CIVIL ENGINEERING

Environmental Engg : Vol-I

(Water Supply Engineering)

Comprehensive Theory
with Solved Examples *and* Practice Questions

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CHAPTER

1

Water Demand

1.1 INTRODUCTION

Environmental engineering is the branch of engineering that deals with the applications of scientific and engineering principles to the improvement and maintenance of the environment with the goals of protecting human health, preserving the valuable ecosystem found in nature and enhancing the quality of human life. In this course of environmental engineering, we will mainly focuses on the water demand, its quality parameter, treatment process and in the similar way for waste water we will discuss about its quality, treatment and disposal.

Whenever an engineer is given the design the duty to design a water supply scheme for a particular section of the community, it becomes imperative upon him, to first of all, evaluate the amount of water available and the amount of water demanded by the public. In this chapter, we are going to study about later part of his duty i.e. to evaluate water demand. We will learn about various types of demands that needs to be fulfilled. We will also study about variations, in demands. In the later part of chapter, we will learn some of the methods that are used for purpose of population forecasting.

1.2 WATER DEMAND

Estimation of demand for water is the key parameter in planning a water supply scheme. The agriculture sector consumes more than 80 percent of total water potential created in our country. The remaining portion is utilized to meet domestic, industrial and other demands.

The improvement in life-style and associated industrial development of a nation pushes up the per capita demand for water.

1.3 VARIOUS TYPES OF WATER DEMAND

The prediction of precise quantity of water demanded by the public is very difficult, because there are so many variable factors affecting water consumption. There are some certain thumb rules and empirical formulas, which are used to assess this quantity, which may give fairly accurate results.

There are different types of water demands, which are as follows:

1.3.1 Domestic Water Demand

Domestic water demand 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 is near about 50 to 60% of the total water consumptions. The IS code caps a limit on domestic water consumption between 135 to 225 *l*pcd. As per IS code, the minimum domestic water demand under ordinary conditions for a town with full flushing system should be taken as 200 *l*pcd although it can be minimized upto 135 *l*pcd for economically weaker section and LIG colonies (low income group) depending upon prevailing conditions. The breakup 200 lpcd and 135 lpcd is given in table 1 and table 2.

Minimum domestic water consumption (Annual average) for Indian towns and cities with full flushing systems as per	
Use	Consumption in liters per head per day (*lh/d*)
Drinking	5
Cooking	5
Bathing	25
Washing of clothes	15
Washing of utensils	15
Washing and cleaning of houses and residence	
Lawn watering and gardening	15
Flushing of water closets, etc.	45
Total	200

Minimum domestic water consumption (Annual average) for weaker sections and LIG colonies in small Indian Towns and cities	
Use	Consumption in (*lh/d*)
Drinking	5
Cooking	5
Bathing	55
Washing of clothes	20
Washing of utensils	10
Washing and cleaning of houses and residences	10
Flushing of water closets, etc.	30
Total	200

NOTE

In developed and an efficient country like USA, this figure usually goes as high as 340 *l*pcd. This is because more water is consumed in rich living standards, in air-conditioning, air-cooling, bathing in bath tub, dish washing of utensils, car washing, home laundries, garbage grinders, etc.

1.3.2 Industrial Water Demand

The industrial water demand expresses the water required for industries which are either existing or are likely to be started in future, in the city for which water supply is being planned. This water requirement will thus vary with the types and number of industries present in the city. In industrial cities, the per capita requirement may finally be computed to be as high as 450 *l*pcd as compared to the normal industrial requirement of 50 *l*pcd. The approximate quantities of water required by different industries per unit of their production are shown in table below:

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

1.3.3 Institutional and Commercial Water demand

Water requirements of institutions such as hospitals, hotels, restaurants, schools and colleges, railway stations, offices, factories etc. should also be assessed and provided for, in addition to domestic and industrial water demands. However, the requirement will vary with nature of city and with the number and type of commercial establishments and institutions present in it.

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

The individual requirements would be as follows:

1. Schools/Colleges : 45 to 135 *l*pcd
2. Offices : 45 *l*pcd
3. Restaurants : 70 *l*pcd
4. Cinema and theatres : 15 *l*pcd
5. Hotels : 180 *l*pcd
6. Hospitals : 340 *l*pcd (when beds is less than 100), and 450 *l*pcd (when beds exceed 100)
7. Airports : 70 *l*pcd
8. Railway : 70 *l*pcd (for junction with bathing facility)

The individual approximate water requirements of such institutions/commercial units are shown in table below:

Water Requirements for Commercial Buildings (as per IS code)		
S.No.	Type of building	Average consumption in (*l*pcd)
1.	Factories	
	(a) Where bathrooms are required to be provided	45
	(b) Where no bathrooms are required	30
2.	Hospitals (Including laundry, per bed)	
	(a) Number of beds less than 100	340
	(b) Number of beds exceeding 100	450
3.	Nurses homes and medical quarters	150
4.	Hostels	135
5.	Hotels (per bed)	180
6.	Restaurants (per seat)	70
7.	Offices	45
8.	Cinemas, auditoriums and theatres (per seat)	15
9.	Schools	
	(a) Day scholars	45
	(b) Residentials	135

1.3.4 Demand for Public Uses

This includes water requirement for parks, gardening, washing of roads etc. A nominal amount, not exceeding 5% of the total consumption may be provided to meet this demand. A figure of 10 *l*pcd is usually added on this account while computing total water requirements.

1.3.5 Fire Demand

In densely populated and industrial areas, fire generally breakout and may lead to serious damages, if not controlled effectively. Big cities, therefore, generally maintain full fire fighting squads. Fire fighting personnel require sufficient quantity of water, so as to throw it over the fire at high speed. A provision should, therefore be made in modern public water scheme for fighting fire breakouts.

The quantity of water required for extinguishing fires should be easily available and kept in storage reservoirs. When a fire breaks out, fire hydrants are fitted in water mains at about 100 to 150 meters apart and fire fighting pumps are immediately connected into them by fire brigade personnel. These pumps then throw water at very high pressure on fire. 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.

Now, to estimate the quantity of fire demand, consider a city having population of 50 lakhs. Suppose, in this city, 6 fires break out in a day and each fire stands for 3 hours. Generally, 3 jet streams are simultaneously thrown i.e. one burning property and one each one adjacent property on either side of burning property. The discharge of water stream should be about 1100 lit/minutes. Now, total amount of water required for fire in this city shall be given as

$$= 6 \times (3 \times 1100) \times (3 \times 60) = 3564000 \text{ litre/day}$$

So, the amount of water required per person

$$= \frac{35,64,000}{50 \text{lakhs}}$$

$$< 1 \text{ litre per capita day}$$

Thus, from the above example, it can be stated that total amount of water required for fire demand is less than 1 lpcd.

Calculation of Fire Demand

(i) For cities having population exceeding 50,000, the water required in kilo litre may be computed using the relation.
Kilo litre of water required = $100\sqrt{P}$, where P = Population in thousand

(ii) **Kuchling's Formula :** It states that

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

(iii) **Freeman's Formula :** It states that $Q = 1136\left[\frac{P}{5} + 10\right]$

(iv) **National Board of Fire Underwriters Formula :**

- **For Central congested high valued city**
  (i) When population is less than or equal to 2 Lakhs, then $Q = 4637\sqrt{P}\left[1 - 0.01\sqrt{P}\right]$
  (ii) When population is more than 2 Lakhs, a provision for 54,000 litres/minute may be made with an extra additional provision of 9,100 to 36,400 litres/minute for a second fire.
- **For a residential city**
  The required draft for fire-fighting may be as follows:
  (i) Small or low building = 2200 litres/minute
  (ii) Larger or Higher building = 4,500 litres/minute
  (iii) High values residency, apartments, tenements = 7650 to 13500 litres/minute
  (iv) Three storeyed buildings in densely built up section = upto 27000 litres/minute
- **Buston's Formula :** It states that, $Q = 5663\sqrt{P}$

In all the above formulas, Q is amount of water required in litre per minute and P is population in thousands.

> **NOTE:** All the above formulas suffer from the drawback that they are not related to the type of district served and give equal results for industrial and non-industrial areas.

Example 1.1 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) Kuchling's formula, $Q = 3182\sqrt{P} = 3182\sqrt{200}\, l/\text{min}$ $\dfrac{45000.27 \times 24 \times 60}{10^6} = 64.8\,\text{MLD}$

1.3.6 Water Required to Compensate Losses in Thefts and Wastes

This includes the water lost in leakage due to bad plumbing or damaged meters, stolen water due to unauthorised water connections, and other losses and wastes. These losses should be taken into account while estimating the total requirements.

Even in the best managed water works, this amount may, be as high as 15% of the total consumption, which is nearly 55 *l*pcd.

1.4 THE PER CAPITA DEMAND (q)

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

It may be, therefore expressed as Per Capita Demand(q) in litres per day per person ...(i)

$$= \frac{\text{Total yearly water requirement of the city in litres (i.e V)}}{365 \times \text{Design Population}}$$

Thus, total yearly requirement of city can be estimated using eq. (i) provided that per capita demand is already known or assumed.

For an average Indian city, as per recommendation of I.S. code, the per capita demand(q) may be taken as given in table.

Break up for per capita demand (q) for an average Indian City	
Use	**Demand in *l*pcd**
(i) Domestic Use	200 (59.7% or 60%)
(ii) Industrial Use	50
(iii) Commercial Use	20
(iv) Civic or Public Use	10
(v) Waste and thefts, etc.	55
(vi) Fire demand	< 1
	Total = 335 = Per Capita Demand (q)

1.4.1 Factors Affecting Per Capita Demand

The annual average demand for water (i.e. per capita demand) considerably varies for different towns or cities. This figure generally ranges between 100 to 360 lpcd for Indian conditions. The variations in total water consumption of different cities or towns depend upon various factors, which must be thoroughly studied and analysed before fixing the per capita demand for design purpose. These factors are discussed below:

(a) Size of the City

Per capita demand (q) of water is generally large in big cities as compared to those of small cities. The reason for this can be the fact that in big cities, huge quantities of water are required for maintaining clean and healthy environments. For example, big cities are generally sewered and as such require large quantities of water.

On an average, per capita demand for Indian towns may vary with population as given, in table.

Variation in Per Capita Demand (q) with population in India		
S. No.	**Population**	**Per Capita Demand in lpcd**
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

(b) Climatic Conditions

At hotter and dry places, the consumption of water is generally more, because more of bathing, cleaning, 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 metal contracts with cold.

(c) Types of Gentry and Habits of People

Rich and upper class communities generally consume more water due to their affluent living standards. Communities of middle class consumes average amount of water. Poor slum dwellers consume very low amount of water. The amount of water required is therefore directly dependent upon economic status of consumers.

(d) Industrial and Commercial Activities

The pressure of industrial and commercial activities at a particular place increase the water consumption by large amount. Many industries require huge amounts of water and as such increases per capita demand.

(e) 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.

(f) 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 storeys, water consumption shall be definitely more.

This water consumption increases because of two reasons:

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

(ii) The losses and wastes 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.

(g) 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.

OBJECTIVE BRAIN TEASERS

Q.1 Consider the following statements:
The daily per capita consumption of water apparently increase with
1. higher standard of living of people
2. availability of sewerage in the city
3. metered water supply
4. wholesome and potable public supply of water

Which of the above statements are correct?
(a) 1, 2 and 3 (b) 2, 3 and 4
(c) 1, 3 and 4 (d) 1, 2 and 4

Q.2 As compared to geometrical increase method of forecasting population, arithmetical increase method gives
(a) Lesser value (b) Higher value
(c) Same value (d) Accurate value

Q.3 The total domestic consumption in a city water supply, is assumed
(a) 20% (b) 30%
(c) 40% (d) 60%

Q.4 The fire demand for ascertaining the empirical formula

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

(a) Kuchling's formula
(b) Buston's formula
(c) Freeman's formula
(d) Underwriter's formula

Q.5 According to Goodrich, the ratio of peak demand rate to mean demand is
(a) $\frac{\text{Maximum daily demand}}{\text{Average daily demand}} = 180\%$
(b) $\frac{\text{Maximum weekly demand}}{\text{Average weekly demand}} = 148\%$
(c) $\frac{\text{Maximum monthly demand}}{\text{Average monthly demand}} = 128\%$
(d) All of the above

Q.6 In the equation $P = \frac{P_s}{1+m\log_e^{-1}(nt)}$ of a logistic curve of population growth, the constant m is
(a) $P_s \times P$ (b) P_s/P
(c) $\frac{P_s - P_0}{P_0}$ (d) KP_s

Q.7 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) $P_s = \frac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2}$
(b) $P_s = \frac{2P_0P_1P_2 - P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$
(c) $P_s = \frac{P_0P_1P_2 - P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$
(d) $P_s = \frac{P_0P_1P_2 + P_2^2(P_0+P_1)}{P_0P_2 - P_1^2}$

Q.8 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) $\log\left(\frac{P_s - P}{P}\right) + \log\left(\frac{P_s - P_0}{P_0}\right) + KP_st = 0$
(b) $\log\left(\frac{P_s - P}{P}\right) - \log\left(\frac{P_s - P_0}{P_0}\right) + KP_st = 0$
(c) $\log\left(\frac{P_s - P}{P}\right) \times \log\left(\frac{P_s - P_0}{P_0}\right) + KP_st = 0$
(d) $\log\left(\frac{P_s - P}{P}\right) \div \log\left(\frac{P_s - P_0}{P_0}\right) + KP_st = 0$

Q.9 Consider the following statements:
1. Maximum hourly consumptions of the maximum day is called peak demand.
2. The hourly variation factor is generally taken as 1.5.
3. Peak factor tends to reduce with the increasing population

Which of these statements is/are correct?
(a) Only 2 (b) Both 1 and 2
(c) Both 1 and 3 (d) 1, 2 and 3

Q.10 The population of a town in three consecutive year are 5000, 7000 and 8400 respectively. The population of the town in the fourth consecutive year according to geometrical increase method is

(a) 9500 (b) 9800
(c) 10778 (d) 10920

Q.11 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.12 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.13 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.14 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

Direction: Each of the next consists of two statements, one labelled as the **'Assertion (A)'** and the other as **'Reason (R)'**. You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:

(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.15 **Assertion (A):** In estimating population for assessing water supply demand, the geometric progression (GP) method gives correct estimate for a developing city.

Reason (R): In the GP method, a constant rate of increase in population is assumed.

Q.16 **Assertion (A):** The future population is predicted on the basis of knowledge of the city and its environment

Reason (R) : The future population depends on the trade and expansion of the city, discovery of mineral deposits, power generation etc.

Q.17 Which one of the following Acts/Rules has provision for "No right to appeal"?

(a) Environment (Protection) Act, 1986
(b) The hazardous waste (management and handling) rules, 1989
(c) Manufacture, storage and import of Hazardous chemical rules, 1989
(d) Environment (Protection) Rules, 1992

Q.18 When was the water (prevention and control of pollution) Act enacted by the Indian Parliament?

(a) 1970
(b) 1974
(c) 1980
(d) 1985

Q.19 Per Capita water demand is defined as the litre of water consumed daily by each person. Naturally it has to be some average value, over a period of time. Over how much period, the averaging is done here:
(a) 24 hours (b) 1 year
(c) 10 years (d) 35 year

Q.20 The water treatment units may be designed, including 100% reserves, for water demand equal to
(a) Average daily (b) Twice of (a)
(c) Maximum daily (d) Twice of (c)

Q.21 Which of the following statements about Design period are true?
1. It is concerned with economy of investments
2. It takes into account of aspects like life and durability and ease or difficulty of use of installations.
3. It considers the frequency of occurrence of extremes of river flow
4. It is concerned with estimating future requirements.

Codes:
(a) 1, 2, 3 and 4 (b) 2 and 3
(c) 1, 2 and 4 (d) 1, 3 and 4

Q.22 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.23 Which among the following brings about the Hazardous waste management and handling rules in India?
(a) Central Pollution Control Board
(b) Ministry of Environment and Forests
(c) Ministry of Urban Development
(d) Ministry of Rural Development

Q.24 Water losses in water supply system, are assumed as
(a) 5% (b) 7.5%
(c) 15% (d) 25%

Q.25 The pipe mains carrying water from the source to the reservoir are designed for the
(a) maximum daily draft
(b) average daily draft
(c) maximum hourly draft of the maximum day
(d) maximum weekly draft

Q.26 The distribution system in water supplies is designed on the basis of
(a) average daily demand
(b) peak hourly demand
(c) coincident draft
(d) greater of (b) and (c)

Q.27 The multiplying factor, as applied to obtain the peak hourly demand, in relation to the average daily demand (per hour of course), is
(a) 1.5 (b) 1.8
(c) 2.0 (d) 2.7

Direction: Each of the next consists of two statements, one labelled as the **'Assertion (A)'** and the other as **'Reason (R)'.** You are to examine these two statements carefully and select the answers to these items using the codes given below:

Codes:
(a) Both A and R are individually true and R is the correct explanation of A
(b) Both A and R are individually true but R is not the correct explanation of A
(c) A is true but R is false
(d) A is false but R is true

Q.28 **Assertion (A):** The leakage losses are less when the water supply is intermittent.
Reason (R): Pressure is less in intermittent water supply.

ANSWER KEY

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

HINTS & EXPLANATIONS

3. (d)

Total domestic consumption in a city water supply is assumed to 55 to 60%

4. (c)

The freeman's formula $Q = 1136\left[\frac{P}{5} + 10\right]$

6. (c)

The constant m in logistic curve $m = \frac{P_s - P_0}{P_0}$

11. (c)

Year	Population	Decadal increase
1970	40,000	6000
1980	46,000	7000
1990	53,000	5000
	2000	58,000

$$\therefore \text{Design growth rate} = \frac{6000 + 7000 + 5000}{3}$$
$$= 6000 \text{ per decade}$$

In 2010 population will be

$P = 58000 + 6000 = 64000$

Population	Increase	% Increase
5000	2000	40
7000	1400	20
8400		

So, Growth rate per decade,

$$k = \sqrt[2]{0.4 \times 0.2} = 0.283$$

So, population at end of next decade

$$= 8400(1 + 0.283) = 10777.2$$
$$\simeq 10778$$

12. (c)

Population after n years

$$P_n = P_0 + n\bar{x}$$

$\bar{x}$ is arithmetic design growth rate per decade

Given $P_0 = 28000$

For $n = 20$, $P_{20} = 48000$

$$\therefore \bar{x} = \frac{48000 - 28000}{20} = 10000 \text{ per decade}$$

The population when design capacity will be reached,

$$P_n = \frac{6000 \times 1000}{150} = 40000$$

$\therefore$ Number of years to reach the plant at design capacity,

$$\eta = \frac{P_n - P_0}{\bar{x}} = \frac{40000 - 28000}{10000} = 1.2 \text{ decade}$$
$$= 12 \text{ years}$$

20. (d)

Water treatment units are generally designed for maximum daily demand. However, sometimes, to consider repair and break down cost, maximum daily demand is taken as twice of average daily demand.

CONVENTIONAL BRAIN TEASERS

Q.1 (i) The population of 5 decades from 1930 to 1970 are given in table below. Find out the population after one, two and three decades beyond the last known decade, by using arithmetic increase method.

Year	1930	1940	1950	1960	1970
Population	25000	28000	34000	42000	47000

(ii) Compute the population of the year 2000 and 2006 for a city whose population in the year 1930 was 25000, and in the year 1970 was 47000. Make use of geometric increase method.

Solution :

(i) The given data in question table is extended in 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

Year	Population	Increase in population (x)
(1)	(2)	(3)
1930	25000	
1940	28000	3000
1950	34000	6000
1960	42000	8000
1970	47000	5000
Total		22000
Average increase per decade $(\bar{x})$		$\bar{x} = \frac{22000}{4} = 5500$

The future populations are now computed by using equation as,

$$P_n = P_0 + n \cdot \bar{x}$$

∴ (a) Population after 1 decade beyond 1970

$$P_{1980} = P_1 = P_{1970} + 1 \cdot \bar{x}$$
$$= 47000 + 1 \times 5500$$
$$= 52500$$

(b) Population after 2 decades beyond 1970

$$P_{1990} = P_2 = P_{1970} + 2 \cdot \bar{x}$$
$$= 47000 + 2 \times 5500$$
$$= 58000$$

(c) Population after 3 decades beyond 1970

$$P_{2000} = P_3 = P_{1970} + 3 \cdot \bar{x}$$
$$= 47000 + 3 \times 5500$$
$$= 63500$$

(ii)

In this question, the intermediate census data between 1930 to 1970 is not given, and hence geometric mean method of all known decades is not possible. The growth rate per decade (r) can, however, be computed by using as

$$r = \sqrt[t]{\frac{P_2}{P_1}} - 1 = \sqrt[4]{\frac{47000}{25000}} - 1$$
$$= 0.17095$$
$$= 17.095\% \text{ per decade}$$

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

Hence, $P_{2000} = P_3$ (after 3 decades from 1970 onward)

$$= P_{1970}\left(1+\frac{r}{100}\right)^3$$

$$= 47000\,(1 + 0.17095)^3$$

$$= 47000(1.17095)^3$$

$$= 75459.9 \simeq 75460$$

Population for the year 2006, means that it is after 36 years (3.6 decades) from 1970 onward.

$$P_{2006} = P_{3.6} = P_{1970}\,(1 + 0.17095)^{3.6}$$

$$= 47000\,(1.17095)^{3.6} = 82954$$

Q.2 Consider the following data of population for a city:

Year	1990	2000	2010	2020
Population	220800	345450	500910	678220

Calculate the following:

(i) Expected population of city in year 2030 as per geometrical increase method.

(ii) Expected population of city in year 2040 as per decremental decrease method.

(iii) Saturation population of city as per logistic curve method by considering t_0 = 1990

Solution :

Year	Population	Increment in population	Rate of increment	Decrement in rate of increment
1990	220800			
		124650	56.45%	
2000	345450			11.45%
		155460	45.00%	
2010	500910			9.6%
		177310	35.40%	
2020	678220			

(i) Average rate of increment $= \sqrt[3]{r_1 r_2 r_3}$

$$= \sqrt[3]{56.45 \times 45 \times 35.40}$$

$$\bar{r} = 44.80\%$$

$$\Rightarrow \quad P_{2030} = P_{2020}\left(1+\frac{\bar{r}}{100}\right)^n$$

$$n = 1$$