UPPSC-AE 2025

Uttar Pradesh
Public Service Commission

Combined State Engineering Services Examination

Assistant Engineer

Civil Engineering

Environmental Engineering

Well Illustrated **Theory** *with*
Solved Examples and **Practice Questions**

MADE EASY PUBLICATIONS

Environmental Engineering

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CHAPTER 1

Water Demand

1.1 Introduction

Following Operations are Necessary for a Water Supply Scheme

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1.2 Water Demands

Whenever an engineer is given the duty to design a water supply scheme for a particular section of the community, the first study is to consider the demand and then the second requirement is to find sources to fulfill that demand.

1.2.1 Various Types of Water Demand

I. Domestic Water Demand : This includes the water required in private building for drinking, cooking, bathing, gardening purposes etc. Which may vary according to the living conditions of the consumers.

- The total domestic water consumption usually amounts to 50 to 60% of the total water consumptions.
- The IS code lays down a limit on domestic water consumption between 135 to 225 L/c/d.
- Under ordinary conditions (as per IS code) the minimum domestic water demand for a town with full flushing system should be taken at 200 L/c/d although it can be reduced to 135 L/c/d for economically weaker Sections and LIG colonies (Low Income Group) depends upon prevailing conditions.

Example - 1.1 The average domestic consumption of water in a city, under normal conditions is

(a) 105 *l.p.c.d.* (b) 115 *l.p.c.d.*
(c) 125 *l.p.c.d.* (d) 135 *l.p.c.d.* [UPPSC]

l.p.c.d. = litres per capita per day

Solution: (d)

As per IS:1172-1993, water consumption in city,

Under normal condition = 135 *l*.p.c.d

Full flushing system = 200 *l*.p.c.d

Hence option (d) is correct.

II. Industrial Water Demand : The industrial water demand represents the water demand of industries which are either existing or likely to be started in future, in the city for which water supply is being planned.

- This quantity varies with the number and types of industries present in the city.
- In industrial cities, the per capita water requirement may finally be computed to be as high as 450 L/c/d as compared to the normal industrial requirement of 50 L/c/d.

Water Required by Certain Important Industries

Name of Industry	Unit of Production	Approximate Quantity of Water required per unit of production/raw material in kilo litres
1. Automobiles	Vehicle	40
2. Fertilizers	Tonne	80 - 200
3. Leather	Tonne (or 1000 kg)	40 (or 4)
4. Paper	Tonne	200 - 400
5. Petroleum Refinery	Tonne (Crude)	1 - 2
6. Sugar	Tonne (Crushed cane)	1 - 2
7. Textile	Tonne (goods)	80 - 140
8. Distillery (Alcohol)	kilo litre	122 - 170

III. Institutional and Commercial Water Demand : The water requirements of institutions such as hospitals, hotels, restaurants, schools and colleges, railway station etc. should also be assessed and provided for in addition to domestic and industrial water demands discussed above.

On an average, a per capita demand of 20 lpcd is usually considered to be enough to meet such commercial and institutional water requirements. Although this demand may be as high as 50 lpcd for highly commercialised cities.

Water demand of certain commercial establishments:

(i) Offices 45 *l*pcd

(ii) Schools 45 to 135 *l*pcd

(iii) Hostels 135 *l*pcd

(iv) Hotels 180 *l*pcd

(v) Hospitals 450 *l*pcd

(vi) Cinema halls 15 *l*pcd

IV. Demand for Public Uses : This includes water requirement for parks, gardening, washing of roads etc. On this account a nominal amount not exceeding *5%* of the total consumption may be provided.

V. Fire Demand : The quantity of water required for extinguishing fire is not very large, the total amount of water consumption for a city of 50 lakh population hardly amounts to 1 lpcd. But this water should be easily available and kept always stored in storage reservoirs.

Following requirement must be met for the fire demand:

- Three jet streams are simultaneously thrown from each hydrant; one on the burning property, and one each on adjacent property on either sides of the burning property. The discharge of each stream should be about 1100 litres/minute.

- The minimum water pressure available at fire hydrants should be of the order of 100 to 150 kN/m^2 and should be maintained even after 4 to 5 hours of constant use of fire hydrant.

Estimation of fire demand

- For cities having population exceeding 50000, the water required in kilo litres, may be computed by the formula of $100\sqrt{P}$, where P = Population in thousands.
- Some other formula's (Kuichling's, Freeman, National Board of fire under writers, Buston's formula) are also used.

1. Kuichling's Formula:

$$Q = 3182\sqrt{P}$$

Where, Q = Amount of water required in litres/minute ; P = Population in thousands.

2. Freeman Formula:

$$Q = 1136\left[\frac{P}{5}+10\right]$$

3. National Board of Fire underwriters Formula:

(A) For a central congested high valued city:

(i) When population ≤ 2 lakhs: $Q = 4637\sqrt{P}\left[1-0.01\sqrt{P}\right]$

(ii) When population ≥ 2 lakhs: A provision for 54600 litres per minute may be made with an additional provision of 9100 to 36400 litres/minute for a second fire.

(B) For a residential city:

(i) For small or low buildings: Q = 2200 litres/minute.

(ii) For large or higher buildings: Q = 4500 litres/minute.

4. Buston's Formula:

$$Q = 5663\sqrt{P}$$

P and Q have the same meaning as above.

Example - 1.2 Compute the 'fire demand' for a city of 2 lakh population by any two formulae (including that of the National Board of Fire Underwriters)

Solution:

(i) The rate of fire demand as per National Board of Fire Underwriters Formula for a central congested city whose population is less than or equal to 2 Lakh is given by

$$Q = 4637\sqrt{P}\left[1-0.01\sqrt{P}\right] = 4637\sqrt{200}\left[1-0.01\sqrt{200}\right]$$

$$= 56303.08\ l/\text{min} = \frac{56303.08\times 60\times 24}{10^6}\text{MLD} = \mathbf{81.08\ MLD}$$

(ii) Kuichling's formula, $Q = 3182\sqrt{P} = 3182\sqrt{200}\ l/\text{min}$; R = 45000.27 l/m = **64.8 MLD**

VI. Water Demand for losses & theft

- This includes the water lost in leakage due to bed plumbing, stolen water due to unauthorised water connections, and other losses and wastes.
- This amount may be as high as 15% of the total demand.

1.3 The Per Capita Demand (q)

It is the annual average amount of daily water required by one person and includes the domestic use, industrial and commercial use, public use, wastes, thefts etc.

Per capita demand (q) in litres per head per day

$$q = \frac{\text{Total yearly water requirement of the city in litres } (V)}{365 \times \text{design population}}$$

Factors Affecting Water Demand or Per Capita Demand

Total water demand is affected by following factors.

1. Size of the City

Demand increases with size of city.

Table: Variation in Per Capita Demand (q) with population in India

S. No.	Population	Per Capita Demand in Liters/day/Person
1.	Less than 20000	110
2.	20000 - 50000	110 - 150
3.	50000 - 2 Lakhs	150 - 240
4.	2 Lakhs - 5 Lakhs	240 - 275
5.	5 Lakhs - 10 Lakhs	275 - 335
6.	Over 10 Lakhs	335 - 360

- Above figures can have variation up to 25%
- I.S. code permits maximum value of 335 lpcd for Indian condition.

2. Climatic Conditions

At hotter and dry places, the consumption of water is generally more, because more of bathing, clearing, air-coolers, air-conditioning etc. are involved. Similarly, in extremely cold countries, more water may be consumed, because the people may keep their taps open to avoid freezing of pipes and there may be more leakage from pipe joints since metals contract with cold.

3. Types of Gentry and Habits of People

Rich and upper class communities generally consume more water due to their affluent living standards.

4. Industrial and Commercial Activities

The pressure of industrial and commercial activities at a particular place increase the water consumption by large amount.

5. Quality of Water Supplies

If the quality and taste of the supplied water is good, it will be consumed more, because in that case, people will not use other sources such as private wells, hand pumps, etc. Similarly, certain industries such as boiler feeds, etc., which require standard quality waters will not develop their own supplies and will use public supplies, provided the supplied water is upto their required standards.

6. Pressure in the Distribution Systems

If the pressure in the distribution pipes is high and sufficient to make the water reach at 3rd or even 4th storage, water consumption shall be definitely more.

This water consumption increases because of two reasons:

(i) People living in upper storage will use water freely as compared to the case when water is available scarcely to them.

(ii) The losses and waste due to leakage are considerably increased if their pressure is high. For example, if the pressure increase from 20 m head of water (i.e. 200 kN/m^2) to 30 m head of water (i.e. 300 kN/m^2), the losses may go up by 20 to 30 percent.

7. Development of Sewerage Facilities

The water consumption will be more, if the city is provided with 'flush system' and shall be less if the old 'conservation system' of latrines is adopted.

8. System of Supply

Water may be supplied either continuously for all 24 hours of the day, or may be supplied only for peak period during morning and evening. The second system, i.e. intermittent supplies, may lead to some saving in water consumption due to losses occurring for lesser time and a more vigilant use of water by the consumers.

9. Cost of Water

If the water rates are high, lesser quantity may be consumed by the people. This may not lead to large savings as the affluent and rich people are little affected by such policies.

10. Policy of Metering and Method of Charging

When the supplies are metered, people use only that much of water as much is required by them. Although metered supplies are preferred because of lesser wastage, they generally lead to lesser water consumption by poor and low income group, leading to unhygienic conditions.

1.4 Variations in Demand and their Effects on the Design of a Water Supply Schemes

- The smaller the town, the more variable is the demand
- The shorter the period of draft, the greater is the departure from the mean

(i) **Maximum daily Consumption:** It is generally taken as 180 percent of the average

Therefore, Maximum daily demand = 1.8 (i.e. 180%) × Average daily demand = 1.8q

(ii) **Maximum hourly Consumption :** It is generally taken as 150 percent of its average.

Therefore, Maximum hourly consumption of the maximum day i.e. peak demand

= 1.5 (i.e. 150%) × Average hourly consumption of maximum daily demand

$$= 1.5 \times \left(\frac{\text{Maximum daily demand}}{24}\right) = 1.5 \times \left(\frac{1.8 \times q}{24}\right) = 2.7\left(\frac{q}{24}\right)$$

= 2.7 (Annual average hourly demand)

(iii) **Maximum Weekly Demand :** Maximum weekly Consumption = 1.48 × Average weekly

(iv) **Maximum Monthly Demand :** Maximum monthly consumption = 1.28 × Average monthly

NOTE

Goodrich formula is used to compute maximum or peak demand.

$$\boxed{P = 1.8(t)^{-0.1}} \qquad P = \frac{\text{Maximum demand}}{\text{Average demand}}$$

where, t = time in days, t = 1 for maximum daily, $t = \frac{1}{24}$ for maximum hourly

P = Annual average draft for time in t day

The GOI manual on water supply has recommended the following values of the peak factor, depending upon the population.

Table: Peak Factor

S.No.	Population	Peak Factor
1.	Upto 50000 50001 - 200000 Above 2 Lakh	3.0 2.5 2
2.	For Rural water supply scheme, where supply is effected through stand post for only 6 hours	3

Evidently, the peak factor tends to reduce with increasing population.

REMEMBER : As far as the design of distribution system is concerned, it is hourly variation in computation that matters.

1.5 Coincident Draft

For general community purpose, the total draft is not taken as the sum of maximum hourly demand and fire demand, but is taken as the sum of maximum daily demand and fire demand, or the maximum hourly demand, whichever is more. i.e. maximum of

(i) Maximum daily demand + Fire demand (ii) Maximum hourly demand

Example - 1.3 Coincident draft in relation to water demand, is based on

(a) Peak hourly demand
(b) Maximum daily demand
(c) Maximum daily + fire demand
(d) greater of (a) and (c)

Solution: (c)

Example - 1.4 A water supply scheme has to be designed for a city having a population of 1,00,000. Estimate the important kinds of drafts which may be required to be recorded for an average water consumption of 250 *l*pcd. Also record the required capacities of the major components of the proposed water works system for the city using a river as the source of supply. Assume suitable data.

Solution:

(i) Average daily draft = (per capita average consumption in litre/person/day) × population

= 250 × 1,00,000 litres/day = 250 × 10^5 litres/day = 25 MLD

(ii) Maximum daily draft may be assumed as 180% of annual average daily draft

$$\therefore \quad \text{Maximum daily draft} = \frac{180}{100}[25 \text{ MLd}] = 45 \text{ MLD}$$

(iii) Maximum hourly draft of the maximum day: It may be assumed as 270 percent of annual average hourly draft

$$\therefore \quad \text{Maximum hourly draft of maximum day} = \frac{270}{100}[25 \text{ MLd}] = 67.5 \text{ MLD}$$

(iv) Fire flow may be worked out from

$$Q = 4637\sqrt{P}\left[1-0.01\sqrt{P}\right] = 4637\sqrt{100}\left[1-0.01\sqrt{100}\right] = 41733 \; l\text{itre/min}$$

where P = in thousand population

$$= \frac{41733 \times 60 \times 24}{10^6} \text{million litres/day} = 61 \text{ MLD}$$

$$\text{Coincident draft} = \text{maximum daily draft + fire draft}$$

$$= 45 + 61 = \mathbf{106 \text{ MLD}}$$

which is greater than the maximum hourly draft of 67.5 MLD

1.6 Design Period of Water Supply Unit

- A water supply scheme includes huge and costly structures (such as dams, reservoirs, treatment works, penstock pipes, etc.) which can not be replaced or increased in their capacities, easily and conveniently. For example, the water mains including the distributing pipes are laid underground, and cannot be replaced or added easily, without digging the roads or disrupting the traffic.
- In order to avoid these future complications of expansion, the various components of a water supply scheme are purposely made larger, so as to satisfy the community needs for a reasonable number of years to come.
- This future period or the number of years for which a provision is made in designing the capacities of the various components of the water supply scheme is known as design period.
- The design period should neither be too long nor should it be too short. The design period cannot exceed the useful life of the component structure, and is guided by the following considerations.

Factors Governing the Design Period

- Useful life of component structures and the chances of their becoming old and obsolete. Design period should not exceed there respective values.
- Ease and difficulty that is likely to be faced in expansions, if undertaken at future dates.
- Amount and availability of additional investment likely to be incurred for additional provision.
- The rate of interest on the borrowings and the additional money invested.
- Anticipated rate of population growth, including possible shifts in communities, industries and commercial establishment.

Design Period Values

Water supply projects, under normal circumstances, may be designed for a design period of 30 years excluding completion time of 2 years. The design period recommended by the GOI manual on water supply for designing the various components of a water supply projects are given below table.

Table : Design Period of Various Components of Water Supply Project			
S.No.	**Units**	**Design (Parameters) Discharge**	**Design Period**
1.	Water Treatment Unit	Maximum daily demand	15 Years
2.	Main supply pipes (Water mains)	Maximum daily demand	30 Years
3.	Wells and Tube wells	Maximum daily demand	30-50 Years
4.	Demand Reservoir (Overhead or ground level)	Average annual demand	50 Years
5.	Distribution system	Maximum hourly demand/ Coincident draft	30 Years

NOTE

- The *sources of supply* (such as wells) may be designed for maximum daily consumption or some times for average daily consumption.
- The *pipe mains* (to take water from source to service reservoir) and *filter and other treatment units* are designed for maximum daily draft.
- *Pumps* may be designed for maximum daily draft plus some additional reserve for break down and repair.
- *The distribution system* (to carry water from service reservoir to water taps) should be designed for maximum hourly draft of maximum day' or coincident draft with fire, which ever is more.
- *The service reservoir* is designed to take care of hourly fluctuations, fire demands and emergency reserves.

1.7 Population Forecasting

Population census enumerations and growth in population etc. are not only used in demographic sphere but also by Engineer and people concerned with economic growth, national planning and policy decision making in the sector of agriculture, growth in industries and infrastructure, drinking water supply schemes and other social welfare activities etc.

Population Growth

Growth of population is of great concern to people engaged in policy planning and decision making at the national level. Population growth means the change (increase) of population size between two dates.

However, a population increasing in size is said to have a positive growth rate and the one declining is to have a negative growth rate.

The number of inhabitants of a country depends on (i) The rate of growth in population and (ii) Migrations

The second factor is of importance only in new countries and the old countries are the sources of migrants.

In order to predict the future population, as correctly as possible, it is necessary to know the factors affecting population growth. These are three main factors responsible for changes in population.

They are: (i) Births (ii) Deaths (iii) Migrations.

Growth Rate Curve

When all the unpredictable factors such as war, or natural disasters do not produce sudden changes, the population would probably follow the growth curve as discussed in the theory of demographic transition. This curve is S-shaped as shown in figure and is known as "the logistic curve". According to this curve, rate of growth of population varies from time to time.

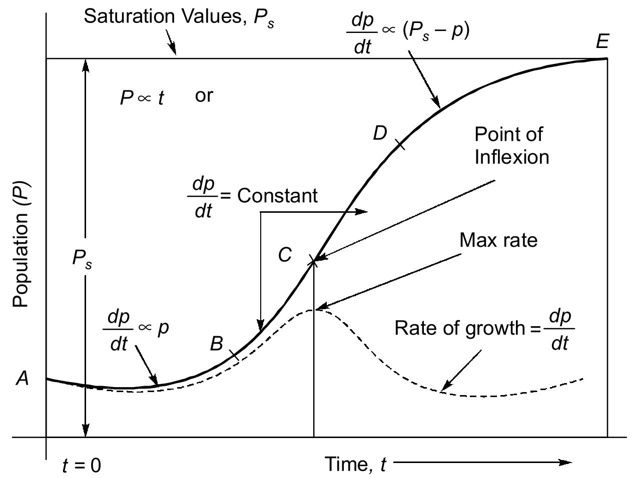
The curve represents early growth AB at an increasing rate $\left(\text{i.e. geometric or log growth, } \frac{dP}{dt} \propto P\right)$ and late growth DE at a decreasing rate $\left[\text{i.e. first order } \frac{dP}{dt} \propto (P_S - P)\right]$ as the saturation value (P_S) is approached. The transitional $\left[\text{i.e. } \frac{dP}{dt} = \text{constant}\right]$. What the future holds for a given population, depends upon, as to where the point lie on the growth curve at a given time.

i.e. in $AB \rightarrow \frac{dP}{dt} \propto P \rightarrow$ increasing growth rate

in $BCD \rightarrow \frac{dP}{dt}$ = Constant $\rightarrow$ High growth rate

in $DE \rightarrow \frac{dP}{dt} \propto (P_s - P) \rightarrow$ Decreasing growth rate

P_s = Saturation value



Growth Rate Curve

1.7.1 Population Forecasting Methods

The various methods which are generally adopted for estimating future populations by engineers are described below. Some of these methods are used when design period is small, and some are used when the design period is large.

The particular method to be adopted for a particular case or for a particular city depends largely upon the factor discussed in these methods and the selection is left to the discretion and intelligence of the designer.

I. Arithmetic Increase Method

In this method, a constant increment of growth in population is observed periodically. This method is of limited application, mostly used in large and established towns where future growth has been controlled.

This method is based upon the assumption that the population increase at a constant rate, i.e. the rate of change of population with time $\left(\text{i.e. } \frac{dP}{dt}\right)$ is constant.

Thus, $\frac{dP}{dt}$ = Constant = k or, $dP = k \cdot dt$

or, $\int_{P_{t_1}}^{P_{t_2}} dP = k\int_{t_1}^{t_2} dt$ $\quad P_{t_2} = P_{t_1} + k(t_2 - k_1)$

Here P_{t_2} and P_{t_1} represent the population at time t_2 and t_1 respectively. This time period is usually reckoned in decades. k is the rate of increase of population per unit time (decade), thus ($t_2 - t_1$) = Number of decades.

The equation can be rewritten as, $\boxed{P_n = P_0 + n \cdot \bar{x}}$

where, P_n = perspective or forecasted population after n decades from the present (i.e. last known census); P_0 = Population at present (i.e. last known census); n = Number of decades between now and future; $\bar{x}$ = Average (arithmetic mean) of population increase in the known decades.

Example - 1.5 The population of 5 decades from 1930 to 1970 are given in table. Find out the population after one, two and three decades beyond the last known decade, by using arithmetic increase method.

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

Solution: The given data in table is extended in next table below, so as to compute the increase in population (x) for each decade (col. 3), the total increase, and average increase per decade ($\bar{x}$), as shown.

The future populations are now computed by using equation as $P_n = P_0 + n \cdot \bar{x}$

$\therefore$ (a) Population after 1 decade beyond 1970

$= P_{1980} = P_1 = P_{1970} + 1 \cdot \bar{x}$

$= 47{,}000 + 1 \times 5500 = 52{,}500$

(b) Population after 2 decades beyond 1970

$= P_{1990} = P_2 = P_{1970} + 2 \cdot \bar{x}$

$= 47{,}000 + 2 \times 5500 = 58{,}000$

(c) Population after 3 decades beyond 1970

$= P_{2000} = P_3 = P_{1970} + 3 \cdot \bar{x}$

$= 47{,}000 + 3 \times 5500 = 63{,}500$

Year (1)	Population (2)	Increase in population (x) (3)
1930	25,000	
1940	28,000	3000
1950	34,000	6000
1960	42,000	8000
1970	47,000	5000
Total		22,000
Average increase per decade ($\bar{x}$)		$\bar{x} = \frac{22000}{4} = 5{,}500$

II. Geometric Increase Method

The method of Geometric progression is applicable to the cities with unlimited scope for future expansion and where a constant rate of growth is anticipated.

The basic difference between arithmetic and geometric progression or increase method of population forecasting is that, in Arithmetic method no compounding is done whereas, in Geometric method compounding is done every decade. This method is, therefore, also known as uniform increase method.

In Geometric increase method, a constant value of percentage growth rate per decade (k) analogues to the rate of compounding interest per annual.

Thus, population after one decade can be given by, $P_1 = P_0 + kP_0 = P_0(1 + k)$

Similarly, population after n decades $\boxed{P_n = P_0(1+k)^n = P_0\left(1+\frac{k\%}{100}\right)^n}$

Where, P_0 refers to initial population i.e. at the end of last known census.

Average percentage growth rate per decade k to be used in the above equation is computed from the percentage growth rate of each decade. The value of k can be calculated as $\boxed{k = \sqrt[m]{k_1 \cdot k_2 \cdot k_3 \cdots\cdots k_m}}$

In geometric increase method the growth rate per decade, $k = \sqrt[t]{\frac{P_2}{P_1}} - 1$

Example - 1.6 Determine the future population of a town by the Geometric increase method for the year 2011, given the following data in Table.

Year	Population in Thousand
1951	93
1961	111
1971	132
1981	161
......	......
2011	?

Solution: The given data is analysed in table below to determine growth rates for each decade.

Table

Year	Population in thousand	Increase in Population in thousand	%age increase in population = growth rate $= \frac{\text{col(3)}}{\text{col(2)}} \times 100$
1951	93		
1961	111	18	19.35
1971	132	21	18.92
1981	161	29	21.97

Constant growth rate, assumed for future

r = geometric mean of past growth rates = $\sqrt[3]{19.35 \times 18.92 \times 21.97}$ = 20.03 % per decade

The population after n decades in now given by equation

$$P_n = P_0\left(1+\frac{r}{100}\right)^n$$

P_{2011} = Population after 3 decades from 1981

$$= P_{1981}\left(1+\frac{20.03}{100}\right)^3 = 1{,}61{,}000(1.2003)^3 = \mathbf{2{,}78{,}417}$$

III. Incremental Increase Method

This method is another case of arithmetic increase with some modifications. Incremental increase method is adopted for cities which are likely to grow progressively of increasing or decreasing rate rather than a constant rate.

According to this method, population after n decades can be given by

$$P_n = P_0 + n\bar{x} + \frac{n(n+1)}{2}\cdot\bar{y}$$

where, $\bar{x}$ and $\bar{y}$ are the average increase of population per decade and average incremental increase respectively. The other notations carry their usual meaning and $\bar{x}$ and $\bar{y}$ are given by

$\bar{x}$ = Average increase of population per decade = $\dfrac{x_1 + x_2 + \ldots\ldots + x_p}{p}$ and

$\bar{y}$ = Average of incremental increase = $\dfrac{y_1 + y_2 + \ldots\ldots + y_p}{p}$

where, $x_1, x_2, x_3 \ldots . x_m$ are increase in each decade, $y_1, y_2, y_3 \ldots .. y_p$ are incremental increase in each decade

NOTE

- The "GOI manual on water and water treatment" recommends the use of geometric mean here; and hence, we can safely use that value.
- Geometric increase method gives high results which is suitable for cities growing with fast rate such as new cities whereas arithmetic increase method gives low results which is suitable for cities growing with slow rate such as old cities.

Example - 1.7 As per the census records for the years 1911 to 1971, the population of a town is given below in the table. Assuming that the scheme of water supply was to commence in 1996, it is required to estimate the population of 10 years hence i.e. in 2006 and also the intermediate population after 15 year since commencement.

Table

Year	1911	1921	1931	1941	1951	1961	1971
Population	40185	44522	60395	75614	98886	124230	158800

Solution: Let us try to get the solutions using all the three methods to which you have been introduced by now. The incremental population and increase in incremental population are summed up in table below:

Table

Year	**Population**	**Increment**	**Incremental increase(y)**
1911	40185	–	–
1921	44522	4337	–
1931	60395	15873	+ 11536
1941	75614	15219	– 654
1951	98886	23272	+ 8053
1961	124230	25344	+ 2072
1971	158800	37570	+ 9226

From the above table, the following parameters can be worked out as

$$\text{Total increase in population} = 118{,}615$$

$$\text{Total of incremental/decrease} = 30{,}233$$

$$\text{Average incremental value decade } (\overline{x}) = \frac{1}{6} \times 118615 = 19769$$

$$\text{Average incremental increase per decade } (\overline{y}) = \frac{1}{5} \times 30233 = 6047$$

1. **By Arithmetic Progression Method**

   Increase in population from 1911 to 1971, i.e. in 6 decades = 158,800 – 40,185 = 118,615

$$K = \frac{1}{6} \times 118{,}615 = 19{,}769$$

Now, using equation $P_n = P_0 + k.n$

$\therefore$ Population in 2006 $= 158{,}800 + 19{,}769 \times 3.5 =$ **227,992**

and population in 2011 $= 158{,}800 + 19{,}769 \times 4 =$ **237,876**

2. **By Geometrical progression method**

   Rate of growth per decade

$$\text{between 1911 and 1921, } k_1 = \frac{4{,}337}{40{,}187} = 0.108$$

$$\text{between 1921 and 1931, } k_2 = \frac{15{,}873}{44{,}522} = 0.356$$

$$\text{between 1931 and 1941, } k_3 = \frac{15{,}219}{60{,}395} = 0.252$$

$$\text{between 1941 to 1951, } k_4 = \frac{23,272}{75,614} = 0.308$$

$$\text{between 1951 to 1961, } k_5 = \frac{25,344}{98,886} = 0.256$$

$$\text{between 1961 to 1971, } k_6 = \frac{34,570}{124,230} = 0.278$$

$$\text{Geometric mean} = \sqrt[6]{0.108 \times 0.356 \times 0.252 \times 0.308 \times 0.256 \times 0.278}$$

or, $k = 0.24426$

Assuming that the future population will grow in geometric progression as in the post during 1911 to 1971.

Now using Equation, $P_n = P_0(1 + k)^n$

$\therefore$ Population in 2006 $= 158{,}800(1 + 0.24426)^{3.5} =$ **341,224**

Population in 2011 $= 158{,}800(1 + 0.24426)^{4} =$ **380,623**

3. **By Incremental increase Method**

Now applying equation
$$P_n = P_0 + n\bar{x} + \frac{n(n+1)}{2} \cdot \bar{y}$$

$$P_{2006} = 158,800 + 3.5 \times 19769 + \frac{3.5 \times 4.5}{2} \times 6047 = \textbf{275,612}$$

$$P_{2011} = 158,800 + 4 \times 19769 + \frac{4 \times 5}{2} \times 6047 = \textbf{298,346}$$

IV. Decreasing Growth Rate Method

If population is reaching towards saturation and growth rate is decreasing, then this method is suitable.

- In this method average decrease in the % increase is calculated and then subtracted from the last % increase computation made for each increased year.
- Calculate the % increase in population for each decade and work out the decrease in percentage increase in each decade and find average percentage decrease say 'r''. The population of upcoming decade from the previous known decade is given as

$$P_1 = P_0 + \left(\frac{r_0 - r'}{100}\right) \times P_0$$

where, P_0 = Population of last known decade
r_0 = Growth rate of last decade
r' = Average decrease in growth rate

Population after next two decades from the last known decade is given as

$$P_2 = P_1 + \left(\frac{r_0 - 2r'}{100}\right) \times P_1$$

NOTE: The validation of decreasing growth rate method is only in those cases, where the rate of growth shows a downward trend.

Example - 1.8 The census record of a particular town is shown in table. Estimate the population for the year 2020 by decreasing growth rate method

Table				
S.No.	**Year**	**Population**	**% increase in Growth rate**	**% Decrease in Growth rate**
1.	1960	55500		
2.	1970	63700	14.77%	
3.	1980	71300	11.93%	+ 2.84%
4.	1990	79500	11.50%	+ 0.43%

Solution:

We know that, $$P_1 = P_0 + \left(\frac{r_0 + r'}{100}\right) \times P_0$$

$$r_0 = \text{growth rate of last known census} = 11.80\%$$

$$r' = \text{Average decrease in growth rate} = \frac{2.84 + 0.43}{2} = 1.635\%$$

$$P_{2020} = P_{2010} + \left(\frac{r_0 - 3r'}{100}\right) \times P_{2010}$$

$$P_1 = P_{2000} = 79500 + \left(\frac{11.5 - 1.635}{100}\right) \times 79500$$

$$P_{2000} = 87343$$

$$P_2 = P_{2010} = 87343 + \left(\frac{11.5 - 2 \times 1.635}{100}\right) \times 87343$$

$$P_{2010} = 94531$$

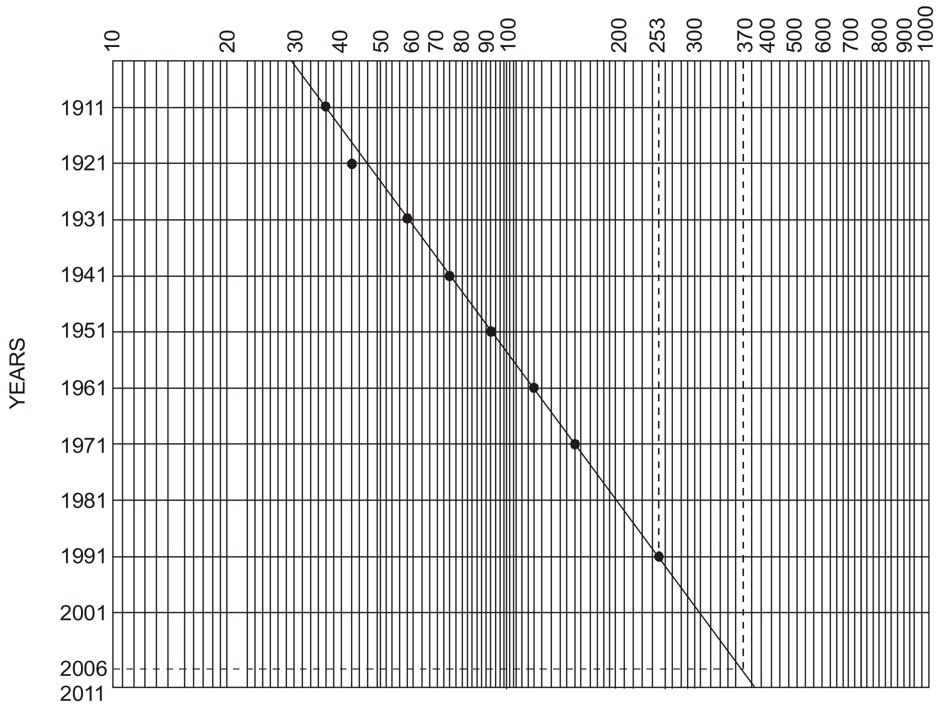
$$P_3 = P_{2020} = 94531 + \left(\frac{11.5 - 3 \times 1.635}{100}\right) \times 94531$$

$$P_{2020} = \mathbf{100{,}765}$$

V. Graphical Projection or Extension Method

In this method from the available data, a graph is plotted between time and population, either on arithmetic paper or on a semi-log paper.

- This time-population curve is then smoothly extended upto the desired year for projecting the future population. The line of best fit may also be by the method of least square.
- If the graph is plotted on semi-log paper with time on arithmetic scale and population on log-scale, the time population curve form a straight line.
- Plotting on simple graph paper give approximate results as the expansion of curve is done by the judgement and skill of designer.



Semi log Plot for Estimation of Future Population

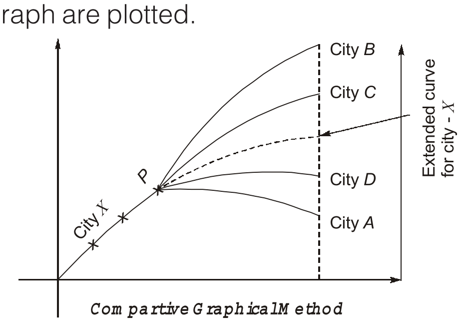
NOTE

- This method is suitable when past record is available for long duration and extension is required for small duration.
- All the above five methods described upto now are based on the assumption that factors and conditions which were responsible for population increase in the past will continue even in future also, with same intensity. That is a vague assumption and may or may not be satisfied. Due to such reasons, the results obtained from these methods may or may not be precise. Inspite all, they are less time consuming and are used by engineers.

VI. Comparative Graphical Method

In this method, the cities of similar condition and characteristics (migration, development activities etc.) are selected, which have grown in similar fashion in the past and their graph are plotted.

Therefore, to estimate the population of a relatively new city, population-time curve of cities having conditions and characteristics similar to the city whose future population is to be estimated, are obtained. Based on a comparison of population time curve for comparable cities, the population-time curve of the city under consideration is extended from the point of last available data upto the desirable future data. The method is explained with the help of an example in the figure above.



Com partive G raphicalM ethod

For example, let the population data of a relatively new city X is given for four decades 1940, 1950, 1960 and 1970; and its present population has reached say 50000 in the last census of the year 1970. It is required its population after 50 years from the last census i.e. at the end of the year 2020. First of all, the population-time curve of the city X is plotted upto the latest census year i.e. 1970. Then from the available population data of cities which had the same population as that of the city under consideration; their respective population-time curve is plotted. Now the population-time curve of city X is extended smoothly as shown in the figure.

VII. The Logistic Curve Method

The logistic method is suitable for regions where the rate of increase or decrease of population with time and also the population growth is likely to reach an ultimate saturation limit because of special local factors.

- The growth of a city which follows a logistic curve, will plot as a straight line on the arithmetic paper with time intervals plotted against population in percentage of saturation.
- P.F. Verhulst has put forward a mathematical solution for the logistic curve. According to him, the entire curve can be represented by an autocatalytic first order equation, given by

Let P_0 = Population at the beginning of census record, P_1 = Population after time t_1 years

P_2 = Population after time t_2 years, P_s = Saturation population

Then population after any time from the start is given as,

$$\boxed{P = \frac{P_s}{1 + m\log_e^{-1}(nt)}} \qquad \text{where, } \frac{P_s - P_0}{P_0} = m \text{ (a constant)}$$

The saturation population (P_s)

$$\boxed{P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}}$$

$$n = \frac{1}{t}\cdot\log_e\left[\frac{P_0(P_s - P_1)}{P_1(P_s - P_0)}\right] = \frac{2.3}{t_1}\log_{10}\left[\frac{P_0(P_s - P_1)}{P_1(P_s - P_0)}\right]$$

Knowing P_0, P_1 and P_2 from census data and using then in these equations, the equation of the logistic curve is thus known.

Example - 1.9 In two periods of each 20 years, a city has grown from 30,000 to 1,70,000 and then to 3,00,000. The saturation population is _____.

(a) 3,32,000 (b) 3,36,000

(c) 3,26,000 (d) 4,32,000

Solution: (1) In this equation, we have

P_0 = 30,000, P_1 = 1,70,000, P_2 = 3,00,000

$t = 0$, t = 20 years, t = 40 years

Using equation,

$$P_s = \text{Saturation Population} = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$= 3,26,000$$

Student's Assignment

Q.1 Which one of the following method gives the best estimate of population growth of a community with limited land area for future expansion?
(a) Arithmetical increase method
(b) Geometrical increase method
(c) Incremental increase method
(d) Logistic method

Q.2 If the average daily water consumption of a city is 24000 cum, the peak hourly demand (of the maximum day of course) will be
(a) 1000 cu m/hr (b) 1500 cu m/hr
(c) 1800 cu m/hr (d) 2700 cu m/hr

Q.3 The suitable method of forecasting population for an old developed large city, is
(a) arithmetic mean method
(b) geometric mean method
(c) comparative graphical method
(d) None of these

Q.4 The suitable method for forecasting population for a young and a rapidly developing city is
(a) arithmetic mean method
(b) geometric mean method
(c) comparative graphical method
(d) None of these

Q.5 A compared to the geometrical increase method of forecasting population, the arithmetical increase method gives
(a) lesser value (b) higher value
(c) equal value
(d) may vary, as it may depend on the population figures

Q.6 The growth of population can be conveniently represented by a curve, which is amenable to mathematical solution. The type of this curve is
(a) semi-log curve
(b) straight line curve
(c) logistic curve
(d) exponential curve

Q.7 If the population of a city is 2 lakh, and average water consumption is 200 lpcd, then the capacity of the pipe mains, should be
(a) 108 MLD (b) 72 MLD
(c) 60 MLD (d) 40 MLD

Q.8 If the population of a central congested high valued city in 2,00,000 and the fire demand is computed to be 45,000 litres per minute, the formula used for the calculation must have been
(a) Freeman's formula
(b) National Board of Underwriters formula
(c) Kuichling's formula
(d) Buston's formula

Q.9 If the average water consumption of a city is 300 lpcd, and its population is 4,00,000 the maximum hourly draft of the maximum day will be
(a) 120 Mld (b) 216 Mld
(c) 324 Mld (d) None of these

Q.10 The per capita demand of water for an average Indian as per IS is
(a) 250 lpcd (b) 300 lpcd
(c) 270 lpcd (d) 200 lpcd

Q.11 The distribution mains are designed for
(a) maximum daily demand
(b) maximum hourly demand
(c) average daily demand
(d) maximum hourly demand or maximum daily demand

Q.12 Water losses in water supply system are assumed as
(a) 5% (b) 7.5%
(c) 15% (d) 25%

Q.13 Which of the following factors has maximum effect on figure of per capita demand of water supply of a given town?
(a) Method of charging of the consumption
(b) Quality of water
(c) System of supply intermittent or continuous
(d) Industrial demand

Q.14 Total domestic consumption in a city water supply, is assumed
(a) 20% (b) 30%
(c) 40% (d) 60%

Q.15 The distribution system in water supplies is designed on the basis of :
(a) average daily demand
(b) peak hourly demand
(c) coincident of draft
(d) greater of (b) and (c)

Q.16 The total water requirement of a city is generally assessed on the basis of
(a) maximum hourly demand
(b) maximum daily demand + fire demand
(c) average daily demand + fire demand
(d) greater of (a) and (b)

Q.17 Water supply includes
(a) collection, transportation and treatment of water
(b) distribution of water to consumers
(c) provision of hydrants for fire fighting
(d) All the above

Q.18 Pollution potential of domestic sewage generated in a town and its industrial sewage can be compared with reference to
(a) their BOD value (b) population equivalent
(c) their volume (d) the relative density

Q.19 As per Indian Standard Specifications, the peak discharge for domestic purposes per capita per minute, is taken
(a) 1.80 litres for 5 to 10 users
(b) 1.20 litres for 15 users
(c) 1.35 litres for 20 users
(d) All options are correct

Q.20 Which of the following represents the value of hourly variation factor?
(a) 1.2 (b) 1.5
(c) 1.7 (d) 2.5

Q.21 When was water (prevention and control of pollution) act enacted by the India Parliament?
(a) 1970 (b) 1974
(c) 1980 (d) 1965

Q.22 On which of the following factors does the populating growth in a town normally depends?
1. Birth and death rates
2. Migration
3. Probabilistic growth
4. Logistic growth
(a) 1 and 4 only (b) 1 and 2 only
(c) 1, 2 and 3 only (d) 2 and 3 only

Q.23 The population of a town as per census records were 2,00,000; 2,10,000 and 2,30,000 for the year 1981, 1991 and 2001 respectively. Find the population of the town in the year 2011 using arithmetic mean method.
(a) 250000 (b) 255000
(c) 240000 (d) 245000

Q.24 The population of a town as per census records were 200000, 210000 and 230000 for the years 1981, 1991 and 2001 respectively. The population of the town as per geometric mean method in the year 2011 is
(a) 244872 (b) 245872
(c) 246820 (d) None of the above

Q.25 P_0, P_1, P_2 be the population of a city at times to t_0, t_1 and t_2 and $t_2 = 2t_1$, the saturation value of the population P_s of the city is

(a) $P_s = \dfrac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2}$

(b) $P_s = \dfrac{2P_0P_1P_2 - P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$

(c) $P_s = \dfrac{P_0P_1P_2 - P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$

(d) $P_s = \dfrac{P_0P_1P_2 + P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$

Q.26 If P_0 is population on the start of a logistic curve, P_s is saturation population and K is a constant of equality, population of the city is given by

(a) $\log\left(\dfrac{P_s-P}{P}\right)+\log\left(\dfrac{P_s-P_0}{P_0}\right)+KP_st=0$

(b) $\log\left(\dfrac{P_s-P}{P}\right)-\log\left(\dfrac{P_s-P_0}{P_0}\right)+KP_st=0$

(c) $\log\left(\dfrac{P_s-P}{P}\right)\times\log\left(\dfrac{P_s-P_0}{P_0}\right)+KP_st=0$

(d) $\log\left(\dfrac{P_s-P}{P}\right)\div\log\left(\dfrac{P_s-P_0}{P_0}\right)+KP_st=0$

Q.27 The population figure in a growing town are as follows:

Year	Population
1970	40,000
1980	46,000
1990	53,000
2000	58,000

Predicted population in 2010 by Arithmetic Regression method is
(a) 62,000
(b) 63,000
(c) 64,000
(d) 65,000

Q.28 The present population of a community is 28000 with an average water consumption of 150 *l*pcd. The existing water treatment plant has a design capacity of 6000m^3/d. It is expected that the population will increase to 48000 during the next 20 years. The number of years from now when the plant will reach its design capacity, assuming an arithmetic rate of population growth, will be
(a) 5.5 years
(b) 8.6 years
(c) 12 years
(d) 16.5 years

Q.29 Which of the following factors has the maximum effect on figure of per capita demand of water supply of a given town?
(a) Method of charging of the consumption
(b) Quality of water
(c) System of supply intermittent or continuous
(d) Industrial demand

Q.30 Which one of the following methods given the best estimate of population growth of a community with limited land area for future expansion?
(a) Arithmetical increase method
(b) Geometrical increase method
(c) Incremental increase method
(d) Logistic method

ANSWER KEY — STUDENT'S ASSIGNMENT

1. (d)	**2.** (d)	**3.** (a)	**4.** (b)	**5.** (a)
6. (c)	**7.** (b)	**8.** (c)	**9.** (c)	**10.** (d)
11. (b)	**12.** (c)	**13.** (d)	**14.** (d)	**15.** (d)
16. (d)	**17.** (d)	**18.** (b)	**19.** (d)	**20.** (b)
21. (b)	**22.** (b)	**23.** (d)	**24.** (b)	**25.** (a)
26. (b)	**27.** (c)	**28.** (c)	**29.** (d)	**30.** (d)

HINTS & SOLUTIONS — STUDENT'S ASSIGNMENT

1. (d)

Since the area is limited and there is no time period specified for population estimation, such as young or old city. Therefore logistic curve method will be best.

2. (d)

Peak hourly demand $= \dfrac{2.7 \times 24000}{24} = 2700$ cum/hr

7. (b)

Average water consumption per day

$$= 200 \times 2 \times 10^5 = 40 \times 10^6$$

$\therefore$ Max. water consumption per day

$$= 1.8 \times 40 \times 10^6 = 72 \text{ Mld}$$

8. (c)

Kuichling's formula:

$$Q = 3182\sqrt{P}$$

$Q \rightarrow$ Amount of water required in litres/minute

$P \rightarrow$ Population in thousand

Given: $P = 200000 = 200$ thousand

$$Q = 3182\sqrt{200}$$

$$Q = 45000 \text{ litres/minute}$$

10. (d)

The IS code lays down a limit on domestic water consumption between 135 to 225 *l*/c/d.
Under ordinary conditions, minimum domestic water demand is 200 *l*/c/d. Although it can be reduced upto 135 *l*/c/d for economically weaker section.