CIVIL ENGINEERING-CE

GATE / PSUs

STUDY MATERIAL

ENVIRONMENTAL (Part-A)

ENGINEERS INSTITUTE OF INDIA

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CONTENT

CHAPTER-1
WATER DEMAND

Major components of a water supply scheme are:

Water source identification → Collection → Transportation → Treatment of water → Water Distribution

Classification of water demand for a city

1. Domestic water Demand:

- This includes the water required in private buildings for drinking, cooking bathing, etc. Which may vary according to living conditions of consumers.
- As per IS: 1172-1993, the minimum domestic consumption for a city with full flushing system should be **200*l* /h/d** (*litre per head per day*) or lpcd (*litre per capita per day*) and for economically high section and LIG colonies it can be reduced to 135 lpcd.
- The domestic water consumption usually amounts to 50-60% of the total water consumption.

2. Industrial Water Demand:

- It represents the water demand of industries, which are either existing or likely to be established in future.
- This water demand vary with the number and types of industries present in the city.
- In industrial cities, water demand may be 450 *lpcd* and in case of small-scattered industries it may be as low as *50 lpcd.*

Water Demand of Certain Important Industries			
S.No.	**Name of Industry and Product**	**Unit of production of Raw material used**	**Approximate quantity of water required per unit of production/raw material in kilo litres**
1.	Automobiles	Vehicle	40
2.	Distillery (Alcohol)	Kilo litre	122—170
3.	Fertilizer	Tonne	80—200
4.	Leather (Tanned)	Tonne	40
5.	Paper	Tonne	200—400
6.	Special Quality paper	Tonne	400—10000
7.	Straw board	Tonne	75—100
8.	Petroleum Refinery	Tonne (Crude)	1—2
9.	Steel	Tonne	200—250
10.	Sugar	Tonne (Crushed cane)	1—2
11.	Textile	Tonne (goods)	80—140

3. Institutional and Commercial water demand:

- Water requirement for institutions like hospitals, hotels, railway stations, school, offices come under this category.
- In general, water demand for it is 20 lpcd which may go up to 50 lpcd for highly commercialized cities.
- Water demand for certain institutions and commercials:
  Offices: 45-90 lpcd (l/h/d)
  Schools: 45-90 (Day scholars) lpcd

135-225 (Residentials) lpcd

Hotels: 180lpcd (per bed)

Airports: 70 lpcd

Hospitals (including laundry) :350 (per bed)(No. of beds < 100)

: 450 (per bed) (No. of beds > 100)

Cinema Halls: 15 l pcd (per seat)

4. **Demand for public uses:**
   - This includes the water requirement for public utility purposes.
   - Generally, water demand for it is taken as 10 lpcd.
   - Water demand in this category is normally taken as a nominal value not exceeding 5% of total consumption.

5. **Fire Demand:**
   - Fire hydrants are usually fitted in the water mains at about 100-150m apart and minimum water pressure available at fire hydrant should be 100 KN/m^2 – 150 KN/m^2 and should be maintained even after 4-5 hrs. of constant use of it.
   - The per capita fire demand hardly amounts to **1 lpcd** and hence it is generally ignored while computing the total per capita water requirement of a city.

Note: The quantity of water required for extinguishing fire is not very large but this water should be easily available and kept always stored in storage reservoir.

Formulas for calculating rate of fire demand

a. **Kuichling formula:**

$$\boxed{Q = 3182\sqrt{P}}$$ Where, Q = water demand (l/min)

- P = Population (in thousands)

b. **Free man formula:**

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

c. **National Board of Fire under writers formulas:**

(i) For a central congested high valued city

$$Q = 4637\sqrt{P}\left[1-0.01\sqrt{P}\right]$$ ………. If population $P \le 2,00,000$

$Q = 54,600\,L/minutes$ with an additional provision of
+
(9,100 – 36,400)l/minutes for a second fire
} ………. If P >2,00,000

(ii) For a residential city

: Small or low buildings, Q = 2,200 litres/minutes (l/min.)

: Large or higher buildings, Q = 4,500 (l/min.)

: High value residence, apartments, tenements, Q = 7,650 to13,500l/min.

d. **Buston's formula:**

$$Q(l/\text{min.}) = 5,663\sqrt{P}$$ where P:(in thousands)

For Indian condition only 2-3 hours storage is fairly adequate, while 5-10 hrs. of storage is considered as minimum requirement is USA.

- All the above formulas are not related to different type of district served and hence it gives equal results for industrial and non-industrial areas.

6. Water required to compensate losses in theft and wastes:

- This quantity may be as high as 15% of the total consumption.

Per Capita Demand (q):

- It is defined as the annual average amount of daily water required by one person including water for domestic use, industrial and commercial use, public use, wastes etc.

$$\therefore \quad q(l/h/d) = \frac{\text{Total yearly water requirement of the city (v)}}{365 \times \text{Design population}}$$

- For an average Indian city, as per IS recommendation, the value of qis335 *lpcd*.

Break up of per capita demand (q) for an Average Indian City

Use	Demand in *l*/*h*/*d*
Domestic use	200
Industrial use	50
Commercial use	20
Civic or public use	10
Wastes and thefts, et	55
	Total = 335 (Per Capita Demand (q))

Factors Affecting Water Demand:

I. Size of city

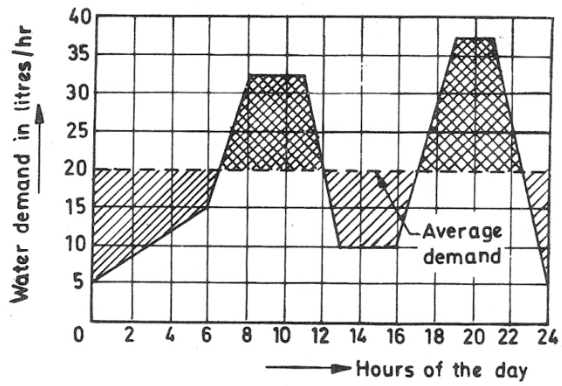
Variations in per capita demand with population in India

S.No.	Population	Per Capita Demand in litres/day/person*
1.	Less than 20,000	110
2.	20,000—50,000	110—150
3.	50,000—2 lakhs	150—240
4.	2 lakhs—5 lakhs	240—275
5.	5 lakhs — 10 lakhs	275—335
6.	Over 10 lakhs	335**—360

Note :
The above figures are liable to variation up to 25%
For Indian conditions, I.S. code permits maximum value of 335 lpcd

II. Climatic condition
III. Habits of people
IV. Industrial and commercial activities
V. Water quality
VI. Pressure in distribution system
VII. Development of sewerage facilities
VIII. System of water supply
IX. Policy of metering and method of charging

Variation in demand (or Draft)



Showing hourly rate of water consumption.

(i) Maximum daily Consumption: $q_{\max}$

$$\boxed{q_{\max} = 1.8 \times q_{avg.}}$$

Where, $q_{avg.}$ = Average daily demand or Annual Average daily demand.

(ii) Maximum hourly consumption: $q_{h-\max}$ or Peak demand

$q_{h-\max} = 1.5 \times$ Average hourly consumption of maximum Daily

$$= 1.5 \times \left(\frac{q_{\max}}{24}\right) = 1.5 \times \frac{(1.8\,q_{avg.})}{24}$$

$$\therefore \quad \boxed{q_{h-\max} = 2.7 q_{avg}}$$

(iii) Maximum weekly consumption

Maximum weekly consumption = 1.48 × Average weekly consumption

(iv) Maximum monthly consumption

Maximum monthly consumption = 1.28 × Average monthly consumption.

(v) Goodrich Formula:

Used to find out the ratio of peak demand to their corresponding means.

$\boxed{p = 180.t^{-0.1}}$ Where, p: % of the annual average draft for the time't' (in days)

t:Time (in days) from 1/24 to 365.

(a) Based on this, for *t* = 7 days (weekly variation)

Maximum weekly demand = 1.48 × average weekly demand

$$\left[p = 180 \times 7^{-0.1} = 148\%\right]$$

(b) For t = 30 days (Monthly variation)

Maximum monthly demand = 1.28 ×Average monthly demand

$$\left[p = 180 \times 30^{-0.1} = 128\%\right]$$

Coincident Draft:

- For general community propose:

Total draft (demand) = Maximum of

(a) Sum of maximum daily demand and fire demand

OR

(b) Maximum hourly demand

Where, the summation of maximum Daily demand and fire demands are known as ***coincident draft***.

Recommendations for designing the capacities of different components of water supply scheme:

- The source of supply may be designed for maximum daily consumption or sometimes for average daily consumption.
- The pipe mains may be designed for maximum daily consumption.
- Filter and other units of a water treatment plant and pumps for lifting water may be designed for maximum daily consumption.
- The distribution system, including the pipes carrying water from service reservoir to distribution system may be designed for maximum hourly draft of the maximum day or coincident draft, whichever is more.
- The service reservoir is designed to take care of the hourly fluctuations, fire demand, emergency reserve etc.
- **Water supply projects, under normal circumstances are designed for a design period of 30 years.**

S.No.	Item	Design period in years
1.	Storage by dams	50
2.	Infiltration works	30
3.	Pumping pump house electric motors and pumps	 30 15
4.	Water treatment units	15
5.	Pipe connections to the several treatment units and other small appurtenances	30
6.	Raw water and clear water conveying	30
7.	Clear water reservoirs at the head works, Balancing tanks, and Service reservoirs (over head or ground level)	15
8.	Distribution system	30

Population forecasting methods:

- Some of the following methods are used when design period is small, and some are used when the design periods are large.
- These methods are based on the laws of probability.

Note: Main factors responsible for changes in population are Births, Deaths and Migrations.

1. Arithmetic Increase Method:

- Based on the assumption that the population increases at a constant rate.

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

Where,

P_n = Forecasted population after 'n' decades from the present

P_0 = Population at present (i.e. last known census)

n = Number of decades between present and future

$\bar{x}$ = Average (*Arithmetic mean*) of population increases in the known decades.

It is suitable for old cities.

2. Geometric Increases Method:

- Here, % decadal growth rate (r) is assumed to be constant.
- This method is also known as "***uniform increase method***"

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

Where, P_n, P_0 have same meaning as mentioned in (1)

r = Assumed growth rate (%)

- Method of determining assumed growth rate (r)

$$r = \sqrt[t]{\frac{P_2}{P_1}} - 1$$

Where,

P_2 = Final known population

P_1 = Initial known population

t = Number of decades (period) between P_1 and P_2

$r_i = \frac{\text{Increase in population}}{\text{original population}} \times 100$ are computed for each known decade,

i.e. $r_1,\ r_2,\ r_3,\ ....\ r_n$

Hence average value of 'r' is found as:

(a) Arithmetic average method: **(Preferred)**

$$r = \frac{r_1 + r_2 + r_3 + ...+ r_n}{t}$$

(b) Geometric average method:

$$r = \sqrt[t]{r_1,\ r_2.....r_n}$$

It gives the highest value and is best suited for new cities.

Note: The "GOI Manual on water treatment" recommends geometric mean method.

3. Incremental Increase Method or Method of Varying Increment:

- Here % decadal growth rate is not assumed to be constant.

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

Where, $\bar{x}$ = average increase in population of known decades

$\bar{y}$ = Average of incremental increases of the known decades.

- The results obtained by this method is somewhere between the results given by arithmetic increase method and geometric increase method. Hence, it is considered to be giving quite satisfactory results and suitable for both old and new cities.

4. Decreasing rate of growth method:

- This method is applicable only in cases, where the rate of growth shows a downward trend.
- In this method, the average decrease in the percentage increase is calculated and then subtracted from the latest percentage increase for each successive decade.

Steps:

1-Calculate the increase in population (Δx) between P_r and P_{r+1} (r = 0, 1, 2 ….)

2-Calculate percentage increase in population i.e. $\left(r_i = \frac{\Delta x}{P_r} \times 100\% \right)$

3-Calculate decrease in percentage increase i.e. $(\Delta r = r_i - r_{i+1},\ i = 1, 2, 3, ...)$

4-Forecasted population, $P_n$is given as:

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

Where, $\bar{r}$ = mean of values of $r_1, r_2 \ldots r_n$

P_1 = Population of at present (i.e. last know ncensus)

P_2 = Forecasted population in next decade

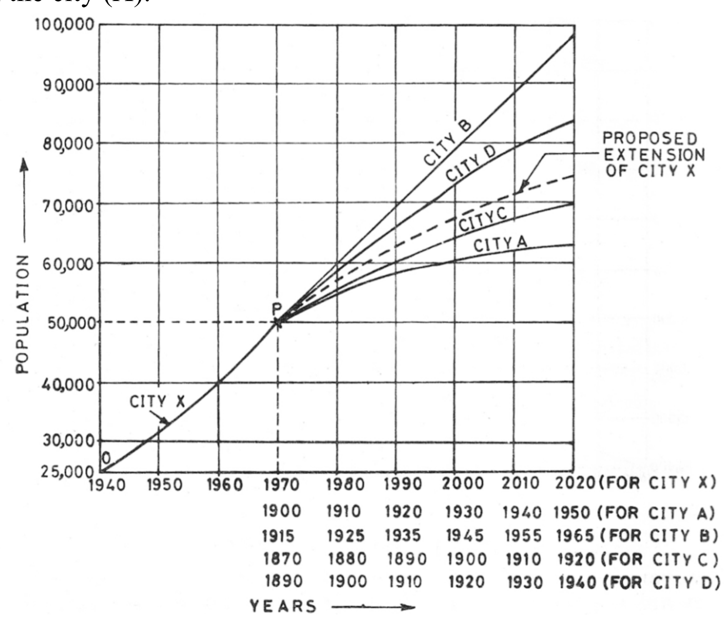
r_0' = *percentage* Increase between present population and last decade population

5. Simple Graphical Method:

- A graph is plotted from the available data, between time and population and the curve is smoothly extended up to the desired year to get the desired value.
- An approximate method.

Comparative Graphical Method:

- Cities of similar conditions and characteristics as that of city under consideration (x) are selected and a graph is plotted for population growth for all this selected city to find future population of the city (X).



6. **Master plan method or zoning method:**
   - Applicable for big and metropolitan cities.
   - A master plan is prepared for a city to regulate the development schemes.

7. **The Ratio method or the approximate method:**
   - In this method, the city's census population record is expressed as percentage of the population of whole country.
   - This method is suitable for those areas whose growth is parallel to the national growth.

8. **The Logistic Curve Method:**
   - Under normal conditions, the population of a city will grow as per the logistic curve as shown in figure.

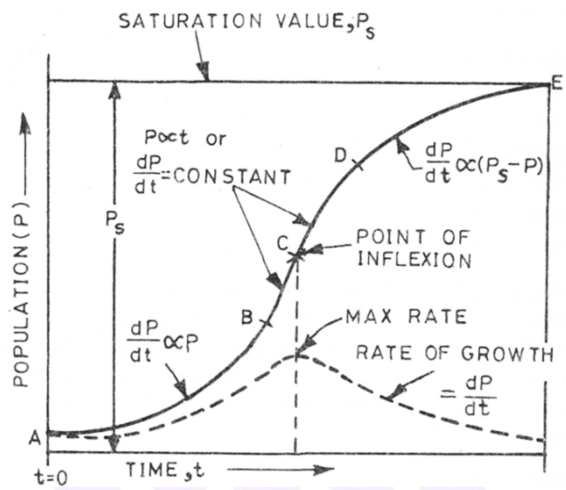


Figure: Ideal population growth curve, called logistic curve.

   - P.F. Verhulst gave a mathematical solution to the logistic curve and defined the entire curve AD by an autocatalytic first order equation as given:

$$\log_e\left(\frac{P_s - P}{P}\right) - \log\left(\frac{P_s - P_0}{P_0}\right) = -k.P_s.t$$

Where P_0 = Population at the starting point of curve A.

P_s = Saturation population

P = Population at any time't' from the origin A.

K = Constant

On solving we get:

$$P = \frac{P_s}{1 + m.\log_e^{-1}(nt)}$$

Where, $m = \frac{P_s - P_0}{P_0}$ (A constant)

$n = -K.P_s$ (A constant)

   - As per, Mclean, P_s, m, n can be found by equation :

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

$$m = \left(\frac{P_s - P_0}{P_0} \right)$$

$$n = \frac{2.303}{t_1} \log_{10} \left[\frac{P_0 (P_s - P_1)}{P_1 (P_s - P_0)} \right]$$

[Where, P_0, P_1, P_2 are values at $t_0 = 0, t_1$ and $t_2 = 2t_1$. respectively.]

Key Points

1. Formulas for calculating fire demand

(*i*) Kuichling formula	$Q = 3182\sqrt{P}$	(l/m)
(*ii*) Free man formula	$Q = 1136\left[\frac{P}{10} + 10\right]$	
(*iii*) National board of fire under writers formula,	$Q = 4637\sqrt{P}\,[1 - 0.01\sqrt{P}]$	
(*iv*) Buston's formula	$Q = \left(\frac{l}{\min}\right) = 5663\sqrt{P}$	

2. Maximum daily consumption, $q_{max} = 1.8 \times q_{average}$

3. Maximum hourly consumption, $q_{h,\,max} = 1.5 \times q_{max} = 2.7\, q_{average}$

4. Population forecasting,

(*i*) Arithmetic increase method $P_n = P_o + n\,\bar{x}$

(*ii*) Geometric increase method $P_n = P_o\left(1 + \frac{I}{100}\right)^n$

(*iii*) Incremental increase method $P_n = P_o + n\bar{x} + \frac{n(n+1)}{2}.\,\bar{Y}$

(*iv*) Logistic curve method $l_n\left(\frac{P_s - P}{P}\right) - l_n\left(\frac{P_s - P_o}{P_o}\right) = -K\,P_s\,t$

We get, $P = \frac{P_s}{1 + m\,\ln^{-1}(n\,t)}$

Where, $m = \frac{P_s - P_o}{P_o}$ $n = -K.P_s$

$$P_s = -\frac{2\,P_o\,P_1\,P_2 - P_1^2(P_o + P_2)}{P_o\,P_2 - P_1^2}$$

$$n = \frac{2.303}{t_1}\log_{10}\left[\frac{P_o(P_s - P_1)}{P_1(P_s - P_o)}\right]$$

Practice Question with Solution

1. The population of a new city, as obtained from a census report has been arranged as follows:

Census Year	Population (in thousands)
1980	80
1990	96
2000	113
2010	138

By the year 2020 this city will have an approximate population (in thousands) [Assume city is expanding at faster or compounding rate]

(*a*) 165 (*b*) 160 (*c*) 157 (*d*) None of these

Ans. **(*a*)**

Sol. When city is expanding at a faster rate or compounding rate, then we predict population using geometric increase method.

% increase from 1980 to 1990 $= \dfrac{96-80}{80} \times 100 = 20\%$

% increase from 1990 to 2000 $= \dfrac{113-96}{96} \times 100 = 17.71\%$

% increase from 2000 to 2010 $= \dfrac{138-113}{113} \times 100 = 22.12\%$

Predicted increase from 2010 to 2020 $= \sqrt[3]{20 \times 17.71 \times 22.12} = 19.86\%$

$\therefore$ Predicted population in 2020 $= 138 \times \dfrac{(119.86)}{100} = 165.4$ thousands

2. **Assertion (A) :** In estimating population for assessing water supply demand, the geometric progression (GP) method gives correct estimations for a developed city.

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

Choose correctly from codes given below:

(*a*) Both statement I and statement II are correct individually and statement II is the correct estimation/explanation of statement I

(*b*) Both statement I and statement II are individually true and statement II is not the correct explanation of statement I

(*c*) Statement I is true but statement II is false

(*d*) Statement I is false but statement II is true

Ans. **(*d*)**

Sol. A developed city will be close to the saturation point and decreasing rate of growth method or logistic curve method will be best.

3. Determine the Future Population of a satellite Town by the Geometric increase method for the year 2011, the following data are given as :

Year	**1951**	**1961**	**1971**	**1981**	**……**	**2011**
Population thousand	**93**	**111**	**132**	**161**	**……**	**?**

Solution: