kc_{end} values are adjusted for climates
where RH_{min} differs from 45 percent or where u_2 is larger or smaller than 2m/s
$Kc_{mid} = Kc_{mid(table)} + [(0.04*(u_2-2)-0.004*(RH_{min} - 45)] *(h/3)^{0.3}$

Plastic mulch reduces Kc by 10 to 30 percent and organic mulch reduces the soil water evaporation according to the depth of mulch.

$$\text{Leaching, } LR = EC_w / (5EC_e - ECw)$$

EC_w and EC_e are the electrical conductivities of the irrigation water and soil respectively.

The suggested alternative equation to find the water demand in the irrigation sector is as follows:

$$\text{Quantity of water applied in the field} = f \text{ (price of water, amount of fertilizers and pesticides used, } ET_C\text{, leaching requirement, crop water requirement, crop production)}$$

Then the regression analysis can be done with appropriate transformation of the variables using the past records and using the coefficients to obtain the future water demand in irrigation. In the PP water demand model, the irrigation efficiency is to be given as input by the user. It is recommended to use the local irrigation efficiency (if any). The inputs required for the irrigation water demand calculation in the PP model are: geographical and topographical information of the area (altitude, latitude, longitude);

monthly average value of climatic parameters (T_{max}, T_{min}, RH, wind speed, sunshine duration, rainfall); planting month; planting date; harvest date; total area under cultivation; type of crop and its standard K_c at different stages; length of each crop stage; type of mulch used, and area under mulching.

User interface

The Visual Basic 6.0 programme is used to develop the user interface with Excel as the back-up for major calculations (Figure 3). This can be installed and run on computers using Office 98 or Office 2000. A "Help" tool is provided in the model to guide the user.

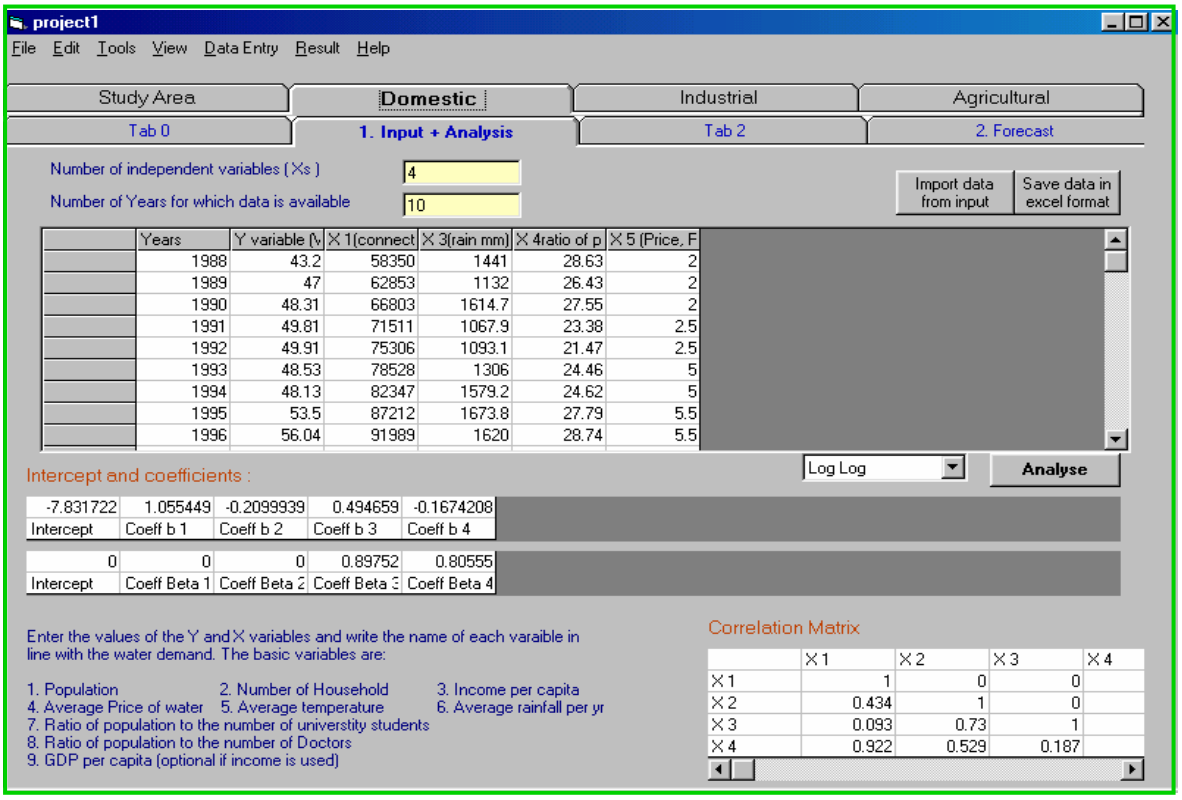

Figure 3. User interface of the domestic water demand model (data input and analysis)

Results and discussion

Factors influencing the domestic water demand

The water demand in Kathmandu Valley was 112 MLD and there were 113 800 water connections in the valley in 2002. The number of connections (especially metered connections) and water pricing were the major water demand management parameters in use in Kathmandu Valley. Approximately 82 percent of the connections was metered. The diameters of the connected pipelines were ½, ¾, 1, 2, 3 and 4". The users were categorized as private, government, public, and industrial. Each category was further divided into metered and non-metered users. The price of water depended on the category and the diameter of the pipeline connected.

Many researches have proved that water demand is dependent on many socio-economic factors. Among them population is the most widely accepted and used parameter. The household size, GDP at current price, and the ratio of the total population to university students are also considered as socio-economic variables affecting water demand.

The number of connections in Kathmandu Valley was increasing in a linear trend at around 5 000 per year from 1988 to 2001. The mean monthly temperature of Kathmandu from 1971 to 2001 was about 19ºC. There was gradual increase in temperature every year and it peaked in 2000. The mean of the total yearly rainfall from 1971 to 2001 was around 1 400 mm.

The educational level of the water user is also a factor that can affect water demand. In this study, the ratio of total population to university students was selected as an indication of the level of education. The assumption behind this is that if people are more educated, they will have higher awareness about hygiene and will use more water. The number of university students has increased. This indicates that the level of education is rising among the water users in Kathmandu Valley. Tribhuvan University (TU) is the oldest and the largest university with the maximum number of students; the data on students from this university is used for the analysis. This is valid for Kathmandu because the number of students in other universities, which are rather new is negligible compared to the student count of TU. Here the number of students includes the students at certificate level and higher.

The water supply line in residences is ½" in diameter. The water tariff for different sizes of pipeline is different. But only the tariff rate for the ½" line was used in the model's development. In 1993, the tariff was increased and remained almost constant up to 2000. After 2001, the tariff increased again. The increase was probably imposed due to the heavy increase in demand and the insufficient supply capacity of the NWSC.

The increase in GDP at the current price is exponential but the increase in GDP per capita is almost linear. The total population in Kathmandu Valley increased to 1 600 000 in 2001 from 600 000 in 1971. The rate of increase from 1991 to 2001 was higher than the previous two decades. This increase can be attributed to the increase in population and the rising trend to divide into single families from the traditional nuclear family.

Domestic water demand model

The analysis was made with data from Kathmandu Valley with nine selected variables (Table 1) as follows:

Y = Water use (MLD)
X 1 = Number of connections
X 2 = Mean monthly temperature (°C)
X 3 = Total annual rainfall (mm)
X 4 = Ratio of population to university students
X 5 = Price per unit water (tariff) (NRs)
X 6 = Per capita GDP (NRs)
X 7 = Population
X 8 = No. of households
X 9 = Household size

Table 1. Data of Kathmandu Valley from 1988 to 2001

Years	Y	X 1	X 2	X 3	X 4	X 5	X 6	X 7	X 8	X9
1988	43.20	58 350	18.30	1 441	28.63	2.0	28.63	10 036 69	1 820 44	5.7
1989	47.00	62 853	18.60	1 132	26.43	2.0	26.43	10 375 72	1 883 75	5.7
1990	48.31	66 803	18.50	1 614	27.55	2.0	27.55	10 714 75	1 947 07	5.7
1991	49.81	71 511	18.32	1 067	23.38	2.5	23.38	11 053 79	2 010 38	5.6
1992	49.91	75 306	18.34	1 093	21.47	2.5	21.47	11 593 50	2 154 90	5.6
1993	48.53	78 528	18.52	1 306	24.46	5.0	24.46	12 133 21	2 299 43	5.5
1994	48.13	82 347	18.73	1 579	24.62	5.0	24.62	12 672 93	2 443 95	5.4
1995	53.50	87 212	18.65	1 673	27.79	5.5	27.79	13 212 64	2 588 48	5.4
1996	56.04	91 989	18.85	1 620	28.74	5.5	28.74	13 752 35	2 733 00	5.3
1997	61.80	96 655	18.50	1 528	28.22	5.8	28.22	14 292 06	2 877 52	5.2
1998	62.21	100 442	19.20	1 770	30.60	6.1	30.60	14 831 77	3 022 05	5.2
1999	62.21	106 589	19.71	1 735	25.62	6.4	25.62	15 371 49	3 166 57	5.1
2000	64.94	108 955	21.40	1 681	24.60	6.7	24.60	15 911 20	3 311 10	5.1
2001	66.03	113 800	20.80	1 407	24.01	9.7	24.01	16 450 91	3 455 62	5.0

Table 2. Correlation matrix

	X1	X2	X3	X4	X5	X6	X7	X8	X9
X1	1								
X2	0.788	1							
X3	0.558	0.388	1						
X4	0.007	-0.171	0.613	1					
X5	0.940	0.748	0.506	0.018	1				
X6	**0.997**	0.810	0.554	0.007	0.940	1			
X7	**0.998**	0.804	0.579	0.037	0.948	**0.998**	1		
X8	**0.995**	0.813	0.586	0.052	0.948	**0.997**	**0.999**	1	
X9	**-0.990**	-0.771	-0.574	-0.061	**-0.950**	**-0.993**	**-0.993**	**-0.993**	1

As shown in Table 2, variables X1, X6, X7, X8, and X9 are highly correlated. So, it was decided to use only X1, since the number of connections is directly related to water use from the supply lines of the NWSC.

The analysis then used the developed domestic water-use model to find the coefficients or model equation for Kathmandu Valley. Data from 1988 to 1997 were used for the multiple regression analysis and data from 1998 to 2001 were used for verification of the model's usefulness.

Three models: linear, semi-log, and log-log, were investigated using independent variables X1 to X5. Other variables (X6 to X9) were not used as they were highly correlated to X1. Including these parameters in analysis would raise the multi co-linearity effect. Then, X2 was also excluded as it accepts the individual null hypothesis (t-statistics = -1.325 and p-value= 0.256 in the linear model, t-statistics = -0.833 and p-value 0.452 in the semi-log model, t-statistics = –2.012 and p-value = 0.115 in the log-log model).

The adjusted R^2 value of 0.965 from the log-log model was highest among the three models under investigation. Others were 0.950, 0.952, and 0.878 in the linear, semi-log 1, and semi-log 2 models respectively. The results indicate the models can explain about 95 percent of variation in water use.

The resulting equation for the log-log model is

$$LnY = -7.831722 + 1.055449*\ln(X1) - 0.209994*\ln(X3) + 0.494659*\ln(X4) - 0.167421*\ln(X5)$$

In this equation, the sign for the number of connections (X1) is positive, as the increase in number of connection will increase water use unless per capita use is drastically reduced, which is not the case for Kathmandu Valley. The elasticity of water use with respect to the number of connections is 1.055. Hence a 1 percent increase in the number of connections will increase water use by 1.055 percent in Kathmandu Valley.

The increase in rainfall (X3) decreases the need for additional water in households for gardening or for lawns. The rainfall elasticity of water use is –0.21, meaning a 10 percent increase in rainfall will decrease water use by 2.1 percent.

The price (X5) elasticity of water use is –0.167. This means that water use will decrease by 1.67 percent if the price rate is increased by 10 percent. This effect of water use by price is rather low. It is probably because not all the connections are metered or the price is low.

The elasticity of water use for the area with respect to X4 is around 0.5. Increase in X4 indicates the decrease in the level of education compared to the population. The hypothesis was that water use increases with an increase in the educational level, as people would then be more aware of hygiene. But the positive sign for X4 in the equation implies that the opposite is true (i.e. water use is increased by the decreased number of university students). Probably, the higher awareness of water abuse in the educated circle was responsible for this result. In fact, Kathmandu Valley has a serious water supply problem and so people are aware that they must use available water efficiently.

The above analysis shows that water use is dependent on four factors: the number of connections, annual rainfall, educational level (ratio of population to university students), and price. Water use has no significant effect on the other parameters of the preliminary selection. Through analysis of water use in other places via different research, it is known that other parameters do have a significant effect on water use but the extent of the effect differs from place to place. In fact the effect of the variables that are not present in the model equation but are somehow affecting water use is accounted for by the value of the intercept.

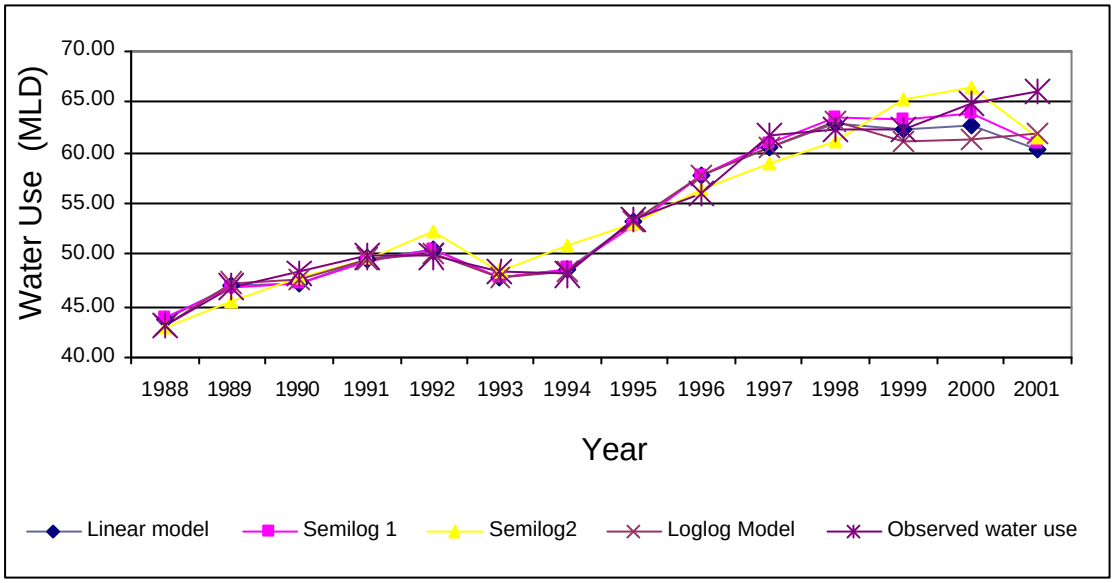

Figure 4. Observed and predicted water use for Kathmandu

Among all the functional forms used, the log-log form is the best in this case with the highest R^2 and the lowest standard error and also the least percent error in the forecast water use for 1989, 1999, 2000, and 2001.

Similar analysis was done using the number of students directly instead of the ratio of the population to university students. The adjusted R^2 values are 0.957, 0.964, and 0.965 for linear, semi-log, and log-log models respectively. Thus, the highest R^2 and the lowest error in percent were observed in the log-log equation:

$$LnY= -4.33601+ 1.398147*\ln(X1) - 0.206054*\ln(X3) - 0.539271*\ln(X4) - 0.149306*\ln(X5)$$

Again, the equation shows the decrease in water use with the increase of the educational level, which is against the hypothesis. But the reason behind this could be the awareness of water scarcity and the students' role in using the water in an efficient way. The water-use elasticity with respect to the number of university students (X4) is around –0.54, which implies 5.4 percent decrease in water use with 10 percent increase in the number of students.

The elasticity of water use with respect to X1 is around 1.4, indicating a change in water use by 14 percent with a 10 percent change in the number of connections. The elasticity of water use with X3 is -0.206; hence the water use will decrease by 2.06 percent with 10 percent increase in yearly rainfall. The price (X5) elasticity of water use as reflected by the slope in the log-log model is around –0.15. Hence a 10 percent increase in price will decrease water use by 1.5 percent. So X5 can be used as the tool to change water use.

By comparing Figures 4 and 5, it is observed that the prediction of water use by the model used for Figure 4 is better than the prediction in Figure 5. Hence, the ratio of population to the number of university students was used as the parameter indicating the level of education and its effect on water use.

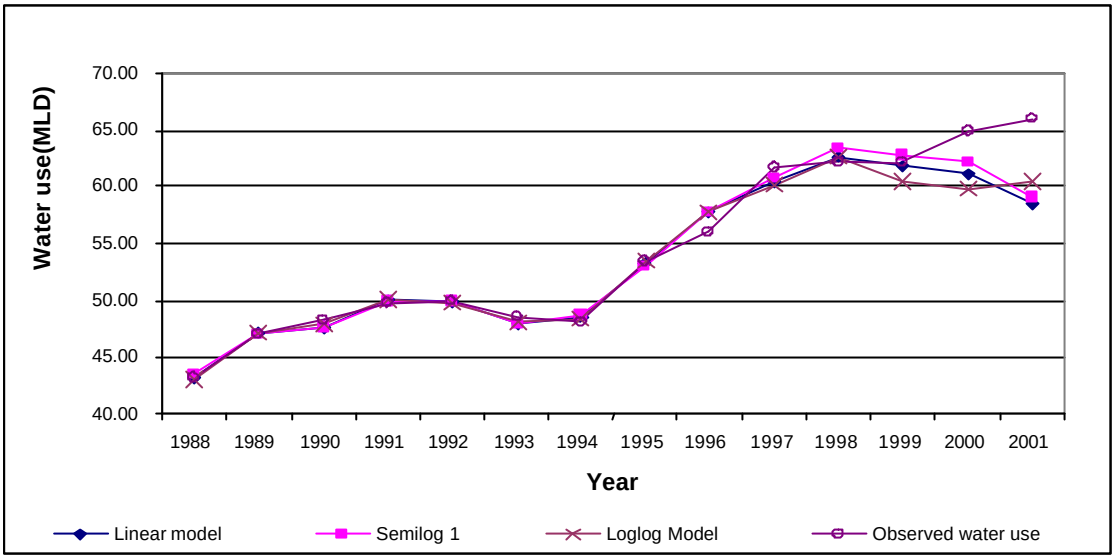

Figure 5. Observed and predicted water use for Kathmandu Valley

Forecast of water use for 2005, 2006, 2010, 2011, 2015, and 2016

To forecast future water demand, it is necessary to forecast the number of connections, rainfall amount, number of university students (or ratio), and the price in the forecast years because these are the explanatory variables.

Forecasting the number of connections

Method I

Using the trend of growth in the number of connections and assuming that the connections will increase in the same pattern, the number of connections was forecast and the best-fit equation was chosen. Based on the highest R^2 criteria, the two-degree polynomial equation (R^2=0.9988) was the most appropriate for forecasting the number of connections in Kathmandu Valley.

$$\text{Number of connections} = 23.069\, x^2 + 3918.9 * x + 54\,746$$

where x = ((forecast year –1988) + 1)

Method II

Assuming that the ratio of population to the number of connections is a constant, the number of connections was forecast. For Kathmandu Valley, the mean of the population to the number of residential connections with the data set from 1988 to 2001 was 15.33.

$$\text{Number of connections} = \text{Population in the forecast year}/15.33$$

Method III

The number of connections is a function of population, number of households, and GDP. The number of connections can be expected to increase with all these factors. But this relation was not used because of the high correlation between each factor inducing multi co-linearity in the equation obtained.

Forecasting the rainfall

The calculation was based on the trend line extrapolation of the yearly total rainfall data. The trend lines were plotted but with all the forms as linear, power, exponential, logarithmic, 2 to 6 degree polynomial, the values of R^2 were less than 0.34. So it was decided to take the mean of the available data of the total yearly rainfall as a constant value (1 475) for the forecast years.

Forecasting the number of university students

Assuming that all the children will go to university after the age of 16, it can be taken that every year the number of students in universities will increase according to birth before 16 years of the forecast year:

No. of university students = Population in forecast year/ratio of population to student

If this assumption is not valid, the trend extrapolation is always the guideline that can be used to assume the same growth pattern as in the past.

Forecasting the population

Population can be forecast using many methods as explained in the theoretical consideration. The most common method is to use the trend line extrapolation technique. Based on the maximum R^2 criteria, the two-degree polynomial equation was chosen as the line of best fit with an R^2 value of 1.

$$Y = 98\,069 * x^2 - 148\,590 * x + 669\,886$$

where,
Y = Population in the future year
x = { ((forecast year –1971) /10) + 1 }

But Kathmandu is a valley bounded by mountains that prevent indefinite expansion of the city. With limited land, the population in the next 30 years cannot increase by more than double the present day population. The decreasing rate of increase method is closer to the two-degree polynomial equation in forecasting the population of Kathmandu.

Forecasting the price of water or tariff

The price of water is a policy decision, which is fixed according to the cost of supplying water. In fact it should be determined according to the total cost of the system (including the infrastructure development and operation and maintenance cost). But in Nepal it is only taken to meet the cost of operation and maintenance. The water tariff can be used as a decision tool to control the use of water. The general hypothesis is that water use and demand will decrease with an increase in water price.

The water tariff in the residential sector was revised every year with an increase of about NRs0.3/1 000 litres. But in 2001, it increased from 6.7 to 9.7 and again in 2002 to 11.9. Hence it can be said that the average rate of increase in recent years has been 2.6 per year. The constant increase of water price is also a consequence of the severe water shortage in Kathmandu. Until the regular operation of the Melamchi Water Supply Project, the water shortage in Kathmandu seemed insoluble. Thus to prevent wasteful use of water, the price was increased every year. Hence taking an increase of water tariff for 1 m^3 to be 2.6 rupees every year, the water tariff for the future was calculated.

After 2016, the Melamchi water supply construction will be completed and people in Kathmandu will obtain water at different rates that will be fixed later according to the project's cost.

Industrial water demand model

The analysis was done data from Kathmandu Valley with six selected independent variables (Table 3) as follows:

Y = Water use by industries (MLD)
X 1 = Number of manufacturing industries
X 2 = Number of employees
X 3 = IGDP (MRs)
X 4 = Price per unit water (tariff) (NRs)
X 5 = Mean monthly temperature(ºC)
X 6 = Total yearly rainfall (mm)

Table 3. Data of Kathmandu Valley from 1991 to 2001

Year	Water use (MLD)	No. of manufacture industries	No of employees	IGDP (MRs)	Water tariff (NRs) for 0.75"	Temp (ºC)	Rainfall (mm)
1991	5.98	5	424	789.4	2.50	18.32	1 067.9
1992	5.99	7	552	1 282.2	2.50	18.34	1 093.1
1993	5.82	11	1 285	1 461.8	11.00	18.52	1 306.0
1994	5.78	11	1 285	1 786.1	11.00	18.73	1 579.2
1995	6.42	15	1 567	1 955.5	18.00	18.65	1 673.8
1996	6.72	22	2 624	2 246.6	18.00	18.85	1 620.0
1997	7.42	25	2 749	2 481.6	18.90	18.50	1 528.3
1998	7.47	32	3 775	2 698.7	19.85	19.20	1 770.8
1999	7.47	42	6 228	3 033.7	20.80	19.71	1 735.5
2000	7.79	52	7 389	3 355.0	21.85	21.40	1 681.1
2001	7.92	55	7 678	3 556.6	26.40	20.80	1 407.9

Industrial water-use data are not very reliable as they are taken at the fixed 12 percent of domestic water use every year, which in reality may change from time to time. So the analysis here is just done for the demonstration of the industrial water demand model.

From the correlation matrix, the variables X1, X2, and X3 were highly correlated. So, only one should be used in the analysis to avoid the effect of multi co-linearity.

Further analysis was carried out using the independent variables X1, X4, X5, and X6. The procedure to test the global and individual hypothesis is the same as in the domestic model. Among the three models, the log-log model was chosen on the basis of the highest adjusted R^2 and lowest standard error criteria.

$$\ln Y = 1.478831 + 0.202604 * \ln(X1) - 0.066796 * \ln(X4)$$

This implies that the industrial water demand in Kathmandu Valley was dependent on the number of industries in the valley (X1) and the tariff structure (X4). The elasticity of industrial water use by the number of industries is 1.478. This implies that the 1 percent increase in the number of industries (X1) will increase water use by 1.478 percent. The price (X4) elasticity of industrial water use is about –0.067, that is the 10 percent increase in water price will reduce water use in industries by 0.67 percent.

Agricultural water demand model

The model is capable of calculating the reference crop evapotranspiration and the irrigation water demand. The model's special feature is accounting for the effect of climate, partial wetting, and mulching. To verify the model, it was compared with the irrigation water demand from the widely accepted Cropwat model. The Cropwat 4 Windows 4.3 was used, but for paddy, Cropwat DOS was used. The effect of shifting the planting date and mulching on the irrigation water demand is also demonstrated here. The main irrigated crops in Kathmandu Valley are paddy, wheat, and potato. Generally wheat and potato are planted with an overlapping time schedule; paddy is another major crop that is planted over much of the valley.

Winter wheat

The local planting date for winter wheat is November to December and the harvesting date is May to June.

Table 4. Irrigation water required for winter wheat

Planting date	Net irrigation required using Cropwat (mm)	Net irrigation required using PP model (mm)	FWS with 100% efficiency (by Cropwat)(L/s/ha)	FWS with 70% efficiency (by Cropwat)(L/s/ha)
25/10 (25 Oct)	282.01	254.80	0.14	0.19
1/11 (1 Nov)	**262.80**	**247.84**	**0.13**	**0.18**
8/11 (7 Nov)	246.14	223.80	0.12	0.17
14/11(14 Nov)	226.72	219.28	0.11	0.16

Table 4 shows the net irrigation water demand for winter wheat as obtained from the PP Water Demand Model and Cropwat 4 Windows 4.3, for different planting dates. If the planting date is changed from (1 November) to (14 November), the net irrigation required for wheat can decrease the net irrigation water demand from 247.84 to 219.28 mm per unit area.

Potato

In general potato is planted on 1 January and harvested on 16 March. The crop water demand calculated here is for monocropping with potato.

Table 5. Irrigation water required for potato

Planting date	Net irrigation required using Cropwat (mm)	Net irrigation required using PP model (mm)	FWS with 100% efficiency (by Cropwat)(L/s/ha)	FWS with 70% efficiency (by Cropwat)(L/s/ha)
25/12 (25 Dec)	242.23	225.28	0.22	0.31
1/1 (1Jan)	**234.22**	**233.67**	**0.21**	**0.30**
8/1 (8 Jan)	222.88	224.35	0.22	0.28

Table 5 shows the net irrigation water demand and the field water diversion for potato. It is clear from this table that shifting the planting date back by one week can reduce the irrigation water demand for a single crop of potato from 233.67 to 224.35 mm per unit area. Although this amount does not seem to be high, if the potato is cultivated in a large area, then it will have a significant effect in the reduction of irrigation water demand.

Paddy

Paddy rice is the main crop in Kathmandu Valley. In the area where irrigation is available, the term lowland rice is applied. Rain-fed paddy cropping also exists in the area — it is called upland rice. The planting times for upland and lowland crops are different. The lowland rice is generally cultivated from 20 June (transplanting date) to 16 October (harvesting date) and the upland rice from 1 May to 20 September.

The date of nursery and date of harvest depend on the selected date of the transplanting. The ET_{crop}, percolation, land preparation water requirement, water requirement for the rice crop itself, and the effective rainfall for the entire period (land preparation to harvesting) are shown in Table 6.

Table 6. Irrigation water required for paddy cultivation

Transplant date day/month	Date of nursery	Date of harvest	ET_{crop} (mm)	Percolation (mm)	Land Prep^{n} (mm)	Ricereqd (mm)	Eff rain (mm)	Net Irrigation required (mm)
13/6	14/5	11/10	423	179	181	783	582	240.4
20/6	**20/7**	**16/10**	**420**	**178**	**181**	**778**	**546**	**267.9**
27 /6	28 /5	25/10	412	177	176	764	509	289.4
4/7	4/6	1/11	408	178	176	761	474	318.7

From Table 6, it is seen that planting the paddy one week before the scheduled time can reduce the net irrigation water demand by around 27.5 mm per unit area.

In Kathmandu Valley, among the vegetable crops, the most important and commonly grown is tomato. Tomato is grown in two seasons, May and December. Organic mulch (OM) and plastic mulches are used and they are known to change the ET_{crop}. The explanation in FAO 56 was used as a guideline to include the effect of mulching in the crop coefficients and also for the length of the growth stages.

Table 7. Effect of mulching on the net irrigation water required for tomato planted on 10 May

Field condition	Net irrigation required using Cropwat (mm)	Net irrigation required using PP model (mm)	Gross irrigation required (E_a=70%) using PP model (mm)
No mulch	8.72	8.11	11.59
Plastic mulch	—-	5.98	8.55
25% area with OM	—-	7.19	10.28
50% area with OM	—-	6.58	9.40

Table 8. Effect of mulching on irrigation water required for tomato planted on 1 December

Field condition	Net irrigation required using Cropwat (mm)	Net irrigation required using PP model (mm)	Gross irrigation required (E_a=70%) using PP model (mm)
No mulch	282.39	263	376.63
Plastic mulch	—-	228.28	326.12
25% area with OM	—-	236.59	337.98
50% area with OM	—-	251.37	359.11

Tables 7 and 8 show the water demand for tomato (planting at different dates) with different mulching situations. The reduction in water demand is greater with the use of plastic mulch than by using organic mulch. In fact the mulching helps to maintain soil moisture content, ultimately reducing the irrigation water requirement.

In the PP Model, other aspects such as correction of K_c, according to the climate and partial wetting are also included as options that can change the crop water demand considerably. The partial wetting factor depends upon the system of irrigation in the field. The climatic factor adjustment is done only under conditions of stress, where RH_{min} is not 45 percent and the wind speed differs from 2 m/s.

Conclusions

The PP Water Demand Model developed was user-friendly and capable of forecasting the water demand in domestic, industrial, and agricultural sectors. The log-log model was the best among the most widely used functional forms: linear, semi-log, and log-log. The number of connections is the most important variable affecting domestic water demand in Kathmandu Valley. GDP, population, and household number were represented by the number of connections. Water use in the valley will increase by 1.055 percent with a 1 percent increase in number of connections. Water use will decrease by 1.67 percent with a 10 percent increase in the price. So these factors can be used to manage domestic water use in Kathmandu Valley.

The number of industries and the industrial water tariff after minimum allowance are the significant variables affecting water use in the manufacturing industries in Kathmandu Valley. The PP Water Demand model can be used to find the reference crop evapotranspiration and the effective rainfall using the climatic data of an area, which is close to the values given by the widely accepted Cropwat model. The PP Water Demand model is also capable of calculating the irrigation requirement in the area. Shifting the planting dates of the crops can reduce the net water demand for irrigation. Mulching was useful in reducing the net water demand. Plastic mulch can reduce water demand more than organic mulch. These factors can be applied in the management of agricultural water demand.