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A handy tool for forecasting population to aid estimation of water demand

M Shyam Sundar[a], N Natarajan[a,$] & M Vasudevan*[,b,†]

[a]Department of Civil Engineering, Dr. Mahalingam College of Engineering and Technology, Pollachi, Tamil Nadu – 642 003, India

[b]Department of Civil Engineering, Bannari Amman Institute of Technology, Sathyamangalam, Tamil Nadu – 642 003, India

[Email: [†]devamv@gmail.com; [$]itsrajan2002@yahoo.co.in]

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Estimation of demographic variations for societal or infrastructural development policies requires accurate prediction of futuristic population for a given locality. Economic viability as well as sustainability at large, of the engineering designs in urban development activities depend on the variations in projected populations for a given design period. Considering the uncertainties in existing calculation practices to derive an average value, present study offers a computationally efficient program capable of forecasting the future population based on the existing past population data using three well-known population forecasting methods, namely, arithmetic increase method, geometric increase method and incremental increase method. The results proved that when compared to manual calculation, the predictions were accurate, precise and computationally efficient. This user-friendly tool will be highly beneficial for various service providers where population forecasting is inevitable. The robustness of the computer code has been demonstrated using six decades of real time census data of Coimbatore city.

[**Keywords**: Averaging methods, Computation efficiency, Computer model, Population forecasting, Water demand]

Introduction

The extent of exploitation of natural resources and consequent environmental degradation in developing urban cities is directly related to the rate of migration of population. Global water demand is likely to surge in the upcoming decade, making almost 33 countries under water-stressed conditions. The frequency and pattern of unprecedented extremities in global climate and associated societal confrontations could reflect upon the limitations in fare datasets to suggest plausible futuristic solutions[1].

Being the basic element of design data, any mistake in the estimation of population can result in serious problems for planners and decision makers. Even while using digital technology for data acquisition and interpretation, the fear of wrong estimation may result in losing confidence in the ability of such tools itself. For example, some of the previous modelling components within the Geographic Information System (GIS) consistently overestimated the population with access to transit[2,3]. Efficient and precise forecasting of targeted population is essential in successful implementation and operation of any development project, be it water, traffic, public health or commercial infrastructure. The outcomes of a population prediction can either be directly used in the design of public service utilities, or can be used to assess the population dynamics as a result of varying conditions.

Population, being a fundamental concept in engineering statistics, comprises the size and composition of database available for simulation and analysis. Generally uncertainty is overruled in population projections corresponding to the vital rates as a result of complex interactions between individual parameters. The uncertainties in population projection with discrete subpopulations can be effectively overcome by the introduction of probabilistic population prediction (PPP) model that can account for multiple possible evolution path for every input parameter[3,4,5]. Besides improving the prediction methodology, it is also important to develop suitable software tools that support the users in translating and analysing results for the desired purpose.

The required quantity of water (demand) for various individual and institutional needs is to be calculated based on the per capita consumption rate and design population. As an inevitable part of engineering design, design strength (population) and design period (life of the scheme) are the most crucial factors to be initially fixed in order to deploy further delicate details of the project[6]. There exists high level of uncertainty in arriving at an average value of consumption rate since the serving population is highly heterogeneous in all aspects[7]. Therefore, it is most essential to incorporate the significant factors using interactive, dynamic simulation techniques to help in estimation and design of large scale infrastructural system. Fuchs *et al.*[8] presented a stochastic model to forecast the German population and labour supply until 2060. They applied the principal components analysis (PCA) to birth, mortality, emigration and immigration rates, which allows for reduction of dimensionality and also considers the correlation of the rates. Wisniowski *et al.*[9] developed a fully integrated and dynamic Bayesian approach to forecast populations by age and sex. Their approach incorporates Lee-Carter type model for forecasting the age patterns, with measures of uncertainty, of fertility, mortality, immigration and immigration within a cohort projection model. Vovan[10] proposed an improved fuzzy time series forecasting model using variations of data that can interpolate historical data and forecast the future. Gulseven[11] forecasted the population of Kuwait using regional and nationality-gender based population data. They obtained most reliable estimates using both linear and exponential population projections with least forecasting error. Modi[12] forecasted the population of Gujarat for design of Dhrafad regional water supply system using special factors such as immediate migration or influx of population using arithmetic method, geometric method and incremental increase method.

It is evident from the literature review that although many population forecasting studies have been conducted in the past, none of the studies have focused on the development of a computer program for the same. Furthermore, even though there exists many conventional statistical averaging models to derive an average value of the target population, such calculations are being performed iteratively[13,14]. In this study, we propose a simple and efficient computer program capable of forecasting the population to serve for the design of urban utilities such as water supply scheme. We compare different existing techniques of averaging and demonstrate the computational efficiency to derive the most accurate prediction within least computational time.

Materials and Methods

Population forecasting methods

The various methods which are adopted for estimating the future population in this study is described below.

Arithmetic increase method

This method is based on the assumption that the population increases at a constant rate, i.e. rate of change of population with time is constant. The expression used for forecasting the population using the arithmetic increase method is as follows (Garg[14]):

$$P_n = P_O + n.\bar{x} \quad \dots (1)$$

Where, P_n is the forecasted population after n decades from the present, i.e. last known census; P_O is the population at the present, i.e. last known census; n is the number of decades between present and the future; $\bar{x}$ is the average (arithmetic mean) of population increase in the known decades.

Geometric increase method

In this method, the percentage increase or percentage growth rate (r) per decade is assumed to be constant and the increase is compounded over the existing population every decade. This method is also known as uniform increase method. The factor that differentiates this method from the arithmetic increase method is that in this method compounding is done every decade. The constant value of percentage growth rate per decade (r) is analogous to the rate of interest per annum used in compound interest calculation.

$$P_n = P_o(1 + \frac{r}{100})^n \quad \dots (2)$$

Where, P_O is the initial population, i.e. the population at the end of last known census; P_n is the forecasted population after n decades, r is the percentage growth rate in %. This growth rate is obtained by computing the geometric average of the percentage growth rates of the several known decades in the past.

$$r = \sqrt[t]{r_1.r_2.r_3 \dots r_t} \quad \dots (3)$$

Where, t indicates the number of decades for which the percentage growth rate is calculated; r_1 represents the growth rate of the first decade, r_2 represents the growth rate of the second decade and so on for t decades.

Incremental increase method

In this method, the growth rate per decade is not assumed to be constant as in the arithmetic or geometric progression methods, but considered as progressively increasing or decreasing depending on whether the average of the incremental increase in the past data is positive or negative. The population for a future decade is calculated by adding the mean arithmetic increase $\bar{x}$ to the last known population as in the arithmetic increase method and to this is added the average of the incremental increases $\bar{y}$, once for the first decade, twice for the second decade, thrice for the third decade and so on. This method assumes that the growth rate in the first decade is $(\bar{x} + \bar{y})$, the growth rate in the second decade is $(\bar{x} + 2\bar{y})$, the growth rate in the third decade is $(\bar{x} + 3\bar{y})$ and the growth rate in the n^{th} decade is $(\bar{x} + n.\bar{y})$ The population is estimated using the following expression:

$$P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}.\bar{y} \quad \dots (4)$$

Where, P_O is the initial population, i.e. the population at the end of last known census; P_n is the forecasted population after n decades, $\bar{x}$ is the average increase of the populations of known decades and $\bar{y}$ is the average of the incremental increases of the known decades.

Finally, the water demand is calculated by considering 135 lpcd as the domestic water demand of each person residing in a city or town.

Computer algorithm

The following algorithm has been adopted to develop the C code for the forecasting of population of a town or city (Fig. 1). The C code has been provided in the Appendix SI (Supplementary data).

Results and Discussion

A computer program has been developed using C programming language for forecasting the population of a city or town for the purpose of water demand estimation. The user can forecast the population using this code based on three population forecasting methods, namely, arithmetic increase method, geometric increase method and incremental increase method. The code has been validated using a few standard population forecasting examples collected from standard textbooks such as Garg[14].

Example 1

The population of 5 decades from 1930 to 1970 is given below in Table 1. The population in 1980, 1990

Table 1 — Population of 5 decades

Year	1930	1940	1950	1960	1970
Population	25,000	28,000	34,000	42,000	47,000

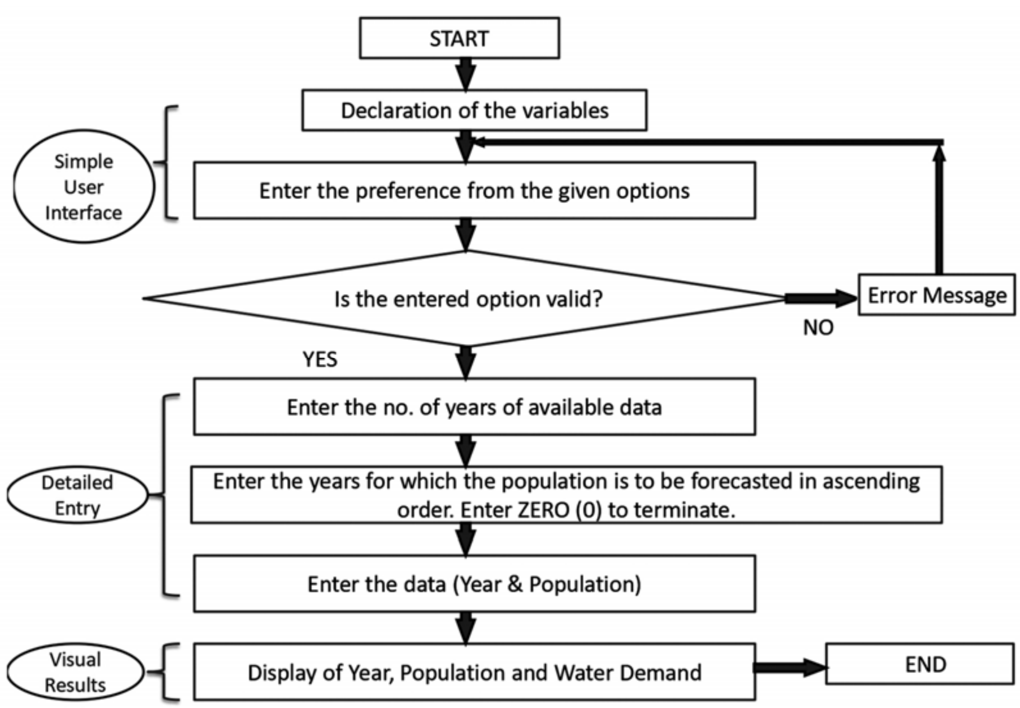

Fig. 1 — Flowchart of the algorithm used for the development of the C code

and 2000 is to be determined using arithmetic increase method, geometric increase method and incremental increase method.

The comparison of the population forecasted based on arithmetic increase method, geometric increase method and incremental increase method from manual calculation and C program is illustrated in Table 2. The execution time for forecasting population based on each method from the C code is provided in Table 3.

It is observed from Table 2 that the results obtained from the code are in corroboration with that obtained from the manual calculation for arithmetic increase method and incremental increase method. The population forecasted using the geometric increase method by the code is different from that obtained manually. The reason for this discrepancy is because C program has considered 23 digits after the decimal point for the calculation of the percentage growth rates unlike the manual calculation where only 2 decimals are considered for the calculation. This is one of the distinct advantages of using a computer program for population forecasting. The accurate calculation of the population by the computer program also enables us to estimate the water demand accurately. It can be observed from the table that there is a huge variation in the water demand estimation, when the population is forecasted using the computer program. Thus, the forecasting of population using the computer program definitely plays a significant role in the water demand estimation of a town or city. Moreover, it can be observed from Table 3 that the C program has taken less than a millisecond to forecast the population for all the three methods on a 64 bit Intel core 1.6 GHz processor with 4 cores and 8 logical processors. Another advantage of using the computer program is that the population can be forecasted for any number of years into the future very easily whereas the manual calculation process is time taking and quite cumbersome. To illustrate this, the population has been forecasted up to the year 2090 based the data provided in Table 1 using the developed code (Table 4).

Table 3 — Execution time for forecasting population from the C code for example 1

Year	Forecasted population		
	Arithmetic increase method	Geometric increase method	Incremental increase method
Execution time (seconds)	0.000585	0.000604	0.000621

Table 4 provides the population forecasted for the years 2010 to 2090 based on the above mentioned three methods using the developed computer program and the time taken for execution is in the order of 1 millisecond, which otherwise would take couple of hours' time when performed manually.

Example 2

The population of 6 decades from 1961 to 2011 is given below in Table 5. The population in 2021, 2031 and 2041 is to be determined using arithmetic increase method, geometric increase method and incremental increase method.

The reason for adopting this example is to validate the robustness of the developed computer program when the population of the city is in terms of several lakhs. The comparison of the population forecasted

Table 4 — Forecasted population from the year 2010-2090

Year	Forecasted population		
	Arithmetic increase method	Geometric increase method	Incremental increase method
2010	69,000	86,228	74,324
2020	74,500	1,00,354	81,895
2030	80,000	1,16,794	90,217
2040	85,500	1,35,928	99,289
2050	91,000	1,58,196	1,09,111
2060	96,500	1,84,112	1,19,682
2070	1,02,000	2,14,274	1,31,004
2080	1,07,500	2,49,377	1,43,076
2090	1,13,000	2,90,231	1,55,897
Execution time (seconds)	0.001104	0.001383	0.001211

Table 2 — Comparison of forecasted population based on arithmetic increase method, geometric increase method and incremental increase method from manual and computational method

Year	Forecasted population					
	Arithmetic increase method		Geometric increase method		Incremental increase method	
	Manual	C program	Manual	C program	Manual	C program
1980	52,500	52,500	54,694	54,700	53,167	53,167
1990	58,000	58,000	63,647	63,661	60,001	60,001
2000	63,500	63,500	74,066	74,090	67,502	67,502

based on arithmetic increase method, geometric increase method and incremental increase method from manual calculation and C program is illustrated in Table 6. The execution time for forecasting population based on each method from the C code is provided in Table 7.

Similar to the observations of example 1, it is observed from Table 6 that the population forecasted based on the arithmetic increase and geometric increase methods are in close agreement with each other unlike the geometric increase method. Even though the discrepancy in the manual and computational forecasting of population using arithmetic and incremental increase method is marginal, the estimated water demand varies by at least by 100 litres. This poses an additional mandate on the water requirement of a locality. From Table 7, it is observed that the execution time has increased from 1 millisecond to 8 milliseconds as the initial population is in terms of lakhs in comparison with the previous example where the population was in terms of only thousands. However, the execution time is still considerably low in spite of high initial population. It is interesting to note that the deviation in the population forecasted by manual and computational method by geometric increase method increases with increase in initial population data. Another interesting observation is that the percentage of deviation also increases with increase in decades of forecasting the population. For example, the deviation in population calculated by manual and computational method is 7598 for the year 2021, 18791 for the year 2031 and 34852 for the year 2041. The percentage deviation is 0.237 %, for 2021, 0.437 % for 2031 and 0.71 % for 2041. Manual calculation of the future population by geometric increase method tends to underestimate the future population of a city or town by several thousands and this misleading information can cause serious discrepancy in the water demand estimation. Thus, the developed code will enable the water demand engineers in accurately forecasting the population and thus avoid shortages in the water demand.

Example 3

A real time data has been used to illustrate the efficiency of the developed computer code. The census data of Coimbatore city for the past six decades has been given in Table 8.

The above data was collected from the Indian government census portal[15]. Using the above 6 decades of population data, the population for 2011 is forecasted both manually and by using computer program. The comparison of the population forecasted based on arithmetic increase method, geometric increase method and incremental increase method from manual calculation and C program is illustrated in Table 9.

From Table 9, it is observed that there is a marginal variation in the population forecasted by arithmetic increase method, geometric increase method and incremental increase method. As mentioned earlier, the estimated water demand varies with variation in

Table 5 — Population of 6 decades

Year	1961	1971	1981	1991	2001	2011
Population	8,58,545	10,15,672	12,01,553	16,91,538	20,77,820	25,85,862

Table 6 — Manually calculated population based on arithmetic increase method, geometric increase method and incremental increase method

Year	Forecasted population					
	Arithmetic increase method		Geometric increase method		Incremental increase method	
	Manual	C program	Manual	C program	Manual	C program
2021	29,31,325	29,31,325	31,93,540	32,01,138	30,19,054	30,19,054
2031	32,76,788	32,76,789	39,44,021	39,62,812	35,39,975	35,39,976
2041	36,22,251	36,22,252	48,70,866	49,05,718	41,48,625	41,48,626

Table 7 — Execution time for forecasting population from the C code for example 2

Year	Forecasted population		
	Arithmetic increase method	Geometric increase method	Incremental increase method
Execution time (seconds)	0.000822	0.000878	0.000874

Table 8 — Population of Coimbatore city based on census

Year	1951	1961	1971	1981	1991	2001
Population	197,755	286,305	356,361	704,511	816,321	930,882

Table 9 — Comparison of forecasted population based on arithmetic increase method, geometric increase method and incremental increase method using manual and computational method for Coimbatore city

Year	Forecasted population					
	Arithmetic increase method		Geometric increase method		Incremental increase method	
	Manual	C program	Manual	C program	Manual	C program
2011	10,77,507	10,77,507	12,09,084	12,09,083	10,84,010	10,84,011
Water demand in litres	14,54,63,445	14,54,63,445	16,32,26,340	16,32,26,205	14,63,41,350	14,63,41,485

the population being forecasted. Thus, the developed computer program is efficient in forecasting the population of a town or city provided the census data is available for the earlier years.

Conclusion

Present study elaborates on the development of a computationally efficient program for systematically forecasting the future population from a given dataset of previous demographic details. The user can select the required scheme of averaging method from three well-known population forecasting methods, namely, arithmetic increase method, geometric increase method and incremental increase method. The predictions are accurate, precise and computationally efficient when compared to manual calculation. This tool will be highly beneficial for water management engineers who do not have any prior knowledge on population forecasting method.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_49(09)1587-1592_SupplData.pdf

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Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

The C-code for population forecasting is developed by MSS and NN. The manuscript is drafted by NN and MV.

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