ASSESSMENT OF CURRENT WATER SUPPLY SCENARIO IN KOLKATA MUNICIPAL CORPORATION AREA: ISSUES & CHALLENGES

A
Thesis
Submitted by

DIVYA MONDAL

EXAMINATION ROLL NO: **M6WRP22011**

Registration No. **150283** of **2019-2020**

For partial fulfilment of the requirements for the degree of

MASTER OF ENGINEERING
In Water Resources and Hydraulic Engineering
Course affiliated to Faculty of Engineering & Technology
Jadavpur University

Under the guidance of

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2022

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC ETHICS

I hereby declare that this thesis contains a literatures survey and original research work by the undersigned candidate, as part of my **Master of Engineering** in **Water Resources & Hydraulic Engineering** in the Faculty of Interdisciplinary Studies, Jadavpur University during the academic session 2019-2022.

All information in this document has been obtained and presented in accordance with academic rules and ethical conduct.

I also declare that, as required by these rules and conduct, I have fully cited and referenced all materials and results that are not original to this work.

Name **: DIVYA MONDAL**

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CERTIFICATE OF RECOMMENDATION

This is to certify that the thesis entitled **"Assessment of Current Water Supply Scenario In Kolkata Municipal Corporation Area: Issues and Challenges"** is a bonafide work carried out by Ms. Divya Mondal under our supervision and guidance for partial fulfilment of the requirement for the Post Graduate Degree of Master of Engineering in Water Resources & Hydraulic Engineering during the academic session 2019-2022.

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CERTIFICATE OF APPROVAL **

This foregoing thesis is hereby approved as a credible study of an engineering subject carried out and presented in a manner satisfactorily to warranty its acceptance as a prerequisite to the degree for which it has been submitted. It is understood that by this approval the undersigned do not endorse or approve any statement made or opinion expressed or conclusion drawn therein but approve the thesis only for the purpose for which it has been submitted.

Committee of the final examination for
the evaluation of the thesis

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**Only in case the thesis is approved

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Place: Jadavpur University

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ABSTRACT

Water is the basic survival element for any living being and human is not exception of that. Though this 'Blue Plant' is named after the abundance of water, still there is non-availability of clean, potable water. As India is the second most populous country in the world with a sixth of world population and the figure stands around 1.38 billion, demand of safe pure water is a crucial thing to look at. There are few metropolitan cities in India and Kolkata is one of them which has been growing day by day as a city with a lot of opportunities in all fields. It is common that beside the existing population, Kolkata is attracting more people. This is causing an exponential growth of population and their demand to access to the potable, safe water. The growth projection of the city needs to be kept in mind for meeting the water demand of the population which is discussed here in the thesis work. In Kolkata, water supply is taken care of by Kolkata Municipal Corporation through their water supply department after necessary purification. The analysis and assessment of the qualitative and quantitative parameter of the water is a concern of this thesis work. KMC provides water to all the domestic ends after necessary purification of water which comprises of some steps. The steps which are involved for purification of water are also discussed here. IS 10500-2012 gives us a view of water quality parameter which is required to keep on check of the purified water by KMC water supply department. The assessment of the water quality is also a part of this thesis.

Keywords: Water supply system, Urban water supply, Analysis of KMC water supply, Kolkata current water supply scenario, issues and challenges of water supply.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUNF OF STUDY:

Water is an inorganic, transparent, tasteless, odourless and nearly colourless chemical substance, which are the main constituent of Earth's hydrosphere and the fluids of all known organisms. It is vital for all known forms of life, even though it provides neither food, energy nor organic micronutrients. Thus, water is indispensable in our life. Water covers about 71% of Earth's surface, mostly in seas and oceans. Small portion of water occurs as ground water, nearly 1.7%, in the glaciers and ice caps of Antarctica and Greenland nearly 1.7% and in the air as vapour, clouds and precipitation, nearly 0.001%. In spite of these much coverage of water in Earth, ironically only a small portion of planet's water is usable. This global lack of abundance of water presents threat to the living-world. Ninety-seven percentage of water is too salty for consumption and agricultural use. Furthermore, much if the rest is held as ice or as other unattainable source. This leaves approximately one percentage of global water as liquid and fresh, ninety eight percentages of which is ground water. So, the management becomes crucial once when we look at the global distribution of fresh water. With this situation of lack of plethora of usable water, there is one more crux which is increasing population. The global population has grown from 1 billion in 1800 to 7.9 billion in 2020. The UN projected population to keep growing, and estimates have put the total population at 8.6 billion by mid-2030, 9.8 billion by mid-2050 and 11.2 billion by 2100. Thus, meeting the demand of fresh potable water maintaining the standard quality of the growing population is inevitably a major task. We are here trying to take glance of the situation and analysis the same.

1.1.1. Global Scenario

Water uses increase everywhere and every year. Currently 69% of all water withdrawn for human use on an annual basis is soaked up agriculture including irrigation. Industry accounts for 23% and domestic use (household, drinking water, and sanitisation) accounts for about 8%. These global averages vary a great deal between regions. From 23% of water use for industrial purposes, High Income Countries use 59% of total water uses, Low Income Countries use 8% of total use. With decease in the resource and increasing trend of water demand by various user sectors, sharing concept is coming up and is becoming complicated too. Conflicts related to water users are increasing everywhere by social, ecological and economical values. Per capita availability of water in 1950 is reduced to 60% in developed countries and 30% in developed countries in 2000, and will reduced to 57-58% in developed countries and 23-24% in developed countries in 2025.

The **Cape Town water crisis** in South Africa was a period of severe water shortage in the Western Cape region, most notably affecting the City of Cape Town. While dam water levels had been declining since 2015, the Cape Town water crisis peaked during mid-2017 to mid-2018 when water levels hovered between 15 and 30 percent of total dam capacity. In late 2017, there were first mentions of plans for "Day Zero", a shorthand reference for the day when the water level of the major dams supplying the City could fall below 13.5 percent. "Day Zero" would mark the start of Level 7 water restrictions, when municipal water supplies would be largely switched off and it was envisioned that residents could have to queue for their daily ration of water. If this had occurred, it would have made the City of Cape Town the first major city in the world to run out of water. The water crisis occurred at the same time as the still ongoing, as of 2021, Eastern Cape drought located in a separate region nearby. The City of Cape Town implemented significant water restrictions in a bid to curb water usage, and succeeded in reducing its daily water usage by more than half to around 500 million litres (130,000,000 US gal) per day in March 2018. The fall in water usage led the City to postpone its estimate for "Day Zero", and strong rains starting in June 2018 led to dam levels recovering. In September 2018, with dam levels close to 70 percent, the city began easing water restrictions, indicating that the worst of the water crisis was over. Good rains in 2020 effectively broke the drought and resulting water shortage when dam levels reached 95 percent.

There's nothing more essential to life on earth than water. Yet, from Cape Town to Flint, Michigan, and from rural, sub-Saharan Africa to Asia's teeming megacities, there's a global water crisis. People are struggling to access the quantity and quality of water they need for drinking, cooking, bathing, handwashing, and growing their food. Amazing progress has been made in making clean water accessible, with people lacking access to clean water decreasing from 1.1 billion in 2000 to 785 million in 2017. But there are still many opportunities to multiply the benefits of clean water through improved sanitation and hygiene behaviour change. The United Nations recognizes the importance of addressing the global water crisis each year on World Water Day, March 22. Without clean, easily accessible water, families and communities are locked in poverty for generations. Children drop out of school and parents struggle to make a living.

Women and children are the most affected — children because they're more vulnerable to diseases caused by dirty water and women and girls because they often bear the burden of carrying water for their families for an estimated 200 million hours each day. Access to clean water changes everything; it's a stepping-stone to development. When people gain access to clean water, they're better able to practice good hygiene and sanitation. Children enjoy good health and are more likely to attend school. Parents put aside their worries about water-related diseases and lack of clean water access. Instead, they can water crops and livestock and diversify their incomes. Communities no longer vie for rights to a waterhole. World Vision is reaching one new person with clean water every 10 seconds and one new person with handwashing behaviour change programming as well.

1.1.2. National Scenario

India: The World's Largest Groundwater User. As per Dr Rajiv Kumar, Vice Chairman, National Institution for Transforming India (NITI) Aayog in August 2021, 1st in India the annual available water after evapotranspiration is 1999 billion cubic metres (bcm), of which the utilizable water potential is estimated at 1122 bcm. India is the largest groundwater user in the world, with an estimated usage of around 251 bcm per year, more than a quarter of the global total. With more than 60 per cent of irrigated agriculture and 85 per cent of drinking water supplies dependent on it, and growing industrial/urban usage, groundwater is a vital resource. It is projected that the per capital water availability will dip to around 1400 cum in 2025, and further down to 1250 cum by 2050.

A report titled “Composite Water Management Index (CWMI)”, published by NITI Aayog in June 2018, mentioned that India was undergoing the worst water crisis in its history; that nearly 600 million people were facing high to extreme water stress; and about 200,000 people were dying every year due to inadequate access to safe water. The report further mentioned that India was placed at the rank of 120 amongst 122 countries in the water quality index, with nearly 70 per cent of water being contaminated. It projected the country’s water demand to be twice the available supply by 2030, implying severe scarcity for hundreds of millions of people and an eventual loss in the country’s GDP.

The CWMI was conceptualized as a tool to instill a sense of cooperative and competitive federalism among the states. This was a first-ever attempt at creating a pan-India set of metrics that measured different dimensions of water management and use across the lifecycle of water. The water data collection exercise was carried out in partnership with the Ministry of Jal Shakti, Ministry of Rural Development, and all the States/Union Territories (UTs). The report was widely acknowledged and provided guidance to States on their success areas, absolutely and relatively, and on recommendations to secure their water future.

CWMI 2.0, released in August 2019, ranked various states for the reference year 2017–18 as against the base year 2016–17. Gujarat held on to its first rank in 2017–18, followed by Andhra Pradesh, Madhya Pradesh, Goa, Karnataka, and Tamil Nadu. Amongst North Eastern and Himalayan States, Himachal Pradesh was adjudged on top. The UTs submitted their data for the first time, with Puducherry declared the top ranker. In terms of incremental change in index (over 2016–17), Haryana held the first position in general States and Uttarakhand amongst North Eastern and Himalayan States. On an average, 80 per cent of the states assessed on the Index over the last three years have improved their water management scores, with an average improvement of +5.2 points.

But worryingly, 16 out of the 27 states still score less than 50 points on the Index (out of 100), and fall in the low-performing category. These states collectively account for ~48 per cent of the population, ~40 per cent of agricultural produce, and ~35 per cent of the economic output of India. Uttar Pradesh, Rajasthan, Kerala, and Delhi, 4 of the top 10 contributors to India’s economic output and accounting for over a quarter of India’s population, have scores ranging from 20 points to 47 points on the CWMI. Food security is also at risk, given that large agricultural producers (states) are struggling to manage their water resources effectively. This is troubling given that assessment on almost half of the Index scores is directly linked to water management in agriculture.

On the positive side, greater focus on water governance and increased data discipline amongst states is building a pathway for driving long-term success.

1.1.3. Kolkata Scenario

Any discussion on the water problems of Kolkata is a paradox indeed, as the city is situated in the lower reaches of one of the world's largest delta regions. But like all other Indian metropolitan centres, Kolkata too is facing water woes, with both its freshwater and groundwater sources dying at a fast pace. River Hooghly -- the main source of the city's freshwater supply -- is contaminated by industrial and domestic sewage from about 262 outlets. According to the 2003 annual report of the West Bengal Pollution Control Board, the biological oxygen demand (bod) -- an indicator of pollution load -- of the river water at the Palta station rose from 0.91 milligrams per litre (mg/l) in 1991 to 2.25 mg/l in 2002. This is alarming because Palta station is one of the two places providing drinking water to the city. The coliform count -- an indicator of bacterial pollution -- of the river water is also startling. The maximum probable number (mpn) of total coliform count per 100 millilitres (ml) of water ranges from 20,000 to 1,100,000 at Palta and Garden Reach stations (the other place catering to the city's drinking water supply). The standard set by New Delhi-based Central Pollution Control Board (CPCB) is 5,000 mpn per 100 ml for drinking water source.

Due to the high levels of pollution in the surface waterbodies, groundwater is being exploited at an unsustainable level. As per the Kolkata Municipal Corporation (KMC), the city's present drinking water demand is around 1,262 million litres per day (MLD). Supply is about 1,209.6 MLD, out of which 1,096.2 MLD is surface water, and 113.4 MLD is groundwater. Officially, there is a gap of 37.8 MLD between demand and supply.
The situation, in fact, is much more distressing -- Kolkata's population is 14 million; in India, per person water requirement on an average is 135 litres. Hence, the city's demand for drinking water should be 1,890 MLD. Considering that KMC is only supplying 1,209 MLD, there is a gap of 586 MLD, which is undeniably met by groundwater extraction. Together with the 113.4 MLD extracted by KMC, this figure translates into a perilous exploitation of groundwater: 699.4 MLD.
The situation becomes more alarming considering that very little recharge takes place in the aquifers. They are confined -- sandwiched between clay layers. The top layer (30-50 metres thick) does not allow rainwater to seep in.
A study by R Bandyopadhyaya, principal secretary, water investigation and development, West Bengal government, shows that the rampant groundwater use has led to the formation of a conical depression in the aquifers. The depression means that the water rushes from all parts of the city towards the south-central areas; as a result, the groundwater levels in the former are going down -- from 0-1.5 metres below ground level in 1956 to 6-8.5 metres below ground level in 1993.

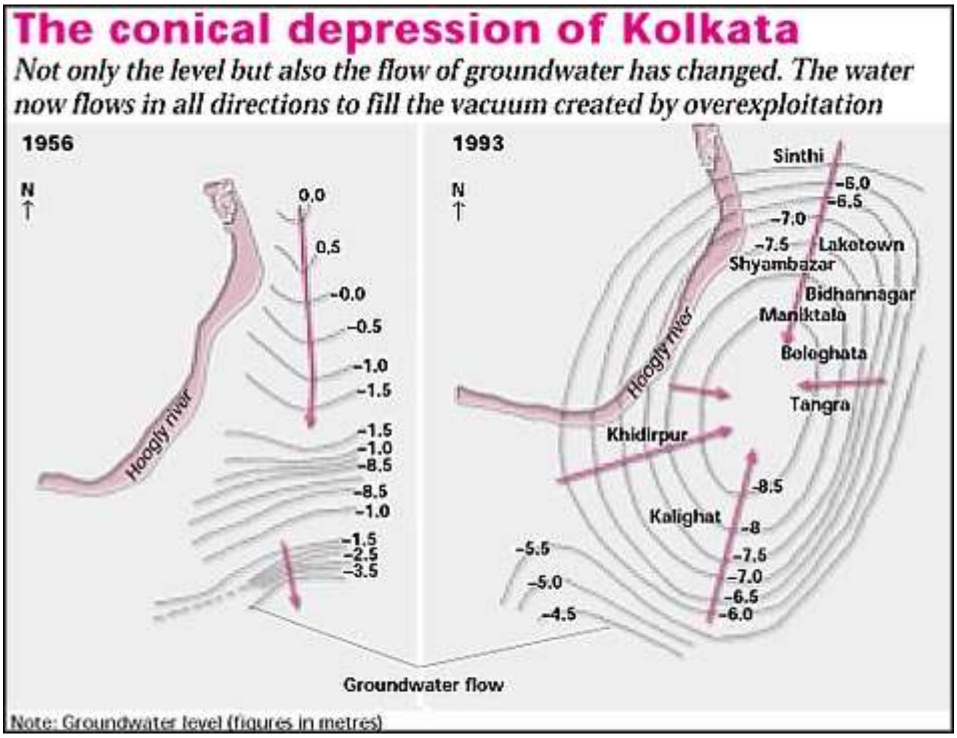


Figure 1: Ground Water level in KMC area

1.2. Objective of Study

The objective of the study is to understand and discuss the followings

(i) Current scenario of Kolkata water supply,

(ii) Its demand with the growing population,

(iii) Water quality at inlet and consumer end.

1.3. Study Area

Our study area is Kolkata. Kolkata, formerly known as Calcutta is the capital of Indian state of West Bengal. It is located on the eastern bank of the Hooghly River. The city is approximately 80 km west of Bangladesh border. According to the 2011 Indian census, Kolkata is the seventh-most populous city in India, with a population of 45 lakh (4.5 million) residents within the city limits, and a population of over 1.41 crore (14.1 million) residents in the Kolkata Metropolitan Area. It is the third-most populous metropolitan area in India. In 2021, Kolkata metropolitan area crossed 1.5 crore (15 million) registered voters. The Port of Kolkata is India's oldest operating port and its sole major riverine port. Kolkata is regarded as the *Cultural Capital* of India. If we mark in the globe it falls on 22.5726 degree N latitude and on 88.3639 degree E longitude. The temperature of the city approximately moves around

32 degree Celsius. Rains brought by the Bay of Bengal branch of the south-western summer monsoon.

Figure 2:Kolkata: location of study area

1.4. The Methodology Adopted for the Research

The overall research methodology is mainly divided into five components: Literature Review for Identification of goal and objective, Collection of the information of the present situation by primary survey and secondary survey, Data Presentation and Organisation of data analysis, Development of a method to assess the current water supply scenario, its issues and challenges in the study area and lastly output and result in analysis for Identifying strategies for scientific and sustainable management of qualitative and quantitative water resource. Survey, study and data from KMC revealed that the river Hooghly is the main source of water supply for Kolkata. After drawing water from the river, KMC treats the water at Indira Gandhi Water Treatment Plant (WTP) of capacity 260 million gallons per day at Palta Water Works.

1.5. Water Scenario In Kolkata:

(i) The Kolkata Metropolitan Area (KMA) is primarily been serviced by two sources, i.e.

(a) Surface water from the perennial river of Hooghly.

(b) Ground water source.

Out of these two sources, the water from river Hooghly is being treated and supplied to a very limited area of KMA from the treatment plant but majority of remaining KMA to depend on the Ground water source.

(ii) In 1848, importance of pure and potable water supple to the city was given a top priority through proper legislation:

- In 1865, work of construction of 6 MGD water works at Palta situated 24 km away from the northern side of Kolkata.
- Between 1888 to 1893 filtration capacity of Palta was increased from 6 MGD to 20.5 MGD.
- In 1905 supply was increased to 26.5 MGD by introducing pressure in 42’’ and 48’’ diameter C.I. gravity transmission pipe from Palta to Tallah.
- Between the year 1907 and 1911, capacity of the plant was increased from 26.5 MGD to 37.5 MGD with addition of 4 numbers primary settling tank and construction of few more slow sand filter beds.
- From 1870 to 1933, per capita supply increased gradually from 15 gallons to 64 gallons and this was again decreased to 31 gallons in 1951 and only 27 gallons in the year 1961. Again in 1962, expansion scheme of 60 MGD was taken up to increase the capacity to 160 MGD.
- Calcutta Metropolitan Water and Sanitation Authority (CMW & SA) presently known as KMW&SA was formed through enactment on 21.10.1996. It was created with the purpose of maintenance, development and regulation of water supply, sewerage and drainage services etc. for the KMA with a view to promotion of public health and for matters connected therewith. In the field of water supply, KMW&SA has constructed and is operating and maintaining 60 MGD (272 MLD) at Garden Reach Water Works situated at the southern side of Kolkata from where KMC was getting water of 40 MGD.

- Kolkata Municipal Corporation further taken augmentation of 100MGD at Palta Water Works in three phases. First phase was commissioned in the year 1997 with 20MGD capacity and total capacity and total capacity had gone up to 180 MGD.

- KMW&SA have further augmented their production capacity at Garden Reach Water Works of 60 MGD in May 2001. Presently, KMC is receiving 91 MGD of water from Garden Reach Water Works.

- In 2nd phase 40 MGD was commissioned in the year 2004 and total capacity gone to 220 MGD at Palta Water Works.

- Construction of 40MGD Plant is completed within next 4 months,

- KMC has taken up augmentation of two water treatment plants with booster pumping station at Watgunj Square of 5MGD and at Jorabagan Park of 8 MGD capacity.

- Due to age old system of water treatment plant it is not possible to achieve 100% efficiency of plant capacity. At present we are getting water at 80% efficiency. There is also problem in age old transmissions main, which are not capable of carrying required quantity of water which requires through refurbishment. As water is coming from treatment plant to storage reservoir continuously (24 hours a day), there is no scope to close down the transmission main for refurbishment. K.M.C. is thinking an alternative route for laying a transmission main so that refurbishment can be done by closing the existing transmission mains one by one. After this refurbishment, K.M.C. will develop the water treatment plant for carrying more water in future. (DPR of Jai Hind Jalprakalpa).

1.6. Need For Development Of Surface Water Source

(i) Kolkata City is North-South bound. Its water supply arrangement has been provided from two sources. One is at Palta known as Indira Gandhi Water Treatment Plant, supplying water to KMC storage station at Tallah which is at the extreme north of Kolkata City. The other sources is maintained and operated by KMW&SA , a sister organisation of KMDA which is at the extreme south end of Kolkata city is at Garden Reach and is known as Garden Reach water works. North –south city rea has already been developed and growth is being observed at the eastern part of Kolkata along EM By-Pass. The eastern part of Kolkata city is fast developing and huge multi-storeyed buildings are coming up as the prospective growth set back. This area is naturally supplied with individual ground water sources and in a small way by KMC also through deep tube wells.

(ii) Ground water contains high dissolved solid and salinity. There have some arsenic contamination in ground water. Some tube wells have already been closed in which arsenic content is beyond desirable limit as per CPHEEO manual. It is reported that eastern zone of Kolkata city to avoid extraction of ground water to provide potable surface water and to achieve the objective of sustainable development of quality of life. The approach should be comprehensive one and development action should be incremental over space and time with a scope of producing proportionate benefits. Therefore, the objective is to provide safe water and adequate sanitisation services to specific target population within a specified time reference.

1.8. The Proposed Outcome of the Research

The following outcome would possibly have emerged through this research study:

(i) A view of an approximate current scenario of water supply in Kolkata Municipal Corporation area and urban areas also.
(ii) The sustainability of the clean and potable water supply in the study area of KMC and its urban areas.
(iii) A report of increasing population in Kolkata and its growing demand of water to survive.
(iv) An idea about qualitative and quantitative parameter of water supply in the city with respect to IS 10500-2012.

1.8. Outline of the Thesis

The thesis consists of six chapters. Chapter 2 contains a literature review. Chapter 3 describes the study area and its characteristics. Chapter 4 conceptualization of ground water vulnerability Chapter 5 illustrates the research methodology and concept behind the study. Chapter 6 describes the results and discussions. The conclusion has been given in Chapter 7. References are given at the end of the dissertation.

CHAPTER 2: LITERATURE REVIEW

2.1 LITERATURE REVIEW

Arjen Hoekstra, University of Twente, et al.(2018), addresses the fulfilment of all different ‘water system services’, considers over-all welfare as well as social equity and environmental sustainability, and addresses both risks and uncertain-ties. Risks include hazards, exposure and vulnerability, the latter including aspects of coping capability and resilience. A systems approach can be helpful to comprehend the complexity of the urban system, including its relation with its (global) environment, and better understand the dynamics of urban water supply.

Isha Ray, University of California, et al.(2009), suggested that governments should not be in the water provision business, but should ensure that private providers are regulated with respect to price structures and water quality and should provide incentives for these providers to serve the poor. This new role for government translates into developing partnerships with the private sector and with civil society for water delivery. To some extent, this is how the Chennai Water Board and Ahmedabad Municipal Corporation have begun to operate. Such partnerships could provide much-needed separation between the service provider and the regulator.

Olivia Jensen, et al.(2020), pointed to the urgent need to develop new sources of water to increase household access to safe water supplies, reduce dependence on low-quality groundwater and control the over-abstraction of groundwater in certain parts of the city in Jakarta. The potential for Intervention for Urban Water Management (IUWM) to address these challenges was considered by stakeholders at focus group discussions.

Karin Sjotstrand, et al.(2017), made some conclusions which includes that there is an international consensus about sustainability in water supply, design and decision making that needs to be addressed. Several studies have proposed for evaluation criteria for sustainability assessments in water sector. Few studies have focused on assessing the sustainability of the formations of inter-municipal corporations or the large scale, inter-municipal policies and interventions that regional decision-makers are faced with.

In a similar work **Samir Ahmed et al.(1995),** unveils the status of urban basic amenities especially water supply, sanitation and housing in nine mega cities, metros) by using published data from different sources and Census of India Report 1991. The various dimensions of the process of deterioration of civic amenities and its impact on city dwellers were systematically analysed by the researcher. To tackle the ongoing crisis in Metros, the need to introduce administrative decentralization with financial backing to strengthen local governments is highlighted in the article.

‘Water Supply and Environmental Management: Developing Water Applications’, a study by **Munasinghe, Mohan et al.(1992),** outlines an approach more efficient analysis, planning and management of water sector programmes describing the concepts and tools of integrated water resource planning and management, with special reference to drinking water. The research work describes the hydrological infrastructure, and policy context of sector development planning, the economic evaluation of water supply projects and programmes using tools of cost — benefit analysis, Water Supply Systems and their operation, demand analysis and forecasting and the specifics of rural and low cost urban[water supply development. A series of case studies that discuss some of the characteristics of water sector management programme in Africa, Brazil and the Philippines are also presented in this study.

Financing investments in Urban Water Supply and sanitation has been a perennial problem in all countries of Latin America and Caribbean. **Lee, Jouravlev (et al.1992,)** explores through statistical analysis, the practicability of financing water supply and sanitation services from income generated by the tariffs. Particular emphasis has been made on the possibility of the whole population paying for sanitation services; an issue of importance given the unequal distribution of income in most cities of the Region. The whole population paying for sanitation services; an issue of importance has given the unequal distribution of income in most cities of the Region.

Saleth. R. M. and Dinar. A. et al.(1997,) in their research study examine the economics of several options for increasing water supplies in Hyderabad city, Andrapradesh State, India. The study estimates user specific alternative pricing schemes; calculates the net willingness to pay; demonstrates the lack of Justification for increased supply options and argues that the low, uneconomical rate structure prevents extremely imposed water transfers.

The link between rapid urban growth and the tremendous strain on ties in India to provide adequate and clean drinking water supply is highlighted **RKhana and Koshy et al. (1992,)**. The authors examine the trend India’s urban growth, strain upon urban Governments in providing drinking water, the resource crunch and identify some solutions to the problem. The solutions suggested by the researchers are integration of water and waste water management combined with health education and health promotion, use of remote sensing and geophysical surveys to locate water resources, protection of Water Sources from pollution. Waste recycles and reuses decentralization of water supply, maintenance of the water distribution system etc.

Asthana, Anand. N. et al. (1997.) examines how a policy of providing free domestic water can be unsustainable. Using a conditional logic model, the researchers look at the demand side and identify the determinants of choice, under assumptions normally associated with developing societies. The model shows that the perceptions on the benefits of safe water are significant. Household variables like female literacy are important variables determining the choice of safe water and the capability to pay and willingness to pay. Hence the researchers argue that government in poor countries needs to have a fresh look at their policy relating to water supply.

Kundu Amitab et al. (1991) makes an attempt to examine the nature and magnitude of disparity in the access to water supply and sanitation facilities of people with different levels of consumption expenditure in urban areas having the data from the 38"‘and 42"“Round of the National Sample Survey (NSS) attempts to consider the disparity in the per capita consumption of water by people in different consumption fractals estimated through micro level survey conducted from time to time. Systematically and analytically the author argues at a large majority among the poor do not get the minimum quantity of water for their daily use. He concludes the article with a critical view that the water availability problem among different size class of population can be attributed to existing organizational structure and pricing policy, which have not been signed specifically to provide the minimum quantity of water to all section of population, despite the claims made on this account.

‘Cost Recovery Potential for Improved Water Supply Services in Dehradun’ by **H.U.Bijlani and Kyeong Ac. Choe et al. (1997)** presents a case study of water supply services in Dehradun city. The main objective of the research study was to provide a pre-feasibility analysis of the cost recovery potential for improved water supply service in Dehradun city, in India, based on empirical evidence. By making a demand and cost analysis for full water supply, the researchers conclude that by plugging the physical leakages and controlling the administrative and management side of the metering and billing, not only would the availability of water go up but it would generate a good margin of extra revenue after meeting all expenses. However, the article doesn’t explain distributional variation in water supply in the city of Dehradun.

Laveesh Bhandari et al. (200l) attempts to relate the need for investment in water supply infrastructure with requirements and economic capabilities of the households. The article highlights the policy issues, and impediments in ensuring accessibility to all. After an in depth analysis of the different aspects of access to water in urban households, the authors opine that poor access is accompanied with low levels of expectations of the citizens.

In a similar study, **Sandelin S. et al. (1994)** describes water and sanitation services in low-income areas in East and West Africa. The case studies highlight the problems of poor institutional frameworks, poorly operated infrastructure, weakness in management, and socio cultural differences, which hamper the provision of water and sanitation services in low-income areas. Although the report shows that programmes have been successful in raising the living conditions of the poor, it is argued that for long-term sustainability in water supply and sanitation, policies and strategies and technologies have to be developed on a local basis.

Black, M et al. (1994)states that at the present trend of urbanisation in developing countries, the cities will place an immense pressure on fresh water supplies. The report states that prevailing trend could lead to a drinking water and sanitary crisis with global implications and the low income settlements will be badly hit by the delivery system. The researcher argues that to avert this crisis there is not only a need for additional funds but, more fundamentally, a change of attitude and policy.

Gilesh H. and Brown. B et al. (1997) citing the case study of Delhi, illustrate the day to day problems and solutions of delivery of water to crowded urban poor populations. The authors argue that the most common problem of the urban poor is lack of clean, safe water supply and sanitation. They also argue that urban population growth, especially in mega cities, in developing countries is straining the ability of the government to supply basic services. The pattern of water use practices, the availability of water across different size class of population, especially the urban poor of Delhi, is critically analysed in the article to show the availability problem of piped water for the poor.

Emmanual Idlovitch and Khas Ringskog et al. (1996) in their article, ‘Private Sector Participation in Water Supply and Sanitation in Latin America’, examine the different options of private sector participation in the provision of water supply and sanitation. Taking the examples of countries in Latin America, where private sector participation in the provision of water supply is gradually coming up after 1990s, and the authors put forth a number of options of private sector participation, which the developing countries can adopt. The researchers conclude the article with the expectation that as the successful experience with private participation in operation and investment area of urban water supply system grows, more government will develop the institutional capabilities to enable a more permanent private sector presence in the water sector.

World Bank et al. (1999) in a study examines the problems of providing water to the poor in the context of privatized urban water supply system. Hurdles are considered and comments made on contract features and regulatory practice that can make a concession design more “pro—poor". Report also discusses how partnership between regulators, local government, civic societies and utility companies, can make progress in the field. The case studies presented draw on the experiences of the Business Partners for Development — Water cluster”, a year old initiative launched by private water companies, NGOs and the World Bank to test innovative methods for providing water supply and sanitation service to the urban poor. The case studies cover Argentina, Bolivia, Ecuador and South Africa.

Whereas **Brook Cowen, P and Tynan .N et al. (1999**) in a study pinpoint to the dangers of private vendor system in water supply to low income settlements. The researchers argue that this approach can inadvertently erect barriers to improving service for low-income households. Policy makers therefore need to rethink their approach to private participation transactions and their regulations.

A similar view is shared by A **University of Birmingham Research Study et al. (1998)** which examined how water supply is organized in some low income countries. The study report identifies a range of supply strategies, each involving different degrees of private investment. The Report concludes that private intervention is not bound to guarantee instant solutions to water supply problems in poor urban environment.

CHAPTER 3: STUDY AREA

3. DESCRIPTION OF STUDY AREA

3.1. Kolkata:

Kolkata is one of the eight Metropolitan Cities of India and Capital of the State of West Bengal. The city located at $22^0$34’21.5220” N latitude, $88^0$21’50.0112 E longitude, is standing on the eastern bank of Hooghly River.

3.1.1. Population:

According to the 2011 Indian census, Kolkata is the seventh-most populous city in India, with a population of 45 lakh (4.5 million) residents within the city limits, and a population of over 1.41 crore (14.1 million) residents in the Kolkata Metropolitan Area. It is the third-most populous metropolitan area in India.

3.1.2. Climate:

Kolkata is subject to a tropical wet-and-dry climate that is designated *Aw* under the Köppen climate classification. According to a United Nations Development Programme report, its wind and cyclone zone is "very high damage risk"

3.1.3. Temperature:

The annual mean temperature is 26.8 °C (80.2 °F); monthly mean temperatures are 19–30 °C (66–86 °F). Summers (March–June) are hot and humid, with temperatures in the low 30s Celsius; during dry spells, maximum temperatures sometime exceed 40 °C (104 °F) in May and June. Winter lasts for roughly two-and-a-half months, with seasonal lows dipping to 9–11 °C (48–52 °F) in December and January. May is the hottest month, with daily temperatures ranging from 27–37 °C (81–99 °F); January, the coldest month, has temperatures varying from 12–23 °C (54–73 °F). The highest recorded temperature is 43.9 °C (111.0 °F), and the lowest is 5 °C (41 °F).The winter is mild and very comfortable weather pertains over the city throughout this season. Often, in April–June, the city is struck by heavy rains or dusty squalls that are followed by thunderstorms or hailstorms, bringing cooling relief from the prevailing humidity. These thunderstorms are convective in nature, and are known locally as *kal bôishakhi* (কালবৈশাখী), or "Nor'westers" in English.

3.1.4. Rainfall:

Rains brought by the Bay of Bengal branch of the south-west summer monsoon lash Kolkata between June and September, supplying it with most of its annual rainfall of about 1,850 mm (73 in). The highest monthly rainfall total occurs in July and August. In these months often incessant rain for days brings life to a stall for the city dwellers. The city receives 2,107 hours of sunshine per year, with maximum sunlight exposure occurring in April. Kolkata has been hit by several cyclones; these include systems occurring in 1737 and 1864 that killed thousands. More recently, Cyclone Aila in 2009 and Cyclone Amphan in 2020 caused widespread damage to Kolkata by bringing catastrophic winds and torrential rainfall.

Climate data for Kolkata (Alipore) 1981–2010, extremes 1901–2012

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	32.8 (91.0)										34.9 (94.8)	32.5 (90.5)	
Mean maximum °C (°F)	29.8 (85.6)	33.5 (92.3)	37.4 (99.3)				35.9 (96.6)	35.0 (95.0)	35.3 (95.5)	35.1 (95.2)	32.9 (91.2)	29.8 (85.6)	
Average high °C (°F)	25.8 (78.4)	29.2 (84.6)	33.5 (92.3)	35.3 (95.5)	35.3 (95.5)	33.8 (92.8)	32.4 (90.3)	32.2 (90.0)	32.4 (90.3)	32.2 (90.0)	30.1 (86.2)	27.0 (80.6)	31.6 (88.9)
Daily mean °C (°F)	20.0 (68.0)	23.6 (74.5)	28.0 (82.4)	30.4 (86.7)	30.9 (87.6)	30.4 (86.7)	29.4 (84.9)	29.3 (84.7)	29.2 (84.6)	28.1 (82.6)	25.0 (77.0)	21.2 (70.2)	27.1 (80.8)
Average low °C (°F)	14.1 (57.4)	17.8 (64.0)	22.4 (72.3)	25.3 (77.5)	26.4 (79.5)	26.8 (80.2)	26.5 (79.7)	26.4 (79.5)	26.0 (78.8)	24.1 (75.4)	19.7 (67.5)	15.2 (59.4)	22.6 (72.7)
Mean minimum °C (°F)	10.7 (51.3)	12.9 (55.2)	17.6 (63.7)	20.4 (68.7)	21.5 (70.7)	23.7 (74.7)	24.3 (75.7)	24.4 (75.9)	23.8 (74.8)	20.6 (69.1)	15.4 (59.7)	11.8 (53.2)	10.4 (50.7)
Record low °C (°F)	6.7 (44.1)	7.2 (45.0)	10.0 (50.0)	16.1 (61.0)	17.9 (64.2)	20.4 (68.7)	20.6 (69.1)	22.6 (72.7)	20.6 (69.1)	17.2 (63.0)	10.6 (51.1)	7.2 (45.0)	6.7 (44.1)
Average rainfall mm	10.4 (0.41)	20.9 (0.82)	35.2 (1.39)	58.9 (2.32)	133.1 (5.24)					180.5 (7.11)	35.1 (1.38)	3.2 (0.13)	1,836.5 (72.3

(inches)													0)
Average rainy days	1.1	1.7	2.2	3.4	7.0					7.4	1.3	0.5	85.9
Average relative humidity (%) (at 17:30 IST)													
Mean monthly sunshine hours	213.9	211.9	229.4	240.0	232.5	135.0	105.4	117.8	126.0	201.5	216.0	204.6	2,234
Mean daily sunshine hours	6.9	7.5	7.4	8.0	7.5	4.5	3.4	3.8	4.2	6.5	7.2	6.6	6.1
Average ultraviolet index	6	7									7	5	
Source 1:India Meteorological Department (sun 1971–2000)Ultraviolet Index													
Source 2: Tokyo Climate Center (mean temperatures 1981–2010)													

Climate data for Kolkata (Dumdum Airport) 1981–207, extremes 1939–2012

3.1.5. SOIL:

Kolkata has mostly alluvial soil. It is an Indo-Gangetic Plain, the soil and water are predominantly alluvial in origin. Kolkata is located over the "Bengal basin", a pericratonic tertiary basin.

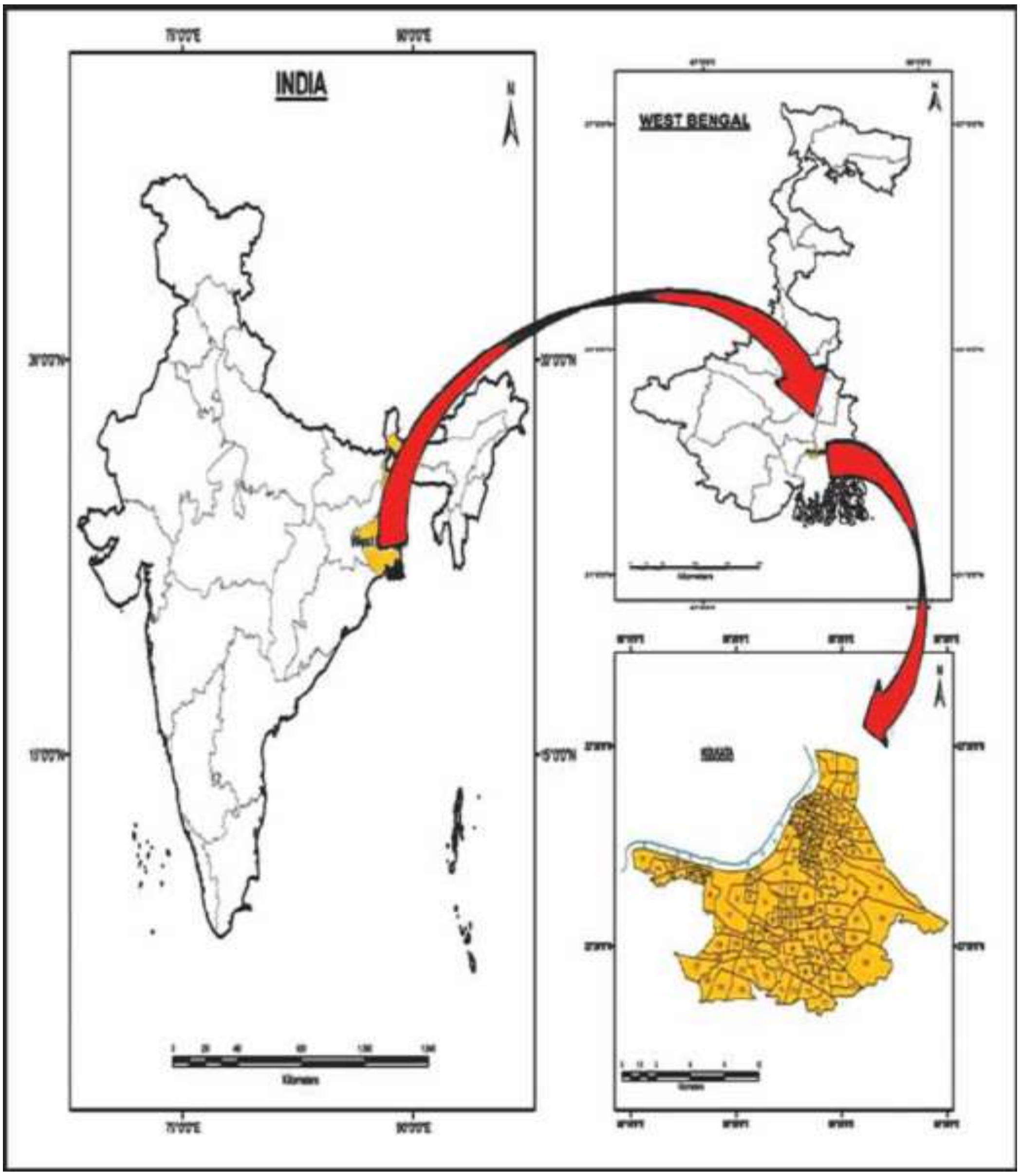


Fig.2. Kolkata: Capital of Indian state of West Bengal

CHAPTER 4: CONCEPTUALISATION

Conceptualisation of Water demand, Water Quality and Water Treatment

4.1. KOLKATA WATER SUPPLY STATISTICS AT A GLANCE:

4.1.1. Source of Water:

The western part of city follows along the right bank of river Hooghly. The river has perennial flow**.** As a result, the city remains at comparatively advantageous position than many other cities in India. The water resources of the river Hooghly is very much precious to us. All the surface water treatment plants at the present moment are located along the right bank of the river.

Surface water and ground water:

There are 4 types of situation: i) Entire water supply from surface water **i**i) Entire water supply from ground water iii) Mixed supply, a combination of both, iv) and last but not least, the rain water harvesting.

Kolkata City water supply is dependent on both surface water source from the river Hugli and ground water sources.

4.1.1.1. Surface Water Sources:

Hooghly River is the main source of potable surface water for the city of Kolkata supplied from the age-old Palta. Water Works now rechristened as Indira Gandhi Water Treatment Plant. The Palta Water Works, spreading over a sprawling stretch of 480 acres, was the first intake point constructed during 1864–1870 for generation and supply of water. Initiated with a capacity of 6 MGD (million gallon per day), filtered water was generated through sedimentation in pre and final settling tanks. Keeping in tune with the growing rate of population and proportionally accelerating rate of demand and keeping in mind the fact, several measures have been taken for enhancement of the capacity and up gradation programmes, apprehending to exceed the demand year wise.

New Palta Water Works at Indira Gandhi Water Treatment Plant is a notable step in this development process. During 2006 the capacity of IGWTP palta was finally enhanced to 260 million gallons every day.

Garden Reach Water Works also plays an important role and having a capacity to produce 120 M.G.D of potable surface water.

Besides, there are two more water treatment plants are in action:

i) Jora bagan water treatment plant: 8MGD,

ii) Watgunge Water Treatment plant: 5MGD

Therefore, IGWTP palta, GRWW and the Water treatment plant at Jora bagan & Watgunge altogether produces 393 MGD treated water.

An underground reservoir of 2.5 MG capacity along with a pumping station is also a part of this project. Raw water for this project is provided by the Raw Water Pumping Station of G.R.W.W Phase II.

Behala Booster Pumping Station: At the beginning , this water treatment plant will supply potable water into the Behala BPS, where from water will be served at its command area including the said municipality The proposed Akra reservoir will also be benefited by this project.

In future, in the adjacent localities like Joka, Thakurpukur, Chota Kalikapur etc., where at present surface water is not reaching the inhabitants, will be provided by potable surface water from this water treatment plant also , for which necessary networks for suitable BPS and pipe line would be completed.

In the year of 2024, about 34 lakhs people will be benefited with adequate potable surface water within its command area.

Thus, the effect of improvement works at Palta Water works along with the increased supply from Garden Reach Water Works, will effect an increase the per capita water supply to 234 liters per day from the present 202 liters per day**.**

4.1.2.Kolkata: Water Supply Statistics at a Glance:

i) Water demand in 2012:293 MGD

ii) Water demand in 2026 :402MGD

iii) Total daily potable water supply (in million litre): 1350 MLD i.e. 300 MGD

iv) Per capita availability of water per day (in litre) :202 litres/per day including 30% UFW

v) Unaccounted water : 35%

vi) Treated surface water supply : 271 MGD

vii) Ground water supply : 25 MGD

viii) No. of Tube Wells Big diameter :439 (power driven)

ix) Small Diameter: 10,050 (hand driven)

x) Average supply hour : 8 hours

xi) No. of connections Domestic: 2,45,019

xii)Coverage of House hold connection :92.70%

xiii) % of house hold covered by surface water : 82.70%

xiv)% of house hold connection by ground water : 10%

xv) Industrial and Commercial: 25,000

xvi)Public Access Standard Posts (in nos.): 17,019

xvii) Unfiltered water through street hydrants (in nos.): 2000

xviii) No. of reservoirs Present:7

ix) Under construction: 14

xx) No of Booster Pumping stations: 17+1 (Tallah)

xxi)No of Booster Pumping stations (under construction) :5

xxii)Length of distribution networks : 5800KM

xxiii) Combined capacity (in million gallon) : 96

4.2. Population Data, Population Growth and Its Calculation

Population Data. The present population of a town or a city can be best determined by conducting an official enumeration, called census. The government of every country generally carries these official surveys at intervals of say about 10 years (called decennial census). Sometimes, smaller period surveys are conducted by State Governments or local bodies. All the useful data available from census department should, therefore, first of all, be collected by the planners of water supply schemes. The data is then used for predicting the future populations of the city at the end of design periods. The present population, if needed, is generally determined by extending the line of the last two preceding enumeration up to the year in question.

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

(i) Births

(ii) Deaths

(iii) Migrations.

Population Forecasting Method. The various methods which are generally adopted for estimating future populations by engineers are described below. Some of these methods are used when the 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 factors discussed in these methods, and the selection is left to the discretion and intelligence of the designer. However, as pointed out earlier, none of these method is exact, and they are all based on the laws of probability, and thus, only approximate estimates for the possible future population can be made.

4.2.1. Arithmetic Increase Method. This method is based upon the assumption that the population increases at a constant rate; i.e. the rate of change of population with time (i.e.$\frac{dP}{dt}$) is constant.

Thus,

$$\frac{dP}{dt} = Constant = K$$

Or $\qquad dP = K.\ dt$

Or $\qquad \int_{p1}^{p2} dP = K \int_{t1}^{t2} dt$

Or $\qquad P_2 - P_1 = K.\ (t_2 - t_1)$

Where suffixes 1 and 2 represent the last and first decades or census, respectively. Thus, $t_2 - t_1$ = No of decades.

The population data for the last 4 to 5 decades, is, therefore, obtained and the population increase per decade (x) is calculated; the average of which ($\bar{x}$) is then used as the *design growth rate* for computing future population.

Thus,

P_1 = Population after 1 decade from present

$= P_0 + 1.\ \bar{x}$

P_2 = Population after 2 decades from present

$= P_1 + 1.\ \bar{x}$

Or $\qquad P_2 = [\ P_0 + 2.\bar{x}\ ] \qquad$ …(i)

Similarly $\qquad P_3 = P_2 + 1.\bar{x}$

Or $\qquad P_3 = [P_0 + 3.\bar{x}\ ] \qquad$ …(ii)

Writing in this fashion, we get

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

Where, P_n = prospective 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 = No of decades between now and future.

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

4.2.2. Geometric Increase Method. In this method, the per decade percentage increase or percentage *growth rate (r)* is assumed to be constant, and the increase is compounded over the existing population *every decade*. The method is, therefore, also known as **uniform increase method.**

The basic difference between arithmetic and geometric progression methods of forecasting future population is that: *whereas, in arithmetic method, no compounding is done*; *in geometric method, compounding is done every decade.* The computations in two methods are, thus, comparable to simple and compound interest computation, respectively.

The assumed *constant value of percentage growth rate per decade (r) is analogous to the 'rate of interest per annum'.*

The above geometric increase can be expressed as:

P_1= Population after 1 decade

$$=P_0 + \frac{r}{100} P_0$$

Where is in percent.

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

Similarly,

P_2 = Population after 2 decades

$$= P_1 + \frac{r}{100}. P_1$$

$$= P_1\left(1 + \frac{r}{100}\right)$$

$$= P_0\left(1 + \frac{r}{100}\right)^2$$

Similarly,

P_3 = Population after 3 decades

$$= P_2 + \frac{r}{100}. P_2$$

$$= P_2\left(1 + \frac{r}{100}\right)$$

$$= P_0\left(1 + \frac{r}{100}\right)^3$$

Proceeding in this way, we can write

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

Where, P_0 = Initial Population; i.e. the population at the end of last known census.

P_n = Future population after n decades.

r = Assumed growth rate (%).

This assumed growth rate (r) can be computed in several ways from the past known population data. One method is to compute, r, as :

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

Where, P_1 = initial known population

P_2 = final known population

t = No. of decades (period)

between P_1 and P_2.

The other method to determine r, is to compare the average of the percentage growth rates of the several known decades of the past.

The growth rates; i.e. $\frac{increase\ in\ population}{original\ population} \times 100\ values,$ are computed for each known decade, and their average may be taken as the assumed constant per decade increase (r).

The average may again be either the arithmetic average i.e.

$$\frac{r_1 + r_2 + r_3 \ldots\ldots\ldots\ldots r_t}{t}$$

Or the geometric average i.e. $\sqrt[t]{r_1.r_2.r_3 \ldots\ldots\ldots\ldots r_t}$

4.2.3. Method of Varying Increment or Incremental Increase Method. In this method, the per decade growth rate is not assumed to be constant as in the arithmetic or geometric progression methods; but is progressively increasing or decreasing, depending upon whether the average of the incremental increases in the past data is positive or negative.

The population for a future decade is worked out by adding the mean arithmetic increase (say $\bar{x}$) to that last known population as in “arithmetic increase method”, and to this 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.

The requisite equation for this method is,

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

Where, P_n = population after n decades from present (i.e. last census)

$\bar{x}$ = average increase of population of known decades.

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

This method will give result somewhere between the results given by ‘arithmetic increase method’ and ‘geometric increase method’ and thus is, considered to be giving quite satisfactory results.

4.2.4. Decreasing Rate of Growth Rate. Since the rate of increase in population goes on reducing, as the cities reach towards saturation, a method which makes use of the decrease in the percentage increase is many a time used, and gives quite rational results. In this method, the average decrease in the percentage increase is worked out, and is then subtracted from the latest, percentage increase for each successive decade. This method is however, applicable only in cases, where the rate of growth shows a downward trend.

4.2.5. Simple Graphical Method. In this method, a graph is plotted from the available data, between time and population. The curve is then smoothly extended up to the desired year. The method, however, gives very approximate results, as the extension of the curve is done by the intelligence of the designer.

4.2.6. Comparative Graphical Method. In this method, the cities having conditions and characteristics similar to the city whose future population is to be estimated are, first of all, selected. It is then assumed that the city under consideration will develop, as the selected similar cities have developed in the past. This method has a logical background, and if statistics of development of similar cities are available, quite precise and reliable results can be obtained. However, it is rather difficult to find identical cities with respect to population growth.

4.2.7. Master Plan Method or Zoning Method. Big and metropolitan cities are generally are not allowed to develop in a haphazard and natural manner, but allowed to develop only in planned ways. The expansions of such cities are regulated by various by-laws of corporations and other local bodies. Only those expansions are allowed, which are permitted or proposed in the master plan of the city.

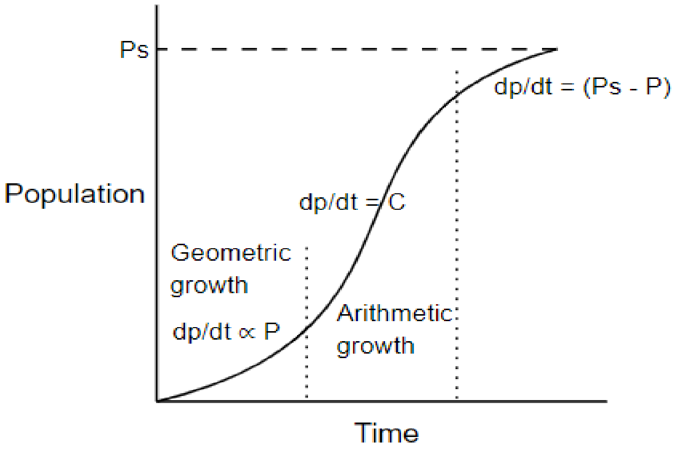
The master plan prepared for a city is generally such as to divide the city in various zone, and thus to separate the residence, commerce, and industry from each other. The population densities are also fixed.

The common figures for population densities which may be taken in master plan preparation or in population estimates are shown below,

Sl No.	Types of Area	No of Persons per hectare
1.	Residential Areas	
	(a) Single family dwellings, large lots	10-40
	(b) Single family dwellings, small lots	40-90
	(c) Multiple family dwellings	90-250
	(d) Apartments or tenement house	250-500 or more
2.	Commercial trade areas	40-75
3.	Industries areas	10-40
4.	Total, exclusive of parks, playground etc.	25-125

4.2.8. The Ratio Method or the Apportionment Method. In this method of forecasting future population of a city or a town, the city’s census population record is expressed as the percentage of the population of the whole country. In order to do so, the local population and the country’s population for the las four to five decades are obtained from the census records. The ratios of the local population to national population are worked out for these decades. A graph is then plotted between time and these ratios, and extended up to the design period, so as to extrapolate the ratio corresponding to the future design year. Sometimes, the last census ratio or the average of the past few areas may be used. This ratio is then multiplied by the expected national population at the end of the design period, so as to obtain the required city’s future population. The expected national population in different future areas are generally available, as they are worked out precisely by the census department by some rational recommended method. This method is, therefore, very suitable for areas whose growths are parallel to the rational growth. However, this method does not take into consideration the abnormal conditions that may prevail in certain local areas.

4.2.9. The Logistic Curve Method. It was explained earlier that under normal conditions, the population of a city shall grow as per the logistic curve shown in fig below. Verhulst has put forward a mathematical solution for this logistic curve.



According to him, the entire curve can be represented by an autocatalytic first order equation given by,

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

Where, P_0 = population at the start point of the curve.

P_s = saturation population.

P = population at any time t from the origin.

K = Constant.

The formula we get,

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

This is the required equation of the logistic curve.

4.3. DRINKING WATER QAULITY

Water is an essential thing for survival of life and thus adequate, safe and accessible water supply must be available to all. Although 3/4th of earth's surface is water, only 1% is available for direct use including drinking and this often requires treatment before it can be used safely. Pure water can never be available in nature. The precipitation, at the instant of its formation holds no impurity but during the process of formation and fall through the earth's atmosphere, it may dissolve some gases, traces of minerals and other substances. When once the precipitation reaches the earth's surface, many more opportunities are presented for the introduction of various physical, chemical or bacterial impurities in it.

The impurity which water dissolves or picks up as suspended matter may sometimes make it more useful and potable for public uses and especially for drinking and sometimes it may render harmful and unfit. For instances, certain minerals such as iron, calcium, magnesium, fluorine etc. in small quantities may be useful and good for health of the people, because human being needs certain amount of these elements in their bodies. But when these materials and others are dissolved in large amount or in certain combinations, the water may become unfit or less useful for municipal, industrial and other uses. For example, sometimes the water may contain toxic or poisonous substances such as arsenic, barium, cadmium, chromium, cyanides, lead, selenium, silver, copper etc which may be very harmful to the public health, even if present in low quantities. Sometimes the water may contain too much of common salt and thereby rendering it brackish and making it undrinkable and less useful for cloth washing or for irrigation and farming. Similarly, sometimes the water may contain harmful bacteria the presence of which may cause disease such as cholera, typhoid, dysentery, gastro-enteritis, jaundice etc. (ref: Peavy, Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering; S.K. Garg 20th edition, Water Supply Engineering and Sincero, Arcadio P. and Sincero Gregoria A., 2011, Environmental Engineering).

4.2. CHARACTERISTICS OF WATER:

The raw or treated water can be checked and analysed by studying and testing their physical, chemical and microscopical characteristics as explained below.

4.3.1. PHYSICAL WATER QUALITY PARAMETER:

Physical parameters define those characteristics of water that respond to the sense of sight, touch, taste or smell. Suspended solids, turbidity, colour, taste, and odour and temperature fall in to this category.

4.3.1.1. Suspended Solids:

Solids can be dispersed in water in both suspended and dissolve forms. Although some dissolve solids may be perceived by the physical senses, they fall more appropriately under the category of chemical parameters.

Solid suspended in water may consist of inorganic or organic particles or of immiscible liquids. Inorganic solids such as clay silt and other soil constituents are common in surface water. Organic material such as plant fibres and biological solids (algal cells, bacteria etc.) are also common constituents of surface water. These materials are often natural contaminants resulting from the erosive action of water flowing over surfaces.

Other suspended material may result from human use of the water. Domestic waste water usually contains large quantities of suspended solids that are mostly organic in nature. Industrial use of water may result in a wide variety of suspended impurities of both organic and inorganic nature. Immiscible liquids such as oil and greases are often constituents of waste water.

Suspended material may be objectionable in water for several reasons. It is aesthetically displeasing and provides adsorption sites for chemical and biological agents. Suspended organic solids may be degraded biologically, resulting in objectionable by-products. Biologically active (live) suspended solids may include disease-causing organisms as well as organisms such as toxin-producing strains of algae.

Most suspended solids can be removed from water by filtration. (Ref: Peavy, Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering).

4.3.1.2 TURBIDITY:

Turbidity is a measure of the extent to which light is either adsorbed or scattered by suspended material in water. Because adsorption and scattering are influenced by both size and surface characteristics of the suspended material, turbidity is not a direct quantative measurement of suspended solids.

Most turbidity in surface water result from the erosion of colloidal material such as clay, silt, rock fragments and metal oxidises from the soil. Vegetable fibres and microorganisms may also contain a wide variety of turbidity-producing material. Soaps, detergents and emulsifying agents produce stable colloids that result in turbidity.

When turbid water in a small, transparent container, such as drinking glass, is held up to the light, an aesthetically displeasing opaqueness or milky colouration is apparent. The colloidal material associated with turbidity provides adsorption sites for chemicals may be harmful or cause undesirable tastes and odours and for biological organisms that may be harmful.

In natural water bodies, turbidity may impart a brown or other colour to water, depending on the light-absorbing properties of solid and may interfere with light penetration and photosynthetic reactions in streams and lakes.

Fortunately, traditional water treatment process has the ability to effectively remove turbidity when operated properly.

Turbidity is measured by Digital Nephelo Turbidity Meter. (Ref: Peavy, Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering)

4.3.1.3. COLOUR:

Pure water is colourless, but water in nature is often coloured by foreign substances. Water whose colour is partly due to suspended matter is said to have apparent colour. Colour contributed by dissolved solids that remain after removal of suspended matter is known as true colour.

Coloured water is not aesthetically acceptable to the general public. In fact, given a choice, consumers tend to choose clear, no coloured water of otherwise poorer quality over treated potable water supplies with an objectionable colour. Highly coloured water is unsuitable for laundering, dyeing, papermaking, beverage manufacturing, dairy production and other food processing and textile and plastic production. Thus, the colour of water affects its marketability for both domestic and industrial use.

While true colour is not usually considered unsanitary or unsafe, the organic compound causing true colour may exert a chlorine demand and thereby seriously reduce effectiveness of chlorine as a disinfectant. Perhaps more important are the products formed by the combination of chlorine with some colour-producing organics. Phenolic compound, common constituents of vegetative decay products produce very objectionable taste and colour compounds with chlorine. Additionally, some compounds of naturally occurring organic acids and chlorine are either known to be, or are suspected of being carcinogens (cancer causing agents)

4.3.1.4 TASTE AND ODOUR:

The terms taste and odour are themselves definitive of this parameter. Because the sensation of taste and smell are closely related and often confused, a wide variety of tastes and odours may be attributed to water by consumers. Substances that produce an odour in water will almost invariably impart a taste as well. The converse is not true, as there are many mineral substances that produce taste but no odour.

Many substances with which water comes into contact in nature or during human use may impart perceptible taste and odour. These include minerals, metals and salts from the soil, end products from biological reactions and constituents of wastewater. Inorganic substances are more likely to produce tastes unaccompanied by odour. Alkaline material imparts a bitter taste to water, while metallic salts may give a salty or bitter taste. Organic material, on the other hand, is likely to produce both taste and odour. Biological decomposition of organics may also result in taste and odour producing liquids and gases in water. Principles among these are the reduced products of sulphur that impart a “rotten egg” taste and odour. Also, certain spices of algae secret and oily substances that may result in both taste and odour.

Consumers find taste and odour aesthetically displeasing for obvious reasons. Because water is thought of as tasteless and odourless, the consumer associates taste and odour with contamination and may prefer to use a tasteless, odourless water that might actually pose more of a health threat.

4.3.1.5. TEMPERATURE:

Temperature is not used to evaluate directly either potable water o wastewater. It is, however, one of the most important parameter in natural surface water systems. The temperature of surface water governs to a large extent the biological spices present and their rates of activity. Temperature has an effect on most chemical reactions that occur in natural water systems. Temperature also has a pronounced effect on the solubility of gases in water.

The temperature of natural water system response to many factors, that ambient temperature (temperature of the surrounding atmosphere) being the most universal. Generally, shallow bodies of water are more affected by ambient temperatures that are deeper bodies. The use of water for dissipation of waste heat in industry and the subsequence discharge of the heated water may result in dramatic, though perhaps localised, temperature changes in receiving streams.

4.3.2. CHEMICAL WATER QUALITY PARAMETERS:

Water has been called the universal solvent and chemical parameters are related to the solvent capabilities of water. Total dissolved solids, pH value, alkalinity, hardness, fluorides, metals, organics and nutrients are chemical parameter of concern in water-quality management. The following review of some basic chemistry related to solutions should be helpful in understanding subsequent discussion of chemical parameters.

4.3.2.1. TOTAL DISSOLVE SOLIDS:

The material remaining in the water after filtration for suspended solids analysis is considered to be dissolved. This material is left as a solid residue upon evaporation of the water and constitutes a part of total solids. Dissolved material results from the solvent action of water , solids, liquids and gases. Like suspended material, dissolved substances may be organic or inorganic in nature. Inorganic substances which may be dissolved in water include minerals, metals and gases. Water may come in contact with these substances in the atmosphere, on surfaces and within the soil materials from the decay products of vegetation, from organic chemical and from the organic gases are common organic dissolve constituents of water. The solvent capability of water makes it an ideal means by which waste products can be carried away from industrial sites and homes.

Many dissolved substances are undesirable in water. Dissolved minerals, gases and organics constituents may produce aesthetically displeasing colour, tastes, and odours. Some chemical may be toxic and some of the dissolved organics constituents have been shown to be carcinogenic. Quite often, two or more dissolved substances specially organic substances and members of the halogen groups will combine to form a compound whose characteristics are more objectionable than those of either of the original materials.

Not all dissolved substances are undesirable in water. For example, essentially pure distilled water has a flat taste. Additionally, water has an equilibrium state with respect to dissolved constituents.

A direct measurement of total dissolved solids can be made by evaporating to dryness a sample of water which has been filtered to remove the suspended solids. The remaining residue is weighed and represents the total solids (TDS) in the water. (Ref: Peavy. Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering).

4.3.2.2. pH VALUE OF WATER:

The pH value of water indicates the logarithm of reciprocal of hydrogen ion concentration present in water. It is thus an indicator of the acidity or the alkalinity of water.

Since the pH is the log of reciprocal of H+, the higher values of pH means lower hydrogen ion concentration and thus represent alkaline solutions; whereas, the lower values of pH means higher hydrogen ion concentrations representing acidic solutions.

Truly speaking, pure water is a balanced combination of positively charged hydrogen ions (i.e. H+) and negatively charged hydroxyl ions (i.e. OH-). In pure or natural waters, their number is equal. Further, it has been found that the product of concentration of H ions and concentration of OH ions in a water solution is constant. This has been found to be equal to 10^{-14} moles/litre. Therefore, if H ion and OH ion concentrations are equal, virtually each will have a concentration equal to $\sqrt{10^{-14}} = 10^{-7}$ moles per litre. A neutral water will, therefore, have a pH equal to $\log_{10} (1/H+) = \log_{10} (1/10^{-7}) = \log_{10} 10^{7} = 7$.

If an acid is added to the neutral or pure water, the number of hydrogen ions will increase because of the hydrogen contained in the acid. For example, if hydrochloric acid is dissolved in water, the dissociation becomes

$$H_2O \leftrightharpoons H^+ + OH^-$$

$$HCL \leftrightharpoons H^+ + Cl^-$$

Then the next concentration of hydrogen ions will exceed that of hydroxyl ions and will be more than the hydrogen ion concentration of neutral water (i.e. 10^{-7}) and thus decreasing the pH value to less than 7 and thereby making the water acidic.

Similarly, if an alkali is dissolved in pure water, the concentration of hydroxyl ions will exceed the hydroxyl ion concentration of neutral water and thus, reducing the concentration of hydrogen ions to less than 10^{-7}. (Their product being constant = 10^{-14} moles/litre). For example, if sodium hydroxide is added to water, the dissociation will be

$$H_2O \leftrightharpoons H^+ + OH^-$$

$$NaOH \leftrightharpoons Na^+ + OH^-$$

The net amount of OH ions present in the alkaline water will, therefore, be more than that present in neutral water and thus reducing the hydrogen ion concentration to less than 10^{-7} and thereby increasing the pH above 7 and making the water alkaline.

Hence, if the pH of water is more than 7, it will be alkaline and if it is less than 7, it will be acidic. The maximum acidity will be at 0 value of pH and the maximum alkalinity will at a value of pH=14.

Testing the pH value of water, therefore, directly tells us as to whether the water is acidic or is alkaline.

However, the permissible pH value for public supplies may range between 6.6 to 8.5.

pH is measured by the Digital pH Meter.

(Ref: Peavy, Howard S. and Rowe, Donald R., Edition 2013, Environmental Engineering S.K.Garg, 20th revised edition, 2010 Water Supply Engineering).

4.3.2.3. ALKALINITY:

Alkalinity is defined as the quantity of ions that will react to neutralise hydrogen ions. Alkalinity is thus a measure of ability of water to neutralise water.

The most common constituents of alkalinity are Bicarbonate (HCO_3^-), Carbonate ($CO_3^=$) and hydroxyl (OH^-). In addition to their mineral origin, these substances can originate from carbon di oxide, a constituent of the atmosphere and a product of microbial decomposition of organic material. These reactions are as follows:

$$CO_2 + H_2O \leftrightharpoons H_2CO_3 \text{ (dissolved } CO_2 \text{ and carbonic acid)}$$

$$H_2CO_3 \leftrightharpoons H^+ + HCO_3^- \text{ (bicarbonate)}$$

$$HCO^-_3 \leftrightharpoons H^+ + CO_3^= \text{ (carbonate)}$$

$$CO_3^= + H_2O \leftrightharpoons HCO_3^- + OH^- \text{ (hydroxide)}$$

In large quantities, alkalinity imparts a bitter taste to water. The principle objection to alkaline water, however, is the reactions that occur between alkalinity and certain cations in the water. The resultant precipitate can foul pipes and other water-system appurtenances. (Ref: Peavy, Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering)

4.3.2.4. HARDNESS:

Hardness is defined as the concentration of multivalent metallic cations in solution. At super saturated conditions the hardness cations will react with the anions in the water to form a solid precipitate. Hardness is classified as carbonate hardness and non-carbonate hardness, depending upon than ions with which it associates. The hardness that is equivalent to the alkalinity is termed carbonate hardness, with any remaining hardness being called non carbonate hardness.

Carbonate hardness is sensitive to heat and precipitates readily at high temperature.

$$Ca\,(HCO_3)_2 \rightarrow CaCO_3 + CO_2 + H_2O$$

$$Mg\,(HCO_3)_2 \rightarrow Mg\,(OH)_2 + 2CO_2$$

The multivalent metallic ions most abundant in natural waters are calcium and magnesium. Hardness may be represented by the sum of the calcium and magnesium ions.

Hard water is undesirable because they may lead to greater soap consumption, scaling of boilers, causing corrosion and incrustation of pipes, making foods tasteless etc.

$2NaCO_2C_{17}H_{33} + \text{Cation}^{2+} \rightarrow \text{Cation}^{2+} + (CO_2C_{17}H_{33})_2 \downarrow + 2Na^+$

Soap Precipitation

Magnesium hardness, particularly associated with the sulphate ion, has a laxative effect on persons unaccustomed to it. Magnesium concentration of less than 50 mg/l is desirable in potable water, although many public water supplies exceed this amount. Calcium hardness presents no public health problem. In fact, hard water is apparently beneficial to the human cardiovascular system.

Hardness can be measured by using spectrophotometric techniques or chemical titration to determine the quantity of calcium and magnesium ions in a given sample.

A generally accepted classification is as follows:

Soft	< 50 mg/l as $CaCO_3$
Moderately hard	50 to 150 mg/l as $CaCO_3$
Hard	150 to 300 mg/l as $CaCO_3$
Very hard	> 300 mg/l as $CaCO_3$

(Ref: Peavy, Howard S. and Rowe, Donald R., Edition 2013, Environmental Engineering and Garg, S.K., twentieth edition, 2010, Water Supply Engineering).

4.3.2.5.FLUORIDE:

Generally associated in nature with a few types of sedimentary or igneous rocks, fluoride is seldom found in appreciable quantities in surface water and appears in groundwater in only a few geographical regions. Fluoride is toxic to humans and other animals in large quantities, while small concentration can be beneficial. Concentration of approximately 1.0 mg/l in drinking water helps to prevent dental cavities in children. During formation of permanent teeth, fluoride combines chemically with tooth enamel, resulting in harder, stronger teeth that are more resistant to decay. Fluoride is often added to drinking water supplies if sufficient quantities for good dental formation are not naturally present.

Excessive intakes of fluoride can result in discolouration of teeth. Noticeable discolouration, called mottling or dental fluorosis is relatively common when fluoride concentration in drinking water exceed 2.0 mg/l, but is rare when concentration are less than 1.5 mg/l. Adult teeth are not affected by fluoride. Excessive dosage of fluoride can also result in bone fluorosis and other skeletal abnormalities.

4.3.2.6. CHLORIDE:

Chloride is widely distributed in nature, generally as the sodium (NaCl) and potassium (KCl) salts. By far the greatest amount of chloride found in the environment is in the oceans.

Sodium Chloride is widely used in the production of industrial chemicals such as caustic soda (sodium hydroxide), chlorine, soda ash (sodium carbonate), Sodium chlorite, Sodium Bicarbonate and Sodium hypochlorite. Potassium chloride is used in the production of fertilizers.

The presence of chloride in drinking water sources can be attributed to the dissolution of salt deposits, leaching of marine sedimentary deposit, seawater intrusion in coastal areas, effluents from chemical industries, oil well operations, sewage, irrigation drainage etc. Each of these sources may result in local contamination of surface water and groundwater. The chloride ion is highly mobile and is eventually transported into closed basins or to the oceans.

Chloride is an essential element and is the main extracellular anion in the body. It is a highly mobile ion that easily crosses cell membranes and is involved in maintaining proper osmotic pressure, water balance and acid base balance.

The toxicity of chloride salts depends on the cation present that of chloride itself is unknown. Although excessive intake of drinking water containing sodium chloride at concentration above 2.5g/l has been reported to produce hypertension, this effect is believed to be related to the sodium ion concentration.

Chloride toxicity has not been observed in humans except in the special case of impaired sodium chloride metabolism, e.g. in congestive heart failure. Healthy individual can tolerate the intake of fresh water. Little is known about the effect of prolonged intake of large amounts of chloride in the diet. As in experimental animals, hypertension associated with sodium chloride intake appears to be related to the sodium rather than the chloride ion.

4.3.2.7. METAL:

All metals are soluble to some extent in water. While excessive amounts of any metal may present health hazards, only those metals that are harmful in relatively small amounts are commonly labelled toxic; other metals fall into the nontoxic group. Sources of metals in natural water include dissolution from natural deposits and discharges of domestic, industrial, or agricultural wastewaters. Measurement of metals in water is usually made by atomic absorption spectrophotometry.

4.3.2.7.1. NONTOXIC METAL:

In addition to the hardness ions, calcium and magnesium, other nontoxic metals commonly found in water include sodium, iron, manganese, aluminium, copper and zinc.

4.3.2.7.1.1. SODIUM:

Sodium by far the most common nontoxic metal found in natural water is abundant in the earth's crust and is highly reactive with other elements. The salts of sodium are very soluble in water. Excessive concentrations cause a bitter taste in water.

Sodium is also corrosive to metal surfaces and in large concentrations, is toxic to plants.

4.3.2.7.1.2. IRON AND MANGANESE:

Iron and manganese quite frequently occur together and present no health hazards at concentrations normally found in natural water. Iron and manganese in very small quantities may cause colour problems. Iron concentration of 0.3mg/l and manganese concentration as low as 0.05mg/l can cause colour problems. Additionally, some bacteria use iron and manganese compounds for energy source and the resulting slime growth may produce taste and odour problems.

4.3.2.7.2. TOXIC METALS:

Toxic metals are harmful to humans and other organisms in small quantities. Toxic metals that may be dissolved in water include arsenic, barium, cadmium, chromium, lead, mercury and silver. Cumulative toxins such as arsenic, cadmium, lead and mercury are particularly hazardous. These metals are concentrated by the food chain, thereby posing the greatest danger to organisms near the top of the chain.

Fortunately, toxic metals are present in only minute quantities in most natural water system. Although natural sources of all toxic metals exist, significant concentration in water can usually be traced to mining, industrial or agricultural sources.

4.3.2.8. ORGANICS:

Many organic materials are soluble in water. Organics in natural water systems may come from natural sources or may result from human activities. Most natural organics consist of the decay products of organic solids, while synthetic organics are usually the result of wastewater discharges or agricultural practices. Dissolved organics in water are usually divided into two broad categories: biodegradables and non-biodegradable (refractory).

4.3.2.8.1. BIODEGRADABLE ORGANICS:

Biodegradable material consists of organics that can be utilized for food by naturally occurring microorganisms within a reasonable length of time. In dissolved form, these materials usually consist of starches, fats, proteins, alcohols, acids, aldehydes, and esters. They may be the end product of the initial microbial decomposition of plant or animal tissue or they may result from domestic or industrial wastewater discharges. Although some of these materials can cause colour, taste and odour problems, the principal problem associated with bio-degradable organics is a secondary effect resulting from the action of microorganisms on these substances.

Microbial utilization of dissolved organics can be accompanied by oxidation (addition of oxygen to, or the deletion of hydrogen from elements of the organic molecule) or by reduction (addition of hydrogen to, or deletion of oxygen from elements of the organic molecule). Although it is possible for the two processes to occur simultaneously, the oxidation process is by far more efficient and is pre-dominant when oxygen is available. In aerobic (oxygen-present) environments, the end products of microbial decomposition of organics are stable and acceptable compounds. Anaerobic (oxygen-absent) decomposition results in unstable and objectionable end products. Should oxygen later become available, anaerobic end products will be oxidized to aerobic end products.

The amount of oxygen consumed during microbial utilization of organics is called the biochemical oxygen demand (BOD).

4.3.2.8.2. NONBIODEGRDABLE ORGANICS:

Some organic materials are resistant to biological degradation. Tannic and lignic acids, cellulose and phenols are often found in natural water systems. These constituents of woody plants biodegrade so slowly that they are usually considered refractory. Molecules with exceptionally strong bonds (some of the polysaccharides) and ringed structures (benzene) are essentially nonbiodegradable.

4.3.2.9. NUTRIENTS:

Nutrients are elements essential to the growth and reproduction of plants and animals and aquatic species depend on the surrounding water to provide their nutrients. Although a wide variety of minerals and trace elements can be classified as nutrients, those required in most abundance by aquatic species are carbon, nitrogen, and phosphorus. Carbon is readily available from many sources. Carbon dioxide from the atmosphere, alkalinity and decay products of organic matter all supply to carbon to the aquatic system. In most cases, nitrogen and phosphorus are the nutrients that are the limiting factors in aquatic plant growth.

4.3.2.9.1. NITROGEN:

Nitrogen gas (N_2) is the primary component of the earth's atmosphere and is extremely stable. It will react with oxygen under high-energy conditions (electrical discharges or flame incineration) to form nitrogen oxides. Although a few biological species are able to oxidize nitrogen gas, nitrogen in the aquatic environment is derived primarily from sources other than atmospheric nitrogen.

Nitrogen is a constituent of proteins, chlorophyll and many other biological compounds. Upon the death of plants or animals, complex organic matter is broken down to simple forms by bacterial decomposition. Proteins, for instance, are converted to amino acids and further reduced to ammonia (NH_3). If oxygen is present, the ammonia is oxidised to nitrite (NO_2) and then to nitrate (NO_3). The nitrate can then be reconstituted into living organic matter by photosynthetic plants.

Nitrate poisoning in infant animals, including humans, can cause serious problems and even death. Apparently, the lower acidity in an infant's intestinal tract permits growth of nitrate reducing bacteria that convert the nitrate to nitrite, which is then absorbed into the bloodstream. Nitrite has a greater affinity for haemoglobin than does oxygen and thus replaces oxygen in the blood complex. The body is denied essential oxygen and in extreme cases, the victim suffocates. Because oxygen starvation results in a bluish discoloration of the body, nitrate poisoning has been referred to as the "blue baby" syndrome, although the correct term is methemoglobinemia. Once the flora of the intestinal tract has fully developed, usually after the age of 6 months, nitrate conversion to nitrite and subsequent methemoglobinemia from drinking water is seldom a problem. Fortunately, the natural oxidation of nitrite to nitrate occurs quickly so that significant quantities of nitrites are not found in natural water. (Ref: Peavy, Howard S. and Rowe, Donald R., edition 2013, Environmental Engineering).

4.3.2.9.2. PHOSPHORUS:

Phosphorus appears exclusively as phosphate (PO_4^{3-}) in aquatic environments. There are several forms of phosphate, however, including orthophosphate, condensed phosphate (pyro-, meta-, and polyphosphates) and organically bound phosphates. These may be in soluble or particulate form or may be constituents of plant or animal tissue. Like nitrogen, phosphates pass through the cycles of decomposition and photosynthesis. Phosphate is a constituent of soils and is used extensively in fertilizer to replace and or supplement natural quantities on agricultural lands. Phosphate is also a constituent of animal waste and may become incorporated into the soil in grazing and feeding areas. Runoff from agricultural areas is a major contributor to phosphate in surface water. The tendency for phosphate to adsorb to soil particle limits its movement in soil moisture and groundwater, but results in its transport into surface water by erosion.

Municipal waste water is another major source of phosphate in surface water.

4.3.3. BIOLOGICAL WATER – QUALITY PARAMETERS:

Water may serve as a medium, in which literally thousands of biological species spend part, if not all, of their life cycles. Aquatic organisms range in size and complexity from the smallest single-cell microorganism to the largest fish. All members of the biological community are, to some extent, water-quality parameters, because their presence or absence may indicate in general terms the characteristics of a given body of water.

4.3.3.1. PATHOGENS:

From the perspective of human use and consumption, the most important biological organisms in water are pathogens, those organisms capable of infecting, or of transmitting diseases to, humans. These organisms are not native to aquatic systems and usually require an animal host for growth and reproduction. They can, however, be transported by natural water systems, thus becoming a temporary member of the aquatic community. Many species of pathogens are able to survive in water and maintain their infectious capabilities for significant periods of time. These waterborne pathogens include species of bacteria, viruses, protozoa and Helminths (parasitic worms).

4.3.3.1.1. BACTERIA:

The word bacteria comes from the Greek word meaning “rod” or “staff”, a shape characteristics of most bacteria. Bacteria are single-cell microorganisms, usually colourless, and are the lowest form of life capable of synthesizing protoplasm from the surrounding environment. In addition to the road shape (bacilli) mentioned above, bacteria may also be spherical (cocci) or spiral-shaped (spirilla). Gastrointestinal disorders are common symptoms of most diseases transmitted by waterborne pathogenic bacteria. Cholera, the disease that ravaged Europe during the eighteenth and nineteenth centuries, is transmitted by Vibrio comma. Among the most violent of the waterborne bacterial diseases, cholera causes vomiting and diarrhoea that, without treatment, result in dehydration and death. Symptoms of typhoid, a disease transmitted by the waterborne pathogen, Salmonella typhosa, include gastrointestinal disorders, high fever, and ulceration of the intestines and possible nerve damage. Although immunization of individuals and disinfection of water supplies have eliminated cholera and typhoid in most parts of the world, areas of developing countries where overcrowding and poor sanitary conditions prevail still experience occasional outbreaks of these two diseases.

4.3.3.1.2. VIRUSES:

Viruses are the smallest biological structures known to contain all the genetic information necessary for their own reproduction. So small that they can only be "seen" with the aid of an electronic microscope, viruses are obligate parasites that require a host in which to live. Symptoms associated with waterborne viral infections usually involve disorders of the nervous system rather than of the gastrointestinal tract. Waterborne viral pathogens are known to be, or suspected of being, waterborne.

Immunization of individuals has reduced the incidence of polio to few isolated cases each year in developed nations.

4.3.3.1.3. PROTOZOA:

The lowest form of animal life, protozoa is unicellular organisms more complex in their functional activity than bacteria or viruses. They are complete, self-contained organisms that can be free-living or parasitic, pathogenic or non-pathogenic, microscopic or macroscopic. Highly adaptable, protozoa are widely disturbed in natural water, although only a few aquatic protozoa are pathogenic. Protozoal infections are usually characterised by gastrointestinal disorders of a milder order than those associated with the bacterial infections. Protozoal infections can be serious nonetheless, as illustrated by an epidemic in Chicago in 1993 in which over 1400 people were affected and 98 deaths resulted when drinking water was contaminated by sewage containing Entamoeba Histolytic. Many cases of giardiasis, or back papers disease, have been reported in recent years among persons that drank untreated water from surface streams. This infection is caused by Giardia lamblia, a protozoan that may be carried by wild animals living in or near natural water systems. Under adverse environmental circumstances, aquatic protozoa form cysts that are difficult to deactivate by disinfection. Usually complete treatment, including filtration, is necessary to remove protozoa cysts.

4.3.3.1.4. HELMINTHS:

The life cycle of helminths, or parasitic worms, often involve or two or more animal hosts, one of which can be human and water contamination may result from human or animal waste that contains helminths. Contamination may also be via aquatic species of other hosts, such as snails or insects. While aquatic systems can be the vehicle for transmitting helminthal pathogens, modern water-treatment methods are very effective in destroying these organisms. Thus, helminths pose hazards primarily to those persons who come into direct contact with untreated water. Sewage plant operators, swimmers in recreational lakes polluted by sewage or storm water runoff from cattle feedlots, and farm labourer employed in agricultural irrigation operations are at particular risk.

4.3.3.2. PATHOGEN INDICATORS:

An indicator organism is one whose presence presumes that contamination has occurred and suggests the nature and extent of the contaminants. The ideal pathogen indicator would (1) be applicable to all types of water, (2) always be present when pathogens are present, (3) always be present when pathogens are present, (4) lend itself to routine quantative testing procedures without interference from or confusion of results because of extraneous organisms and (5) for the safety of laboratory personnel, not be a pathogen itself.

Most of the waterborne pathogens are introduced through faecal contamination of water. Thus, any organism native to the intestinal tract of humans and meeting the above criteria would be a good indicator organism. The organisms most nearly meeting these requirements belong to the faecal coliform group. Composed of several strains of bacteria, principal of which is Escherichia Coli, these organisms are found exclusively in the intestinal tract of warm-blooded animals and are excreted in large numbers with feces. Fecal coliform organisms are non-pathogenic and are believed to have a longer survival time outside the animal body than do most pathogens.

The total coliform group is widely used as the indicator organism of choice for drinking water. The major criticism of this group as an indicator is that some of its members (such as Enterobacter aerogenes) are widely distributed in the environment. However, when it is assumed that all of its members originated in feces, a safety factor is provided. This approach is reasonable when applied to provision of safe drinking water but suffers when fecal contamination of water is suspected.

4.4. WATER-QUALITY REQUIREMENTS:

Water-quality requirements vary according to the proposed use of the water. Water unsuitable for one use may be quite satisfactory for another and water may be deemed acceptable for a particular use if water of better quality is not available.

Water –quality requirements should not be confused with water-quality standards. Set by the potential user, water-quality requirements represent a known or assumed need and are based on the prior experience of the water user. Water-quality standards are set by a governmental agency and represent a statutory requirement.

4.5. WATER QUALITY STANDARDS:

As per **WHO** guidelines, the safe drinking water does not represent any significant risk to health over a lifetime of consumption including different sensitivities that may occur between life stages.

As per **IS 10500-2012 (drinking water-specification),** drinking water is defined as the water which is intended for human consumption for drinking and cooking purposes from any source and it includes water (treated or untreated) supplied by any means for human consumption.

According to this code, drinking water shall comply with the specified requirements of physical parameters, chemical parameters.

Table 1: ORGANOLEPTIC AND PHYSICAL PARAMETERS AS PER IS 10500-2012:

Sl No.	Characteristics	Unit	Requirement (Acceptable Limit)	Permissible limit in the absence of alternate source	Remarks
1.	Colour	Hazen units, Max	5	15	Extended to 15 only, if toxic substances are not suspected in absence of alternate source.
2.	Odour		Agreeable	Agreeable	a) Test cold and when heated b)Test at several dilutions
3.	pH Value		6.5-8.5	No relaxation	-
4.	Taste		Agreeable	Agreeable	Test to be conducted only after safety has been established

5.	Turbidity	NTU, Max	1	5	-
6.	Total Dissolved Solids (TDS)	Mg/l, Max	500	2000	-

Table 2: General Chemical Parameters concerning substances undesirable in excessive amounts as per IS 10500-2012:

Sl No.	Characteristics	Unit	Requirement (acceptable limit)	Permissible limit in the absence of alternate source
1.	Chloride (as Cl)	Mg/l, Max	250	1000
2.	Fluoride (as F)	Mg/l, Max	1	1.5
3.	Total Hardness (as CaCO3)	Mg/l, Max	200	600
4.	Aluminium (as Al)	Mg/l, Max	0.03	0.2
5.	Ammonia (as total ammonia-N)	Mg/l, Max	0.5	No Relaxation
6.	Calcium (as Ca)	Mg/l, Max	75	200
7.	Copper (as Cu)	Mg/l, Max	0.05	1.5
8.	Free residual chlorine	Mg/l, Max	0.2	1.0
9.	Iron (as Fe)	Mg/l, Max	1.0(as per latest corrigendum)	1.0(as per latest corrigendum)
10.	Magnesium (as Mg)	Mg/l, Max	30	100
11.	Manganese (as Mn)	Mg/l, Max	0.1	0.3
12.	Nitrate (as NO_3)	Mg/l, Max	45	No Relaxation
13.	Sulphate (as SO_4)	Mg/l, Max	200	400
14.	Total Alkalinity	Mg/l, Max	200	600
15.	Zinc (as Zn)	Mg/l, Max	5	15

Table 3: Bacteriological quality of drinking water as per IS 10500-2012

Sl No.	Organisms	Requirements
1.	All water intended for drinking: a) E. Coli or thermotolerant coliform	Shall not be detectable in any 100 ml sample
2.	Treated water entering the distribution system: a) E. Coli or thermotolerant coliform bacteria b) Total coliform bacteria	a) shall not be detectable in any 100ml sample b) Shall not be detectable in any 100 ml sample.
3.	Treated water in distribution system: a) E Coli or thermotolerant coliform bacteria b) Total coliform bacteria	a) shall not be detectable in any 100 ml sample b) Shall not be detectable in any 100 ml sample.

4.6. DIFFERENT UNITS OF GARDEN REACH WATER WORKS:

4.6.1. Garden Reach Water Works

Garden reach water works under K.M.W & S.A Plant was constructed to supply water in Kolkata and nearby areas. In 1985 Water treatment Plant was constructed at Garden Reach of 60 MGD capacity to provide water to South Kolkata. Later in 2002 GRWW capacity was increased to 120 MGD.

There are two working phase for the treatment plant and the third phase is under construction.

The treatment plant comprise of –

1. Collection of Water
2. Conveyance of Water
3. Treatment and Purification of Water
4. Distribution of water to the consumer

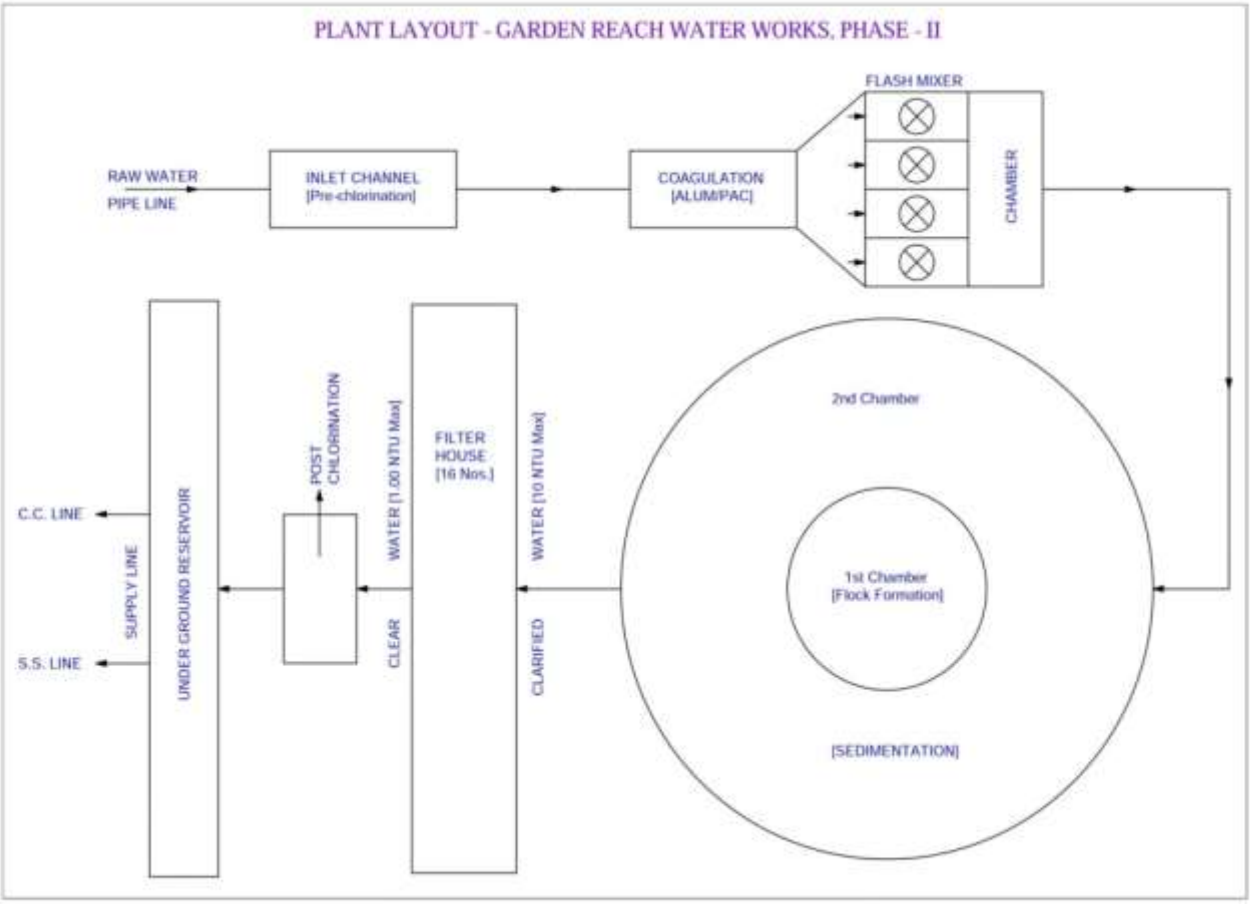


Figure 3 Flow chart of Methods of purification in GRWW

4.6.1.1. Phase I and Phase II:

In Phase I and Phase II of GRWW, *Clari - Flocculation* is done by a *Clari – Floculator* by bringing the raw water from the Ganga, with a detention period of 55 minutes. There are 16 *Filter Beds* to execute the process of *Back Wash*. Back Wash by only water is done in Phase I and Air Back Washing is done in Phase II of Garden Reach Water Works. *Clear Water Reservoir* and *Clear Water Pump House* exist in both the phases. Some details of these two phases are:

1. For a Jetty Structure 120 MS Shaft Piles of 125 mm dia. are spaced at 2500 mm c/c and driven 22 mm below the deck level. They are suitably braced with R.S.J Clamps.
2. For Suction Pipes 1550 mm dia. and 12 mm thick fabricated mild steel having a total length of 25 m is used.
3. Three 770 kW motors, three 680 HP Pumps having a capacity of 1580 LPS under 20.7 m head is available in Raw Water Pumping Station.
4. 1575 mm dia. and 12 mm thick fabricated steel of total length 3.7 km is used for Raw Water Rising Main.

5. Two mixing Zones in series of total capacity 2000 cumec to allow detention period of about 60 seconds with arrangement for electrically driven agitation are present.

Clari-Floculator: Four Units each of 54.89 m dia. and the side water depth of 4.127 m with flocculation compartment of diameter 22.86 m. The Overflow Rate is 37000 Lit/cumec/day and Flocculation Period of 35 minutes with a local detention time of 215 minutes.

Figure 4 Clari-Floculator

Filter: 60 Rapid Sand Gravity Filter of rating 6 cumec/sq. m/hour and each bed of approximately 125 sq. m filtration area. The depth of media consists of 1150 mm comprising 625 mm Sand supported by 525 mm Gravel.

6. Capacity of 84150 cumec is divided in three interconnected chamber in clear water reservoir
7. Three 1875 KM Motors, three 2180 HP Pumps with capacity of 2120 LPS under 67 m head is available as filter water pumping station.
8. For primary grid, Kolkata System of 5725km and Municipal System of 41570 km is working.
9. For secondary grid, Sothern Sub urban Municipality of 135 km and Budge Budge Municipality of 10 km is working.

Figure 5 Filter

4.6.1.2. Phase III:

A new phase is being constructed in Garden Reach Water Treatment Plant, which is modified compare to the other two phases (Phase I and Phase II) and capacity of the new phase is 15 MGD/day.

Some special attention is given to the new scheme here. There are many changes that have been implemented in this phase as compared to the other two phases from construction point of view. The cost amount of this new phase is approximately Rs 23 crores. The new phase is being constructed since two years, with the help of some civil engineers and co- workers.

Some of the equipment's used in this phase is:

a) Chemical House
b) One tube settler and clarifier
c) Rapid sand filter with some beds
d) One sludge point with four inlet
e) Clear water pump house
f) Ground water reservoir
g) Settling tank
h) Some special process for back washing like air backwashing.

This project will increase the water distribution capacity in Kolkata as well as at the side area in Kolkata.

Garden Reach water works has a capacity to produce 120MGD of portable surface water in a day. There exist some pockets where the inhabitants are not getting sufficient quantity of water and this condition may aggravate further due to the increase population.

Considering this issues, it has been proposed to augment the present capacity of Garden Reach Water Works by another 15 MGD plant. This plant is designed to consist of a rapid sand filtration system with a pre-treatment unit of flocculation and plate settler type of clarifier. An underground reservoir of 2.5 MG along with a pumping station is also a part of project. Raw water in this project is provided by the Raw Water Pumping Station of GRWW Phase II.

At the beginning this water treatment plant will supply portable water to the Behala Booster Pumping Station, where from water will be served at its command area including the said municipalities.

The proposed Akra reservoir will also benefit from this project. In future, adjacent localities like Joka, Thakurpukur, Chota Kalikapur etc. Where at present surface water is not available will be provided by portable surface water from this treatment plant.

By the year 2024, about 34 lakhs people will be benefitted with adequate portable surface water within its command area.

The project report for phase III was KMWSA, and was approval of KMDA and Kolkata Municipal Corporation (KMC) is funding the entire project.

The implementation period for the construction of the project was planned for 18 months. On completion, the asset created will be handed over to Kolkata Municipal Corporation for Operation and Maintenance, Pumping Station and booster chlorinator. To feed the water from GRWW into this UGR, a dedicated pipeline is said by KMC.

4.6.2. STATUS OF GARDEN-REACH WATER:

1. Garden Reach Water Treatment Plant (GRWW) is Trans-Municipal Project for KMC, Maheshtala, Budge Budge and Pujali.
2. Commissioned at early 80's with installed capacity of 60 MGD, though it could not able to produce water more than 40 MGD.
3. Southern region of KMC gets water from GRWW network covering the area, particularly;
    - Part of Bhawanipore, Kheddirpore, Tollygunge and Jadavpur-CC Grid
    - Garden Reach and Behala-SS Grid
    - After commission it could not be able to build up the desired pressure in this locality.

4. In early this century, four Booster Pumping Station was commissioned with augmentation of GRWW upto a capacity of 120 MGD (Behala-1999, Garfa-2003, Bansdroni-2004 and Ranikhuti-2004).
5. Behala BPS (1999) -Borough XIII and Borough XIV supplemented with SS grid water.
6. Garfa BPS (2003) - Br XII, but could not cover up the whole borough, at present there is a crisis of Surface water supply in its distant places of the command zone, which is presently supplemented by ground water-104 Nos. of big dia. tube well.
7. Bansdroni BPS (2004) - Br XI (Ward 111, 112, 113, & 114).
8. Ranikhuti BPS (2004) – Br XI & part of Br XI supplemented with CC Grid, at present there is crisis of surface water supply in its distant places of the command zone which is presently supplemented by ground water-54 Nos. of big dia. tube well.

4.6.3. PLATE AND TUBE SETTLERS:

Pate and Tube Settlers have been developed as an alternative to shallow basins and are used in conjunction with both existing and especially designed sedimentation basin. Plate and Tube Settlers are shallow settling devices consisting of stacked offset trays or bundles of small plastic tubes of various geometries. They are used to enhance the settling the characteristics of sedimentation basin.

The shape, hydraulic radii, angle of inclination and length of the plate and tube settlers will vary according to the particular installation. Normal practice is to insert the plate or tube settlers in sedimentation basin (either rectangular or circular) of sufficient depth. The flow within the basin passes upward through the plate or tube modules. The solids that settle out within the plates or tubes moves by means of gravity counter current, downward and out of the tube modules to the basin bottom.

To be self-cleaning, Plate or Tube Settlers are usually set at an angle between 45° and 65° above the horizontal. When the angle of inclination of plate or tube is more than 60°, the efficiency of settling basin decreases. If the plates and tubes are inclined at an angle less than 45°, the settler will tend to accumulated solids which must be flushed out periodically. The needs for flushing possess a problem with the use of Plate and Tube Settlers where the characteristics of solids to be removed vary daily.

Tube Settlers are a light weight structure composed of closely spaced tubes on an incline (usually between 45° and 60°). Clarifier up flow is passed through these tubes. Settling within these tubes and contact clarification of fine flog results in a build-up of particles on the tube surface. Particles combine to form agglomerates which become heavy enough to slough against the upward flow and slide down the tube slope to join the sludge blanket below.

Tubes are supplied in module form, each being 1m wide x 1m long x .67m high. The modules are arranged on a supporting framework to form a layer within the clarifier. The Tube Settlers are suspended at a height 700mm below the top water level.

Advantage of Tube Settlers:

1. Solid removal efficiency will be higher leading to clarified water turbidity as less than 10 NTU.
2. The load on filter will be less.
3. Treatment plant capacity of the existing WTP could be increased by 50% to 60%.

Advantage of Plate Settlers:

1. It has a compact design, space saving and cost saving.
2. It has no moving parts, no spare parts and low maintenance.
3. It includes a simple installation, saves money, immediate start up at full capacity.
4. With the ease of access, it includes individual removal of each lamella plate and is easily available for inspection.
5. It has the sludge handling benefits, high under flow sludge concentration, low cost for sludge withdrawal.

6. It involves a flexible system, retrofitting of existing tank and a custom design.

Disadvantage of Tube and Plate Settlers:

1. Algae growth in tubes and plates may cause maintenance and odder problems.
2. Easy to clean lamella but not in tabular module.
3. Careful attention is necessary for the design of inlet and outlet structures to avoid turbulence and uneven flow.
4. Sometimes high pressure hose water is injected to flush out the solids.

4.6.4.Methods of Purification of Water:

The various methods or the techniques or the techniques which may be adopted for purifying the public water are:

1. Screening
2. Sedimentation tanks or Plain Sedimentation
3. Sedimentation with aided with Coagulation
4. Filtration
5. Disinfection
6. Aeration
7. Softening

4.6.4.1. SCREENING:

Screens are generally provided in front of the pumps or the intake works, so as to exclude the large sized particles, such as debris, animals, trees, branches, ice, etc. Coarse Screens (generally called trash racks) are sometimes placed in front of the Fine Screens. Coarse Screens consist of parallel iron rod placed vertically or at a slight slope, at about 2.5 to 5 cm apart. The Fine Screens are usually are made of woven wire mesh with openings not more than 6 mm square. The coarse screens first remove the bigger floating bodies and the organic solids, and the fine screens then remove the fine suspended solids.

The fine screens normally get clogged, and are to be cleaned frequently. The fine screens are, therefore, avoided these days, and the finer particles are separated in “Sedimentation” rather than in “Screening”. The coarse screens are also now normally kept inclined at about 45° - 60°making to the horizontal, so as to increase the opening area to reduce the flow of the velocity, and thus, making the screening more effective. While designing the screens, clear opening should have sufficient total area, so that the velocity through them is not more than 0.8 to 1 m/sec. The material which is collected on the upstream side of the screens, a rake transverses the front of screen either continuously or intermittently.

In mechanically cleaned screens, the cross bars, if present, will obstruct raking, and should, therefore, be avoided as far as possible.

4.6.4.2. SEDIMENTATION AIDED WITH COAGULATION:

Very fine suspended mud particles and colloidal matter present in water cannot settle down in plain sedimentation tank of ordinary detention period. Such particles can, however, be removed easily by increasing their size by changing them into flocculated particles. For this purpose, certain chemical compounds called **coagulants**, are added to the water, which on through mixing, from a gelatinous precipitate called **floc.** The very fine colloidal particles present in water, get attracted and absorbed in these flocs, forming the bigger sized flocculated particles.

The colloidal particles do, in fact, possess surface charges resulting from preferential adsorption or from ionization of chemical groups on the surface. Most of colloidal particles in water or waste water are negatively charged. The stationary charged layer on the surface is surrounded by a bound layer of water.

In this bound layer, called the **Stern layer**, ions of opposite charge drawn from the bulk solution, produce a rapid drop in potential, called the **Stern Potential** (η). A more gradual drop, called **Zeta Potential** (ζ) occurs between the shear surfaces of the bound water layer and the point of electro neutrality in the solution.

The surface charge on colloidal particles gives them long term stability, and hence the particles which might otherwise settle or coalesce are mutually repelled by their like charges. **Coagulation** is a chemical technique which is directed towards the destabilization of the charged colloidal particles. **Flocculation**, on the other hand, is the slow mixing technique which promotes the agglomeration of the destabilized particles.

For all particles purposes, however, the entire process of addition of chemicals (coagulation) and mixing (flocculation) is usually referred to as coagulation. The coagulated water is finally made to pass through the sedimentation tank, where the flocculated particles settle down, and are thus removed.

The use of coagulation is generally necessary for clarifying raw waters containing turbidities greater than 30 to 50 mg/l, but in actual practice, plain sedimentation is rarely used these days, and the coagulation before sedimentation is almost universally adopted in all the major water treatment plants, and is followed by rapid sand filtration.

Use of Alum as Coagulant: Alum is the name given to Aluminum sulphate with its chemical formula as **$Al_2 (SO_4)_3.18H_2O$.** The alum when added to raw water reacts with the bicarbonate alkalinities, which are generally present in raw supplies, so as to form a gelatinous precipitate (floc) of Aluminium hydroxide. This floc attracts other fine particles and suspended matter (colloids), and thus grows in size, and finally settles down to the bottom of the tank. The chemical equation is:

$$\mathbf{Al_2(SO_4)_3.18H_2O + 3Ca(HCO_3)_2 = 3CaSO_4 + 2\overset{\downarrow}{Al(OH)_3} + 6\overset{\uparrow}{CO_2}}$$ Al hydroxide ppt.

From the above equation, it becomes evident that the addition of alum to water imparts permanent hardness to it, in the form of calcium sulphate. The carbon dioxide gas, which is evolved, causes corrosiveness.

Figure 6 Coagulant

The amount of alum required for coagulation depends on the turbidity and colours of raw water. The use of the optimum amount of a coagulant is indicated by the formation feathery flakes; and can be approximately determined by the laboratory testing (Jar Test) which is adjusted with the actual results obtained at the treatment plant. The dose of alum may vary from 5 mg/l for highly turbidity waters. The average normal dose is about 17 mg/l.

4.6.4.3. SEDIMENTATION TANKS:

The clarification of water by the process of sedimentation can be effected by providing conditions under which the suspended material present in water can settle out. Storage reservoirs may also serve as sedimentation basins, but they can effort proper sedimentation, because of factors, such as, the density currents, the turbulence caused by winds, etc.; and hence they cannot be relied upon. Special basins are, therefore, constructed in order to purify the surface waters of rivers or reservoirs by the process of sedimentation.

But of three forces, which control the settling tendencies of the particles (enumerated earlier), the two forces, i.e., the velocity of flow, and shape and size of the particles, are tried to be controlled in these settling tanks. The third force i.e., the velocity of water or the temperature of water is left uncontrolled, as controlling the same is not practically possible. The velocity of flow can be reduced by increasing the length of travel and by detaining the particles for a longer time in the sedimentation basin. The size and shape of the particles can be altered by the addition of certain chemicals are called **coagulants**, and they make a sedimentation quite effective by leading to the settlement of even very fine and colloidal. However, their use is not made in **"plain sedimentation"** but is made under the process titled **"sedimentation with coagulants".**

Sedimentation basins are generally made of reinforced concrete, and may be rectangular or circular in plan. Long narrow rectangular tanks with horizontal flow are generally preferred to the circular tanks with horizontal radial or spiral flow. The capacity and other dimensions of the tank should be properly designed, so as to effect a fairly high percentage of removal of the suspended materials. A plain sedimentation tank under normal conditions may remove as much as 70% of the suspended impurities present in water.

Types of Sedimentation Tanks: The sedimentation tank should be basically divided into two types; viz.

1) *Horizontal flow tanks; and*
2) *Vertical or up flow tanks*

Horizontal Flow Tanks: In the design of horizontal flow tanks, the aim is to achieve, as nearly as possible, the ideal conditions of equal velocity at all points lying on each vertical lying in the settling zone. The direction of flow in the tanks is substantially horizontal.

Among the horizontal flow tanks, we may have different types of designs, such as:

I. Rectangular tanks with longitudinal flow
II. Circular tanks with radial flow, with central feed

Vertical or Up flow settling tanks: Vertical flow tanks usually combine sedimentation with flocculation, although they may also be used for plain sedimentation. They may be square or circular in plan, and may have **hopper bottom**. The influent enters at the bottom of the unit. The up flow velocity decreases with increased cross-sectional area of the tank. The clarified water is withdrawn through the circumferential or central weir.

When used with coagulants, the flocculation takes place in the bottom of the tank leading to formation of blanket of floc through which the rising floc must pass. Because of this phenomenon, these tanks are also called **Up flow sludge blanket clarifiers.**

4.6.4.4. FILTRATION:

Various filtration processes are used in drinking-water treatment. Filtration can act as a consistent and effective barrier for microbial pathogens. The most commonly used filtration processes in potable water treatment, vary the pore size of the filter media and the sizes of different microbial particles. These size spectra are useful for understanding removal mechanisms and efficiencies, and for developing strategies to remove microbes by different filtration processes.

BACKWASHING FILTER:

Backwashing Water Filters are large tank style filters that get their name from the fact that they clean and renew themselves by backwashing. Backwashing consists of reversing the flow of water so that it enters from the bottom of the filter bed than exist through the top of the filter tank.

The filter bed itself is a granular substance that is usually referred to as the filter medium. Media are numerous and varied. Common media are granular carbon, sand, granet, anthracite, zeolite, granular manganese dioxide and greensand. Many media are known by their brand names of the leading product in the category. For example Centaur, Filox, Birm and KDF.

The large tank style filters shows the filter in “service” position. This is how it works when it is doing the job it is designed to do. The unfiltered water enters the left and is routed by the control valve into the filter tank. The water than filters slowly through the medium until it reaches the bottom of the tank where it is collected through a specially designed sieve “basket” at the bottom of the centre tube seen in the picture. The filtered water than passes up through the centre tube, called “riser” or a “dip tube”, passes through the control valve and exists the right side of the filter.

The Backwash:

As the filter operates in the service mode, it traps and holds particles in the filter bed. Also, since water’s nature is to follow the path of least resistance, after a time begins to cut channels through the medium. As channels or holes in the media bed form, the water begins to flow around rather than through the medium. This process is called “channelling”, and it reduces the effectiveness of the filter considerably.

At present, the control valve initiates a backwash to clean the medium of collected particles and to resettle the bed and eliminate the channels that have formed.

The backwash is accomplished by sending water down the riser tube from which it enters the filter tank at the bottom. The force of water is such that it actually lifts the media bed, swirling and tossing the granular medium. The water leaves the filter tank through the control valve which routes it through the filters drain line. Particles that were being held in the bed are washed to drain.

The backwash is an intense rinsing and tossing of the medium that last for several minutes. In a standard residential filter, a typical backwash lasts about 10 minutes.

After the backwash, the control valve initiates a rinse of the bed during which the water flows downward through the medium, up through the riser tube and out the drain. The purpose of this rinse is to rinse and settle the bed and prepare it for return to service flow.

Incidentals about Backwashing Filters:

Tanks: Also called mineral Tank, most are made of polypropylene and polythene with fibreglass reinforcement. Mineral tanks are very strong and usually guaranteed for up to 10 years by the manufacturer.

Control Valves:

Most modern filter use timer style controls in which an electric timer initiates and controls the backwash of the filter at a preselected time. Meters which backwash the media when a certain number of gallons have been treated are used widely on water softeners but much less frequently on filters. Some very sophisticated setups can initiate backwash in response to a pressure differential between the incoming and outgoing water but for most situations, the standard, reliable timer control is preferred on backwashing filters.

Media:

With a few minor modifications, a backwashing filter can server many purposes according to the filter medium used. Here are some of the more common granular media used in backwashing filters.

Granular Activated Carbon:

For chlorine and chloramines reduction, taste or odor improvement, general chemical reduction. Carbon can also remove sediment and even iron if the iron is pre-treated properly. Granular carbon is the preferred treatment for many chemical contaminants. It is perhaps the most versatile and universal of the filter media.

Birm:

For reduction of iron and manganese, under the right conditions. As iron media, birm is relatively light in weight and hence easy to backwash. It is also low in cost, so it is a popular iron medium although it has some drawbacks.

Calcite:

It is used to increase the pH of acidic water. Calcite is a sacrificial medium that dissolves as it works and has to replace.

Centaur Catalytic Carbon:

Reduction of chlorine, chloramines, hydrogen sulphide and iron. A relatively grade of specially prepared carbon, Centaur is a favourite for chloramines removal on city water systems.

Multi-media:

Consisting of layers such as natural elements as grant, sand, and anthracite. Used for the reduction of sediment and oxidized iron, multi-media filters are slowly being replaced by newer granular zeolite media.

Filter Ag, Chemosorb, Micro Zn:

These are all common “sediment” media. They reduce particles in water down to 20 to 5 microns. These are usually natural zeolite products.

Greensand:

Reduction of iron and hydrogen sulphide. Greensand is usually used with a potassium permanganate feeder.

Filox:

A natural mined mineral, Filox in known for high level iron removal and reduction of hydrogen sulphide odours. It is very dense.

Backwash Rate:

Backwash flow rates differ significantly from filter to filter. The correct back flow rate is essential to proper operation of backwashing filter. The correct backwash flow rate is determined by considering the square footage of the surface media bed and the density of the media. The filter must have flow control installed in the drain line to allow a backwash flow rate sufficient to raise and cleanse the media bed but restrictive enough to prevent media from being washed out the drain line. For example, a carbon bed in a 10”X 54” filter tank is usually installed in a five gallon-per-minutes flow restrictor. Five GPM is sufficient to lift and clean the bed, but carbon is dense enough that it will not be washed out of the drain line during backwash. By contrast, KDF, a very dense medium, requires a backwash of more than 15 GPM in the same filter.

Service Flow:

Service flow of the filter is limited by the size of the tank and the nature of the medium. Some media require longer to work than others. Media are rated according to the service flow they can supported by a measurement called ”empty bed contact time” in filter maker jargon. When the recommended contact time for the medium is violated by the excess service flow, the filter is less effective and the life of the medium is usually shortened. It should be noted that empty bed contact time requirements are frequently violated in residential filters. For example, filter carbon in a 10”X 54” filter tank has a performance limit of about 3 gallons per minute, but such filters are frequently used in residential applications with much higher flow rates. There is no great harm in this since the under sized filter removes most of the chlorine most of the time. However, if the same filter is used to reduce dangerous organic chemical from well water, its upper service flow rate should be limited to perhaps 1 GPM, and exceeding this limit could have serious consequences

Importance of filter backwash:

When solids accumulate within a filter bed, they create a resistance to flow. This resistance is measured as loss of head (pressure increase) for the filter bed. The filter is backwashed, usually with finished water, to remove the accumulated particles. The need for backwashing may be determined using various criteria — a terminal head loss, a fixed time interval, or a breakthrough of solids (measured as turbidity or particle counts). Options for disposal of the spent filter backwash water may include discharge to a sewer or a receiving stream. Because backwash water may contain disinfectants and other chemicals that may be harmful to the biological life of a stream, direct discharge to streams may be restricted. Similarly, discharge to sewers may be restricted, based on the constituents and total quantity of the backwash water. For many water treatment plants, particularly in arid or water-scarce areas with limited raw water resources, it is often necessary to reuse backwash water. When the water is recycled, accumulation of microbial and algal contaminants is a concern. For example, algal toxins may be released from stored treatment sludges when the overlying water is recycled (Drikas et al., 2001). Because of the resistance of oocysts to conventional disinfectants, *Cryptosporidium* has been a major concern for the handling and operation of recycled process streams. The level of treatment required for spent filter backwash water before recycle will vary from site to site depending on the treatment process and water-quality objectives. Equalization of the recycle flow and sedimentation of the backwash solids, aided by the addition of a polymer coagulant, is sufficient to reduce cyst concentrations to raw water levels in most cases.

DESIGN OF GRANULAR FILTRATION:

In granular filtration, water passes through a filter consisting of a packed bed of granular materials. Microbes or microbe-associated particles are removed as they deposit on the filter medium. The removal occurs within the granular medium (depth filtration) rather than on the top layer only (cake filtration). After a period of operation, the head loss increases (i.e. the pressure increases) or the effluent quality deteriorates to an unacceptable level. The filter then has to be cleaned by backwashing, after which it performs poorly during a ‘ripening period’ before achieving a stable level of performance. Passage of microbial pathogens during the ripening period can be very high. Various strategies are used to minimize this effect, including:

- *filter to waste* — wasting the initial filtered water;
- *slow start* — limiting the initial filtration rate until the filtrate quality is acceptable;
- *delayed start* — leaving the filter inactive for a time following backwash, before bringing it into operation;
- *filter aid* — adding a filter aid to the wash water supply. Granular filters can be constructed as monomedium (e.g. silica sand), dual media (e.g. anthracite coal and sand) and trimedia (e.g. coal, sand and garnet). Granular activated carbon is used when both filtration of particles and adsorption of organic compounds are desired. Depending on raw water quality, granular filtration can be operated in three different modes:
- *Conventional*, which includes addition of coagulants (rapid mixing), flocculation (slow mixing), sedimentation and filtration;
- *direct filtration*, in which the sedimentation step is omitted;
- *In-line filtration*, in which both flocculation and sedimentation steps are omitted. Conventional treatment is appropriate for most source waters, whereas direct and in-line filtrations are used for raw waters with a consistently good quality (low turbidity and color).

4.6.4.4.1. SLOW SAND FILTRATION:

The use of slow sand filtration to protect drinking-water consumers from microbial risk was well established more than 100 years ago. Two of the earliest successful cases were reductions in cholera in Altona (Germany) and typhoid fever in Lawrence, Massachusetts (USA) in the 1890s (Bellamy et al., 1985). Numerous disease outbreaks due to chlorine-resistant protozoan pathogens in the past two decades have increased interest in slow sand filtration because of its ability to remove parasites.

Slow sand filtration involves passing water through a sand filter by gravity at a very low filtration rate, without the use of coagulation pretreatment. The filter typically consists of a layer of sand supported on a layer of graded gravel. Typical design criteria for slow sand filtration are given in Table given below detailed design guidelines can be found in Hendricks (1991). As water passes through the filter, microbes and other substances are removed. The removal mechanisms are not well understood, although they are believed to be a combination of biological, physical and chemical mechanisms (Weber-Shirk & Dick, 1997ab). Specific mechanisms may include biological action (e.g. ciliate protozoa acting as bacterial predators), attachment of microbes to sand media (e.g. by electrochemical forces and through bridging by microbial extracellular polymers) and physical straining.

Table 4- Typical design criteria for slow sand filtration

Design criterion	Normal range
Filtration rate	0.04–0.4 m/h
Sand media Depth	0.5–1.5 m
Effective size	0.15–0.40 mm
Uniformity coefficient	1.5–3.6
Gravel media Depth	0.2–1 m
Graded	Fine to coarse (top to bottom)

Removal of particles by slow sand filtration occurs predominantly, if not entirely, in a thin layer on the top of the sand bed. This biologically active layer, composed of living and dead microorganism sand macro organisms, is termed *schmutzdecke*. As operation progresses, deposited materials and biological growth on the sand medium increase the head loss across the filter. When the head loss reaches the operational limit (normally 1–2 m), the filter is removed from service. It is then usually cleaned by scraping about 2 cm of accumulated material and sand from the top layer of the sand bed, before being returned to service. A typical filter run is from one to six months, depending on the raw water quality and filtration rate. After the sand bed is reduced to a lowest acceptable depth by repeated scrapings, it is necessary to replace the sand down to the gravel support level. Slow sand filtration can provide some degree of protection against microbial pathogens. As coagulation pretreatment is not required, slow sand filtration has little maintenance or chemical cost. If the raw water has a high concentration of suspended particles or algae, physical pretreatment processes (e.g. roughing filter or micro strainers) can be used to prevent clogging of the filter and maintain a reasonable filter run period.

4.6.4.4.2. RAPID SAND FILTRATION:

The slow sand filters can filter water at a very slow rate, and thus require huge areas for their installation. In addition to requiring huge quantities of filtering materials such filters will, therefore, require huge space which may prove to very costly, particularly in congested cities and industrial towns. In order reduce the requirement of space and to increase the rate of filtration, a lot of research was conducted, which was finally led to development of **rapid sand filtration**, or sometimes called **mechanical sand filers.**

Rapid sand filters are of **two types:**

1) One which utilizes comparatively larger sized sand particles, which allow greater rate of filtration as compared to that of slow sand filters. They are called **rapid gravity filters.**

Rapid gravity filters were developed in the last decade nineteenth century through the efforts of G.W.Fuller at Louisville U.S.A. These filters employ coarser sand, with effective size as 0.5 mm or so. On an average, these filters may yield as high as 30 times they yield given by slow sand filters. Waters from the coagulation-sedimentation tanks are used in these filters, and filtered water as treated with disinfectant, so as to obtain portable supplies.

2) One which utilize the development of pressure over the filtering the water and thereby increasing the rate of filtration. They are called **pressure filters.** Pressure filters are just like small rapid gravity filters placed in closed vessels, and through which water to be treated in passed under pressure. Since water is forced through such filters at a pressure greater than the atmospheric pressure, it is necessary that these filters are located in air tight vessels. The raw water is pumped into the vessels by means of pumps. The pressure so developed may normally vary between 30 to 70 metre head of water, i.e. 300 to 700 kN/m².

Rapid gravity filters are used for large municipal supplies, where as pressure filters, being more handy, may be used for small installations, such as for industrial plants and swimming pools.

4.6.4.5. DINSIFECATION OR STERILISATION:

This clause covers the various disinfection processes used in drinking-water treatment to inactivate pathogenic microbes. It looks first at factors affecting the efficiency of disinfection process, and then goes on to consider the following disinfection processes:

- *Pretreatment oxidation* — in which oxidants are added to water early in the treatment process.
- *Primary disinfection* — a common component of primary treatment of drinking-water, and important because granular filter media do not remove all microbial pathogens from water
- *Secondary disinfection* — used to maintain the water quality achieved at the treatment plant throughout the distribution system up to the tap.

Principles for the selection of an appropriate disinfection system:

This manual is intended as a guide to the disinfection technologies currently available and as a guide to their application and operation in practice. The selection of the appropriate disinfection system should be made on an individual supply by supply basis. The EPA does not favour or endorse any particular disinfection method but recommends that the selection and application of an appropriate disinfection technology should have regard to the following principles:

- The assessment of catchment and source risks with respect to the clarity, organic content, and the likely risk of pathogenic micro-organisms in the source water.

- The evaluation of particular source risk following analysis of raw water monitoring to determine the extent of pathogen removal/inactivation required of the disinfection system. The disinfection technology must be capable of removing or inactivating all pathogens potentially present in the final water.

- The determination of the pre-treatment process(es), necessary to ensure the required pre-treatment of the water (with respect to colour, turbidity and TOC) and/or inorganic chemical removal, upstream of the disinfection system to ensure it is capable of performing adequately.

- An assessment of the adequacy of contact time for chemical disinfection technologies and the necessity to ensure that minimum contact times required for disinfection are achieved.

- The verification of the efficiency of the disinfection treatment. Any disinfection technology used must be capable of being verified, and that such verification is recorded, at all times as required by Regulation 13.

- An assessment of the requirement to ensure that a residual disinfectant is present in the distribution network for all but very small distribution networks.

- An assessment of the capital and operational cost of the disinfection technology. Where disinfection technologies achieve equally effective outcomes the water supplier should have regard to the financial implications from the capital and ongoing operational aspects to ensure that the most cost effective solution is selected.

The above factors should be considered by a water supplier on a site specific basis to determine the disinfection system to be operated at each water treatment plant. While the manual discusses the commonly used and widely accepted technologies, the absence of an emerging or new disinfection technology from this manual should not be interpreted as precluding it from use. The above principles should be used to assess any new or novel disinfection technology. Where the technology is found to be effective, verifiable and cost effective it can be considered for use for the disinfection of drinking water.

TYPES OF DINSIFECTION:

PRIMARY DISINFECTION:

A disinfection barrier is a common component of primary treatment of water. Primary disinfection is typically a chemical oxidation process, although ultraviolet (UV) irradiation and membrane treatment are gaining increased attention. This section looks at different types of disinfectant — chlorine, monochlorine, chlorine dioxide, ozone, UV light and mixed oxidants — in terms of their effectiveness against various pathogenic microorganisms

➢ Chlorine:

Chlorine gas and water react to form HOCl and hydrochloric acid (HCl). In turn, the HOCl dissociates into the hypochlorite ion (OCl^-) and the hydrogen ion (H^+), according to the following reactions:

(1) $Cl_2 + H_2O \Leftrightarrow HOCl + HCl$

(2) $HOCl \Leftrightarrow H^+ + OCl^-$

The reactions are reversible and pH dependent:

- Between pH 3.5 and 5.5, HOCl is the predominant species
- Between about pH 5.5 and 9.5, both HOCl and OCl^- species exist in various proportions
- Above pH 8, OCl^- predominates.

The OCl^- and HOCl species are commonly referred to as free chlorine, which is extremely reactive with numerous components of the bacterial cell. HOCl can produce oxidation, hydrolysis and deamination reactions with a variety of chemical substrates, and produces physiological lesions that may affect several cellular processes.

“Chlorine” is a generic term for the active chemical species - hypochlorous acid - that acts as a disinfectant. It is formed from several chemicals (elemental chlorine, sodium and calcium hypochlorite) when they are dosed to water. “Chlorination” is the generic term for disinfection using these chemicals. Chlorine remains the most widely used disinfectant chemical in drinking water treatment for both primary disinfection of treated water and for the maintenance of a residual in distribution systems. It is also commonly used in the oxidation and removal of iron and manganese in water treatment upstream of disinfection.

➢ Monochloramine:

Monochloramine is formed when ammonia and chlorine are dosed, and react, under well controlled conditions. The process is known generically as “chloramination”. Good process control is essential to prevent the formation of strong tastes and by-products. The disinfection capability of monochloramine is poor compared with chlorine, and it is generally used to provide a disinfectant residual or preservative, during distribution, rather than being used for primary disinfection.

The key advantages of monochloramine are:

- It does not form trihalomethanes (THMs), or other chlorination by-products when in the presence of organic matter;

- The taste threshold is typically much greater than for chlorine alone. As a result the introduction of chloramination can significantly reduce customer complaints relating to chlorine tastes.

➢ Ozone:

- Ozone is a very powerful disinfectant compared with either chlorine or chlorine dioxide. It is the only
- Chemical that can provide effective inactivation of either *Giardia* or *Cryptosporidium* at dose levels not much
- Greater than those used routinely for water treatment. It is, however, an expensive disinfection technology in
- Terms of capital and operating costs and to date in Ireland has primarily been used as a pre-disinfection
- Treatment process for the destruction of organic micro pollutants, particularly pesticides and taste and odour
- Compounds, and their removal, when used in conjunction with Granular Activated Carbon (GAC) filtration.
- Although such application simultaneously provides disinfection, chlorine is usually used as a primary
- Disinfectant after an ozonation process on waters abstracted from surface sources. In other countries, ozone
- May be used as the primary disinfectant, in conjunction with a suitable design of contact tank to ensure an appropriate contact time is achieved.

➢ Chlorine dioxide:

Chlorine dioxide is a more powerful disinfectant than chlorine, and the pure chemical does not form THMs by reaction with humid substances. Chlorine dioxide is generated on demand, usually by reaction between sodium chlorite and hydrochloric acid; it can also be made by reaction between sodium chlorite and chlorine, although careful control is required to ensure by-product formation is small. Chlorine dioxide is likely to be substantially more expensive than chlorine.

➢ Ultraviolet (UV) radiation:

Effective primary disinfection can be provided by a suitable intensity and duration of UV radiation to give a UV “dose” usually expressed in mJ/cm^2 (= mWs/cm^2, the product of UV intensity in mW/cm^2 and contact time in seconds). The target dose will depend on the application, but a dose of $40mJ/cm^2$ is commonly used for UV disinfection systems, validated for the broad spectrum inactivation of possible waterborne pathogens such as bacteria, viruses and protozoan parasites such as *Cryptosporidium*. In an Irish context, where over

90% of water sources are either from surface waters or surface influenced ground waters, chlorination usually follows UV disinfection for residual generation and the quality assurance of disinfection in the distribution system. Key advantages of UV disinfection are that it is a compact process and can be suited to sites with space constraint. In addition to being effective for inactivation of *Cryptosporidium* and other pathogens, when UV irradiation is used in conjunction with chlorination, it can reduce the subsequent chlorination dose.

SECONDARY DISINFECTION:

- **Chlorination:** *Advantages* -- Stable residual in clean networks. Potential for using chlorine for both primary disinfection and distribution makes for straightforward application.

Limitations -- By-product formation during distribution. Loss of residual in distribution systems with long residence times.

- **Chloramination:** *Advantages* -- Stable residual with no significant byproduct issues. Generally lower rate of taste and odour complaints than for chlorine.

Limitations -- Needs effective control of process to avoid taste and odour due to either dichloramine or trichloramine. Mixing with non-chloraminated supplies in network can cause taste and odour issues.

FACTORS AFFECTING DISINFECTION:

The principal factors that influence disinfection efficiency are disinfectant concentration, contact time, temperature and pH. Disinfectant concentration and contact time are integral to disinfection kinetics and the practical application of the CT concept (CT being the disinfectant concentration multiplied by the contact time). Development and derivations of this disinfection model are discussed in the modeling section below. Temperature, over the range appropriate for drinking-water, affects the rate of disinfection reactions according to the Arrhenius equation, although this may not hold for certain disinfectants at low temperatures. The pH of the disinfectant solution affects the reaction kinetics. For example, the disinfection efficiency of free chlorine is increased at lower pH values, whereas that of chlorine dioxide is greater at alkaline pH levels. Monochloramine is formed within seconds in the pH range 7–9, at chlorine to ammonia nitrogen ratios of less than 5:1 and at 25°C; it is also the predominant species when the pH is greater than 5. Other factors that influence microbial sensitivity to disinfection include attachment to surfaces, encapsulation, aggregation and low-nutrient growth. Increased resistance to disinfection may result from attachment or association of microorganisms to various particulate surfaces, such as Macro invertebrates, Particles that cause turbidity, Algae , Carbon fines ,Glass.

4.6.4.6. AERATION:

Under the process of aeration, water is brought in intimate contact with air, so as to absorb oxygen and to remove carbon dioxide gas. It may also help in killing bacteria in certain extent. It also helps in removing H_2S gas, and iron and manganese to certain extent, from the treated water. The aeration of water can be carried out in one of the following ways;

1) **By using spray nozzles:** In this method water is sprinkled in air or atmosphere through special nozzles which break the water into droplets, thus permitting the escape of dissolved gases. Carbon dioxide gas is thus considerably removed (up to 90% or so) in this method. However considerable head of water is required for the working of these nozzles, which function efficiently at a pressure of 10 to 14 m head of water.

2) **By permitting water to trickle over cascades:** In this method the water is made to fall through a certain height (1 to 3 m) over a series of steps (3 to 10) with a fall of about 0.15 to 0.3 m in each step. The structure so formed is known as **freefall aerator.** The simplest type of freefall aerator is known as **cascade aerator.** Such aerators are widely used as water features. They will take large quantities of water in a comparatively small area at low head, are simple to be kept clean and can be made of robust and durable materials with a long life. The plates can be made of cast iron, or of RCC, or of timber or even of glass. The aerator should preferably be installed in open air. However, for protection against air pollution, freezing and algal growth, it can be installed in a small house having plenty of louvered air inlets. The cascade aerators are efficient in raising dissolved oxygen content of water, but not for CO_2 removal, which is removed only in the range of 60 to 70%.

3) **By air diffusion:** In this method, compressed air is bubbled through the water, so as to thoroughly mix it with water. Perforated pipes are therefore installed at the bottom of the settling tanks, and the compressed air is blown through them. The compressed air is thus bubbled up from the bottom of the tank. During its upward movement through the water body, it gets thoroughly mixed up with water contained in the tank, thereby completing the aeration process.

4) **By using trickling beds:** In this method, the water is allowed to trickle down the beds of the coke, supported over the perforated bottomed trays, and arranged vertically in series. Generally, three beds are used, the depth of each being about 0.6 m with a clear distance about 0.45 m in between. The water is applied from the top through perforated distribution pipes and allowed to trickle down, up to the bottom bed. During this downward motion, the water gets mixed up with air and aeration takes place. The size of the coke to be used, usually ranges between 50 to 70 mm. This method gives better results than what can be obtained by **"cascades"**, but is less than the method of *spray nozzles.*

4.6.4.7. SOFETENING:

The reduction or removal of hardness from water is known as ***water softening.*** It is not always essential to soften raw public supplies to make the water safe for public uses, since the normally prevalent hardness in raw waters is not too high to cause may major harm to human health. The advantage of softening, however, lies chiefly in the reduction of soap consumption, lowered cost in maintaining plumbing fixtures, and improved taste of food preparations. Hence whether or not the hardness of a water supply should be reduced, depends on the relation between the cost of treatment and the obtained resultant saving and satisfaction to the consumers. However, for industrial supplies the softening is more important, because the hard waters are likely to cause scaling troubles in boilers and interfere in the working of dyeing system. The **temporary** or **carbonate hardness**, which is caused by the carbonates and bio carbonates of calcium and magnesium; can be removed by boiling, or by adding lime; whereas, the **permanent** or **non-carbonate hardness** which is caused by the sulphates, chloride and nitrates of calcium and magnesium, has to removed by the special methods of water softening.

It may also be recalled here that the permissible hardness for public supplies normally ranges between 75 to 115 mg/l (where 14.25 mg/l is equivalent to one degree of hardness).

ION EXCHANGE:

Ion exchange is a treatment process in which a solid phase presaturantion is exchanged for an unwanted ion in the untreated water. The process is used for water softening (removal of calcium and magnesium), removal of some radio nuclides (e.g. radium and barium) and removal of various other contaminants (e.g. nitrate, arsenate, chromate, selenate and dissolved organic carbon). The effectiveness of the process depends on the background water quality, and the levels of other competing ions and total dissolved solids. Although some ion exchange systems can be effective for adsorbing viruses and bacteria, such systems are not generally considered a microbial treatment barrier, because the organisms can be released from the resin by competing ions. Also, ion exchange resins may become colonized by bacteria, which can then contaminate treated effluents. Back flushing and other rinsing procedures, even regeneration, will not remove all of the attached microbes. Impregnation of the resin with silver suppresses bacterial growth initially, but eventually a silver-tolerant population develops. Disinfection of ion exchange resins using 0.01% per acetic acid (1 hour contact time) has been suggested (Fleming, 1987).

LABORATORY TEST

Experiment 1: Jar Test

Introduction:

Raw water, after screening, continuous to have impurities in suspension and in solution. One of the objectives of water treatment is to promote the setting of suspended particulate matter. The *coagulation* process utilizes what is known as a chemical coagulant (Aluminium or Iron salts) to promote particle agglomeration. Most suspended particles carry a negative electrostatic charge. This means that they repulse each other and thus stay in suspension. If there electrostatic charge can be neutralised, they would become destabilized, attracted each other agglomerate and settle. Chemical coagulants are added to the raw water and for a brief period rapid mixing is carried out. Having produced the micro floc s, the objective is then to produce a floc of adequate size that will settle under gravity. The next process is to subject the micro flock solution to a slow *flocculation* procedure. Removal of turbidity by coagulation depends on the type colloids in suspension, the temperature, pH and chemical composition of water, the type of dosages of coagulants, and the degree and time of mixing provided for chemical dispersion and floc formation.

Objective:

The objective of the experiment is to understand the process of *coagulation* and *flocculation* using alum to remove the turbidity of water.

Equipment:

1. Volumetric flux (1000 ml)
2. Analytical balance
3. Magnetic stirrer (optional)
4. Beakers (1000 ml)
5. Pipets (10 ml)
6. Stop watch
7. Turbid meter and sample tubes
8. A stirring machine with 6 paddles capable of variable speeds from 0 to 100 RPM

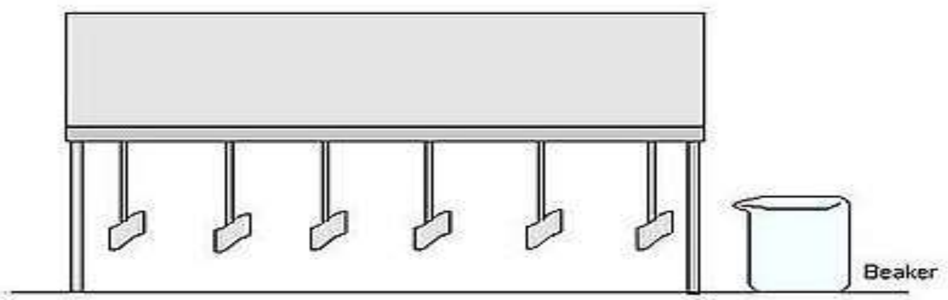


Figure 7 A stirring machine with 6 paddles

Reagents

- Coagulants and coagulant aids

Laboratory Procedure

1. We decide on six dosages of the chemical(s).

We should use the chemicals in use at the treatment plant we visit. These chemicals may include coagulants, coagulant aids, and lime.

The dosages should be in a series with the lowest dosage being lower than the dosage currently used in the plant and the highest dosage being higher than the dosage currently used in the plant. Insert the six dosages into your data sheet.

If pre-lime has to be fed, it is usually best to hold the amount of lime constant and vary the coagulant dosage.

2. We prepare a stock solution of the chemical(s).

It is not necessary to know the purity (strength) of the chemicals you use since the strength will be the same for plant operation. All results of the jar tests are in parts per million or milligrams per litter. (1 ppm = 1 mg/L).

We will need to prepare a stock solution for each type of chemical used. The strength of the stock solution will depend on the chemical dosages which you decided to use in step 1. The table below shows what strength stock solution you should prepare in each circumstance.

Approximate dosage required, mg/L	**Stock solution concentration, mg/L**	**1 mL added to 1 L sample equals**
1-10 mg/L	1,000 mg/L	1 mg/L
10-50 mg/L	10,000 mg/L	10 mg/L
50-500 mg/L	100,000 mg/L	100 mg/L

For example, if all of our dosages are between 1 and 10 mg/L, then we should prepare a stock solution with a concentration of 1,000 mg/L. This means that we could prepare the stock solution by dissolving 1,000 mg of the chemical in 1 L of distilled water. However, this would produce a much larger quantity of stock solution than we need and would waste chemicals. We will probably choose instead to dissolve 250 mg of the chemical in 250 mL of distilled water.

Once we decide on the strength and volume of stock solution to prepare, the procedure is as follows:

1. Weigh out the proper quantity of the chemical using the analytical balance.

Put an empty weigh boat on the balance and tare it. Then add the chemical slowly to the weigh boat until the desired weight has been achieved. It is much easier to add chemical to the weigh boat than to remove it, so add the chemical very slowly and carefully.

2. Measure out the proper quantity of distilled water in the volumetric flask.
3. Add the chemical to the distilled water.

4. Mix well.

If lime is used, it is best to use a magnetic stirrer since lime is not completely soluble in water. In other cases, magnetic stirrers can still be useful.

3. We collect a two gallon sample of the water to be tested. This should be the raw water.

4. Then we measure 1,000 mL of raw water and place in a beaker. Repeat for the remaining beakers.

5. We place beakers in the stirring machine.

6. With a measuring pipet, add the correct dosage of lime and then of coagulant solution to each beaker as rapidly as possible.

The third column of the table in step 2 shows the amount of stock solution to add to beaker. Two examples have been explained below.
If we have prepared a 1,000 mg/L stock solution, then 1 mL of the stock solution added to our 1,000 mL beaker will result in a concentration of 1 mg/L. So, if we wanted to have a chemical concentration in our beaker of 4mg/L, you would add 4 mL of stock solution.
If we prepared a 100,000 mg/L stock solution and wanted to achieve a chemical dosage of 150 mg/L, then we would need to add 1.5 mL of stock solution to beaker.

7. With the stirring paddles lowered into the beakers, start the stirring machine and operate it for one minute at a speed of 80 RPM. While the stirrer operates, we record the appearance of the water in each beaker.

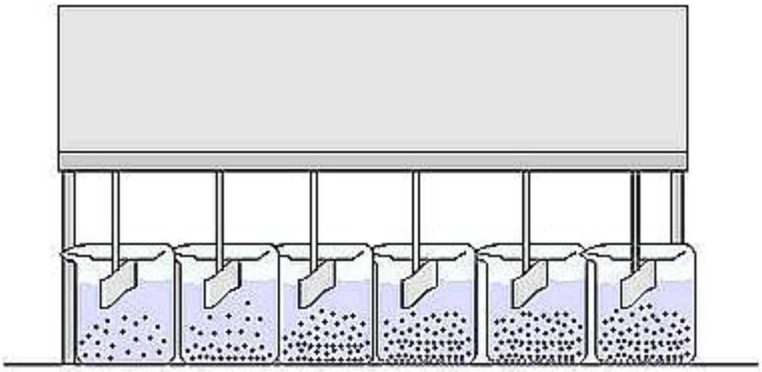


Figure 8 stirring machine operating

8. Then we reduce the stirring speed to 20 RPM and continue stirring for 30 minutes and record a description of the floc in each beaker 5, 10, 15, 20, 25, and 30 minutes after addition of the chemicals.

9. Stopping the stirring apparatus and allow the samples in the beakers to settle for 30 minutes and we record a description of the floc in each beaker after 15 minutes of settling and again after 30 minutes of settling.

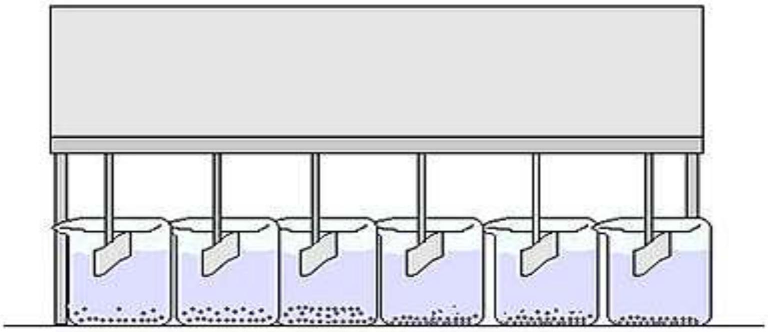


Figure 9 Stirring Machine allowing Settling

10. Determine which coagulant dosage has the best flocculation time and the most floc settled out. This is the optimal coagulant dosage.

A hazy sample indicates poor coagulation. Properly coagulated water contains floc particles that are well-formed and dense, with the liquid between the particles clear.

11. Test the turbidity of the water in each beaker using a turbidometer.

Pipet water out of the top of the first beaker and place it in a sample tube, making sure that no air bubbles are present in the sample. (Air bubbles will rinse while turbidity will sink.) Carefully wipe the outside of the sample tube clean. Place the sample tube in a calibrated turbidometer and read the turbidity. Repeat for the water from the other beakers.

The least turbid sample should correspond to the optimal coagulant dosage chosen in step 10.

12. If lime or a coagulant aid is fed at your plant in addition to the primary coagulant, you should repeat the jar test to determine the optimum dosage of lime or coagulant aid. Use the concentration of coagulant chosen in steps 10 and 11 and alter the dosage of lime or coagulant aid.

Experiment 2: Dissolved Oxygen

Aim:

To determine the dissolved oxygen (D.O) quantity for the given sample water by Winkler's Method.

Apparatus:

1. Conical flask
2. Pipette
3. Burette
4. BOD bottle (300 ml)

Reagents used:

1. Manganese Sulphate
2. Alkali Iodide Azide solution
3. Starch solution
4. 0.025 N Sodium Thiosulphate solution
5. Conc. H_2SO_4

Theory:

Oxygen is generally absorbed by water from the atmosphere. It is consumed by unstable organic matter for their oxidation. Hence, if the oxygen present in water is found out to be lesser then its saturation level it indicates presence of organic matter and consequently make the water suspicious. Fish and the other aquatic life in natural surface water usually need minimum Dissolve Oxygen of about 4 mg/l. much higher value of dissolve oxygen are also not good, since water containing high dissolve oxygen may cause corrosion of the pipes supplying such water. For domestic supplies dissolve oxygen value of about 4.8 mg/l may suffice.

$Mn^{2+} + 2OH^{-} \rightarrow Mn(OH)_2$ (white precipitate)

$Mn^{2+} + 2OH^{-} + 0.5O_2 \rightarrow MnO_2$ (brown hydrated precipitate) + H2O

$MnO_2 + 2I^{-} + 4H+ \rightarrow Mn^{2+} + I_2 + 2H_2O$

Procedure:

1. The sample water is collected in a 300 ml BOD bottle.

2. 2 ml of $MnSO_4$ and 2 ml of Alkali Iodide Azide solution is added by dipping pipette inside the bottle.
3. The bottle is shaken upside down for 15 minutes.
4. The solution is allowed to settle for 10 minutes, drown precipitation is then formed.
5. 2 ml of conc. H2SO4 is added and then shaken well, the brown precipitation dissolves and yellow colour solution is formed.
6. About 20 ml of this solution is collected in a conical flask. Add 2 ml of starch solution. The colour of the solution turns to bluish and titrate this solution with 0.025 N of Sodium Thiosulphate solutions.
7. The end point is indicated when the solution becomes colour less.
8. The Sodium Thiosulphate consumed is the amount of dissolved oxygen present in the sample water.

Precautions:

1. The water should be put properly and then the air bubble is allowed to escape.
2. The addition of MnO4 and alkali iodide azide solution should be done by dipping it inside the bottle containing water sample.
3. While titrating the change in colour at end point should be observed carefully show that no excess drop is allowed to fall.
4. We should be very careful while using conc. H2SO4.
5. Reading should be taken carefully.

Limitation:

1. Less D.O i.e. below 4 mg/l is dangerous for fish and other forms of aquatic life in natural surface water.
2. Much higher D.O values are not good as water containing higher D.O may cause corrosion of pipes supplying such water.

Experiment 3: Total Dissolved Solids

Introduction:

Total Dissolved solids (TDS) are a measure of the combined content of all inorganic and organic substances contained in a liquid in: molecular, ionized or micro-granular (colloidal sol) suspended form. Generally the operational definition shows that the solids must be small enough to survive filtration through a sieve size of 2 micro meters. Total dissolve solids are normally disused only for fresh water systems, as salinity comprises some of the ions constituting the definition of TDS. The principal application of TDS is in the study of water quality for streams, rivers and lakes although TDS is not generally considered a primary pollutant (e.g. it is not deemed to be associated with health effects) it is used as an indication of aesthetics of drinking water and as an aggregate indicator of presence of a broad array of chemical contaminants.

Aim:

To determine the Total Dissolved Solids in a given sample of water/waste-water.

Theory:

Total Residue is the term applied to the material left in the vessel after evaporation of the sample and its subsequent drying in an oven at a definite temperature (103^0 C to 105^0 C) 24 hrs. Total residue includes non-filterable residue (suspended solids) and filterable residue (i.e. dissolve solids). The suspended solids can be found by filtering the water sample for weighing the residue left on filter paper. The difference between the total solids and suspended solid will then represent the dissolve solids.

The total permissible amount of solids in water is generally limited to 500 ppm, although higher amounts upto 1000 ppm are also permitted but they are likely produced certain psychological effects on human system. Quantity of sample can be taken for determination of residue depends upon the amount of the suspended matter present in sample. In general, for

(i) Water sample → 100 ml to 500 ml
(ii) Sewage sample → 50 ml to 100 ml

Apparatus:

1. Silica Crucible (100 ml capacity) – 2
2. Boiler
3. Measuring cylinder (100 ml capacity)
4. Whatman filter paper – 1
5. Analytical balance
6. Retort stand and clamp
7. Filter funnel
8. Large beakers (1000, 500, 250 cm^3)

Procedure:

1. Take a Silica Crucible, clear, dry and weigh.
2. Take some volume of raw water sample and filter it through Whatman filter paper no. 44 using a retort stand and clamp.
3. Now take the filtered sample water in a crucible and boil it until dry.
4. Weigh the crucible and note down the readings.

Repeat the above experiment by using clear water sample

Precautions:

1. All the apparatus must be cleaned and dried properly.
2. Weighing of crucibles must be done very accurate.

3. The filter used should be as per standard.

Experiment 4: pH Test

Aim:

To determine the pH of a given sample of water.

Theory:

The pH value is numerically equal to negative logarithm base 10 of Hydrogen in concentration. It is an indication of acidity or alkalinity of a substance. Higher the pH value means lower Hydrogen in concentration representing acidic solution. Theoretically pure water is equally balanced condition of +ve charged (H^+) and negative charged (OH^-). Further it is found that product of concentration is constant. This constant is found to be equal to 10^{-14} mol/l, thus both H^+ and OH^- passes an equal amount of 10^{-7} mol/l. Neutral water will therefore have pH equal to

$= - \log_{10} (H^+)$

$= - \log_{10} (10^{-7})$

$= - (-7)$

$= 7$

And generally acidic medium has pH lower than 7 and basic medium has pH value more than 7.

Apparatus:

Beaker (volumetric)

Reagent:

Buffer solution of pH 4.0, 7.0 and 9.2

Instrument Required:

Digital pH meter

Procedure:

1. Standardise the pH meter with the help of known pH buffer solution.

2. Wash the electrode in distilled water and see the reading of pH meter. It must read as 7.0. If it is so, the pH meter is standardised.
3. Now dip the electrode into sample and note the readings when it is stable for 30 seconds.
4. The noted reading will show the pH value of sample.

Precautions:

1. Standardisation of pH meter is essential before use.
2. The reading must be noted when it is stable at least for 30 seconds.
3. The use of electrode should be done very carefully as it is very sensitive.

Experiment 5: Hardness test

Aim:

To estimate the total hardness of the given sample of water by E.D.T.A method, being supplied with some E.D.T.A solution in a 250 ml standard flask this on dilution becomes approximately 0.02 N and solid Calcium carbonate.

Principle and Outline:

Ethylene diamine tetracetic acid (E.D.T.A) or its Sodium salt (Na_2H_2Y) from soluble complex with hardness causing Mg^{+2} and Ca^{+2} ions.

$Na_2H_2Y + Ca^{+2} \rightarrow Na_2CaY + 2H^{+}$

$Na_2H_2Y + Mg^{+2} \rightarrow Na_2Mgy + 2H^{+}$

If a small amount of a dye Eriochrome Black – T is added to a solution containing Mg^{+2} and Ca^{+2} ions at a pH of 10, the solution attains wine red colour. If EDTA is added as titrant, the Mg^{+2} and Ca^{+2} ions are complexed. After the sufficient addition of EDTA to complex Mg^{+2} and Ca^{+2} ions the solution turns to blue from wine red. It is the end point. Hardness is expressed in parts by weight $CaCO_3$ per million parts by weight of water (ppm $CaCO_3$ or its equivalent)

A standard solution of $CaCO_3$ is prepared by weighing 0.5 gm. of the substance. A known volume of this solution is titrated against given EDTA solution using Eriochrome Black – T indicator. A buffer solution of NH_4Cl – NH_4OH is added to maintain pH value at 10. Thus EDTA is standardized. Experiment is repeated with water sample. From the titrate value molarity if water sample and hence hardness of water is calculated, (Molecular weight of $CaCO_3$ is 100).

Procedure:

25 ml of given hard water is pipetted out into a conical flask. 2 ml of (NH_4CL – NH_4OH) buffer solution is added followed by 3 drops of EDTA indicator. The solution turns wine red colour. This is titrated against EDTA solution taken in a burette. The end point is indicated when the solution turns to blue colour without reddish tinge. The titration is repeated to get agreeing values.

Estimation of hardness of water:

Solution taken in the burette = given EDTA solution

Solution taken in the flask = 25 ml of hard water + 2 ml of buffer solution

Indicator used = 3 drops of EBT

End point = change the colour from wine red to blue

Formula:

Mg of $CaCO_3$ per litre $= \frac{vol\ of\ EDTA\ used * normality\ of\ EDTA * 10000}{ml\ of\ sample\ taken}$

Experiment 6: Chloride Test

Aim:

To estimate the chloride content of the given sample of water using $AgNO_3$ solution.

Principle and Outline:

NaCl reacts with $AgNO_3$ forming white precipitate of AgCl

$NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$

$AgNO_3$ reacts with K_2CrO_4 forming a pale red precipitate of KNO_3

$2\ AgNO_3 + K_2CrO_4 \rightarrow Ag_2CrO4 + 2\ KNO_3$ (pale red)

Equivalent weight of NaCl = its molecular weight = 58.5

A standard solution of NaCl is prepared in 250 ml standard flask by weighing accurately about 0.5 gm of the crystals. A known volume of this standard solution is titrated against 0.014 N $AgNO_3$ solution using K_2CrO_4 as the indicator. Thus the given $AgNO_3$ is standardized.

The given water sample contains dissolved chloride salts and mineral acid. A known volume of water is treated with solids $CaCO_3$ to neutralize mineral acids and titrate against standardised $AgNO_3$ solution using K_2CrO_4 as indicator. From the titre value normality of water sample and hence chloride content can be calculated. Chloride content in water sample is expressed in ppm of Sodium chloride.

Procedure:

1. **Preparation of standard NaCl solution:** The given NaCl crystals in weighing bottle is accurately weighed and transferred into a 250 ml standard flask. It is dissolved in distilled water and made up to the mark and shaken well for uniform concentration.
2. **Standardisation of $AgNo_3$:** 25 ml of prepared NaCl solution is pipetted into a clean conical flask. 10 drops 5% K_2CrO_4 solution is added as internal indicator. It is titrated against $AgNO_3$ solution taken by the burette. End point is marked by the appearance of pale reddish brown tinge which persists even after brisk swirling. Titration is repeated to obtain concordant values.
3. **Estimation:** 25 ml of sample is pipetted into a clean conical flask. About 1 gm of solid $CaCO_3$ is added followed by 10 drops of K_2CrO_4 indicator. The solution is then titrated against $AgNO_3$ solution as before. Repeat to get agreeing values.

EXPERIMENT 7: RESIDUAL CHLORINE

Orthotolidine Method:

Orthotolidine is an aromatic organic compound which reacts with both free and combined chlorine in acid solution to form a yellow coloured compound, the intensity of the colour being directly proportional to the concentration of chlorine in the sample. Orthotolidine reacts instantaneously with free chlorine. The method is more sensitive to lower concentration of chlorine and is affected by temperature and contact time. The maximum and minimum concentrations of residual chlorine that can be measured by this method are 10mg and 0.01mg/l respectively.

If it is desired to identify both free and combined residual chlorine and also to find but if any additional colour has been produced by interfering substances present in the sample, the orthotolidine arsenite method should be employed.

Apparatus:

Chlorine comparator.

Reagents:

a) Orthotolidine reagent: dissolve 1.35 gm Orthotolidine-di- hydrochloride in 500ml distilled water. Add to this solution with constant stirring, a mixture of 350 ml distilled water and 150 ml conc. HCL. Store in amber coloured bottle away from direct sun light. Prepare every six months.

b) Sodium Arsenic reagent: dissolve 5.0 gm $NaAsO_2$ in distilled water and dilute to 1 litre (caution: highly toxic, avoid ingestion).

Procedure:

a) Take 0.5 ml orthotolidine reagent in 10 ml cell supplied with the comparator and sample upto the mark and mix thoroughly.

b) Compare the colour developed within 10 seconds. The colour developed is that for free residual chlorine.

c) Compare the colour again exactly after 5 minutes. The colour developed includes both for free and combined chlorine.

d) Compare both the colours with standards supplied with the equipment and express results as mg/l chlorine.

Combine Chlorine = Total Residual Chlorine – Free Residual Chlorine

EXPERIMENT 8: BACTERIOLOGICAL ANALYSIS

MULTIPLE TUBE DILUTION TECHNIQUE

INTRODUCTION

Water receives its bacterial pollution from air, soil, sewage, organic wastes, dead plants and animals etc. These bacteria in water may be harmless or harmful, or both to human consumers. Therefore, bacterial examination of water is necessary first and foremost to disclose the presence of microorganism especially that might constitute a health hazard. It is universally recognised that the excreta of man, mammals and birds contain enormous numbers of coliform bacteria. The coliform group comprises all of the facultative and aerobic gram-negative, non-spore forming rod shaped bacteria that ferment lactose with gas formation within 48 hours at 37^0C. Thus, presence of these organisms in water undoubtedly indicates the faecal contamination of water. The presence of other coliform bacteria which are non-faecal and widely distributed in nature may therefore be of little epidemiological significance. Generally, these types of tests are carried out to determine the occurrence of coliform bacteria in water.

The (a) Presumptive Coliform Test or Total Coliform Test and (b) Faecal Coliform Test.

Preparation of Media:

(a) Preparation of Mac Conkey Broth for presumptive coliform test or total coliform test. Take 80gm Mac Conkey Broth powder and dissolve it in 1litre distilled water. Heat the solution to dissolve completely, if required. This is double strength (D.S) Mac Conkey Broth.

(b) Preparation of Brilliant Green Bile Broth (BGLB) for Faecal Coliform Test. Take 4 gm BGLB powder and dissolve it in 100ml distilled water. Heat the solution to dissolve completely, if required.

METHODOLOGY:

(a) For Presumptive Coliform Test or Total Coliform Test (TC):

For one sample arrange 3 sets each containing 5 tubes in the following manner:-

- Take 10 ml of the Mac Conkey Broth (DS) in each of the first 5 tubes and insert one inverted Durham's tube in each tube.
- Take 10 ml of the DS Mac Conkey Broth + 9 ml of distilled water. (Thus becomes single strength or SS) in each of the second 5 tubes and insert one inverted Durham's tube in each tube.
- Take 10 ml of the DS Mac Conkey Broth + 9.9 ml of distilled water (thus becomes SS) in each of the third 5 tubes and insert one inverted Durham's tube in each tube.
- Plug all the tubes (15 tubes for one sample) tightly with non-absorbent cotton wool. Place all the tubes in a wire mesh cage and cover the cage with either brown paper or aluminium foil. Tie the paper with twin thread. Autoclave all the tubes 15 lbs/inch^2 pressure for 15 mins. After autoclaving cool them to room temperature.

(b) For Faecal Coli form (FC) Test:

- Here numbers of tube to be taken depends on the number of tubes showing positive results in the Presumptive test. One tube for FC test should be taken against each positive tube of Presumptive test.
- Take 5 ml of BGLB broth in each tube and insert one inverted Durham's tube in each of item. Plug and autoclave n similar way as mentioned for Mac Conkey Broth.

Inoculation:

(a) For Presumptive Test or Total Coliform Test (TC):

- Take 10 ml of sample in each tube of the 5 tubes containing 10 ml of DS Mac Conkey broth.
- Take 1 ml of sample in each tube of the 5 tubes containing 19 ml SS Mac Conkey broth.
- Take 0.1 ml of sample in each of the 5 tubes containing 19.9 ml SS Mac Conkey broth.
- Samples should be taken with sterilized pipette and inoculation should be done either in laminar flow chamber or in presence of flame.
- Replace the cotton wool plug in all the tubes immediately after inoculation.
- Keep the tubes after inoculation in 37^0C incubator for 48 hours.

(b) For Faecal Coliform Test:

- Inoculate one loop full (use Platinum Loop) of sample from each of the positive tubes in BGLB broth.
- Replace the cotton wool plug after inoculation.
- Keep the tubes containing BGLB broth, after inoculation, in 44^0C water bath or incubation for 24 hours.

CHAPTER 5: RESULT AND DISCUSSION

RESULT AND DISCUSSION

Table 5

POPULATION GROWTH FROM 1950 TO PRESENT AND ITS FURTHER PROJECTION

Year	Population	Growth Rate	Growth
1950	46,04,143	0.00%	
1951	47,24,976	2.62%	1,20,833
1952	48,44,101	2.52%	1,19,125
1953	49,65,889	2.51%	1,21,788
1954	50,90,914	2.52%	1,25,025
1955	52,19,086	2.52%	1,28,172
1956	53,50,669	2.52%	1,31,583
1957	54,85,193	2.51%	1,34,524
1958	56,23,292	2.52%	1,38,099
1959	57,64,868	2.52%	1,41,576
1960	59,10,210	2.52%	1,45,342
1961	60,51,559	2.39%	1,41,349
1962	61,81,753	2.15%	1,30,194
1963	63,14,748	2.15%	1,32,995
1964	64,50,794	2.15%	1,36,046
1965	65,89,384	2.15%	1,38,590
1966	67,31,149	2.15%	1,41,765
1967	68,75,964	2.15%	1,44,815
1968	70,24,100	2.15%	1,48,136
1969	71,75,007	2.15%	1,50,907
1970	73,29,372	2.15%	1,54,365
1971	74,87,766	2.16%	1,58,394
1972	76,51,993	2.19%	1,64,227
1973	78,19,355	2.19%	1,67,362
1974	79,90,617	2.19%	1,71,262
1975	81,65,629	2.19%	1,75,012
1976	83,44,723	2.19%	1,79,094
1977	85,27,237	2.19%	1,82,514
1978	87,14,002	2.19%	1,86,765
1979	89,04,858	2.19%	1,90,856
1980	91,00,166	2.19%	1,95,308
1981	92,89,425	2.08%	1,89,259
1982	94,63,056	1.87%	1,73,631
1983	96,39,932	1.87%	1,76,876
1984	98,20,365	1.87%	1,80,433
1985	1,00,03,655	1.87%	1,83,300
1986	1,01,90,645	1.87%	1,86,980
1987	1,03,81,121	1.87%	1,90,476
1988	1,05,75,427	1.87%	1,94,306
1989	1,07,72,820	1.87%	1,97,393

1990	1,09,74,177	1.87%	2,01,357
1991	1,11,75,951	1.84%	2,01,774
1992	1,13,74,926	1.78%	1,98,975
1993	1,15,76,881	1.78%	2,01,955
1994	1,17,82,708	1.78%	2,05,827
1995	1,19,92,194	1.78%	2,09,486
1996	1,22,05,701	1.78%	2,13,507
1997	1,24,22,407	1.78%	2,16,706
1998	1,26,43,266	1.78%	2,20,859
1999	1,28,68,052	1.78%	2,24,786
2000	1,30,97,153	1.78%	2,29,101
2001	1,32,77,596	1.38%	1,80,443
2002	1,33,56,283	0.59%	78,687
2003	1,34,35,436	0.59%	79,153
2004	1,35,15,168	0.59%	79,732
2005	1,35,95,152	0.59%	79,984
2006	1,36,75,721	0.59%	80,569
2007	1,37,56,767	0.59%	81,046
2008	1,38,38,406	0.59%	81,639
2009	1,39,20,303	0.59%	81,897
2010	1,40,02,798	0.59%	82,495
2011	1,40,85,783	0.59%	82,985
2012	1,41,69,260	0.59%	83,477
2013	1,42,53,231	0.59%	83,971
2014	1,43,37,700	0.59%	84,469
2015	1,44,22,670	0.59%	84,970
2016	1,45,08,143	0.59%	85,473
2017	1,45,94,123	0.59%	85,980
2018	1,46,80,613	0.59%	86,490
2019	1,47,55,186	0.51%	74,573
2020	1,48,50,066	0.64%	94,880
2021	1,49,74,073	0.84%	1,24,007
2022	1,51,33,888	1.07%	1,59,815
2023	1,53,32,793	1.31%	1,98,905
2024	1,55,70,786	1.55%	2,37,993
2025	1,58,45,219	1.76%	2,74,433
2026	1,61,51,407	1.93%	3,06,188
2027	1,64,83,755	2.06%	3,32,348
2028	1,68,36,468	2.14%	3,52,713
2029	1,72,04,528	2.19%	3,68,060
2030	1,75,83,604	2.20%	3,79,076
2031	1,79,70,656	2.20%	3,87,052
2032	1,83,63,504	2.19%	3,92,848
2033	1,87,60,872	2.16%	3,97,368
2034	1,91,61,390	2.13%	4,00,518
2035	1,95,64,170	2.10%	4,02,780

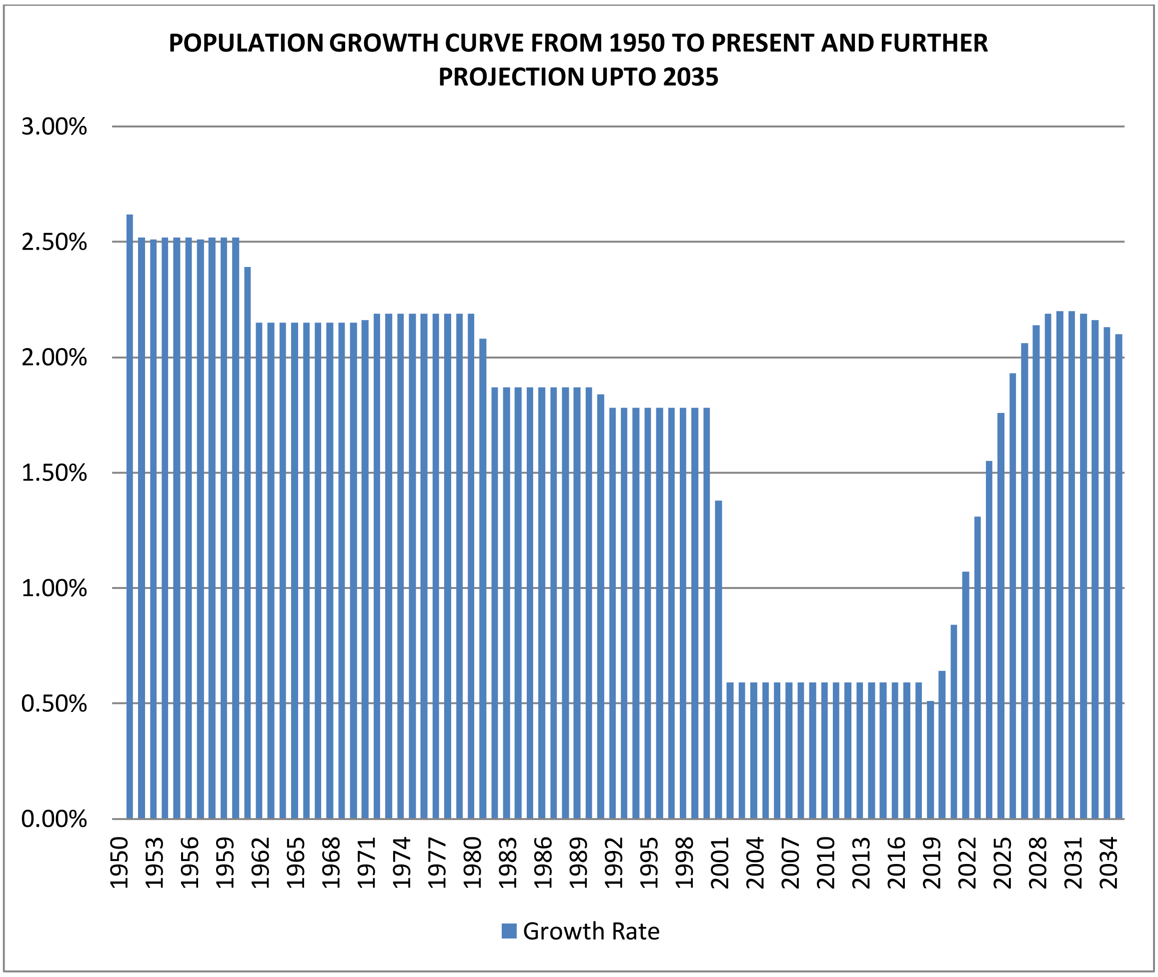


Figure 10 Population growth curve

Table 6: WATER QUALITY PARAMETER OF GANGA AT GARDEN REACH FROM NOVEMBER 2021 TO MAY 2022 IN A TABULATED FORM

PARAMETER	09-11-2021	26-11-2021	09-12-2021	24-12-2021	06-01-2022	25-01-2022	10-02-2022	22-02-2022	07-03-2022	22-03-2022	06-04-2022	21-04-2022	06-05-2022	23-05-2022
BOD	2.45	2.6	2.15	3.2	3.55	4.35	3.85	3.1	3.2	2.45	2.05	2.95	2.2	2.3
Dissolved O2	4.5	6.1	6.5	7.4	7.7	7.2	7.6	6.9	7.1	5.7	5.4	5.3	5.2	5.2
E- Coli	27000	17000	33000	33000	23000	33000	46000	23000	46000	33000	49000	46000	33000	33000
Nitrate –N	1.05	1.76	1.19	0.61	1.06	0.063	1.85	0.73	0.85	0.36	0.53	0.46	0.3	0.69
pH	7.51	7.99	7.44	7.36	7.48	7.86	7.2	7.68	7.42	7.68	7.88	7.49	7.64	7.62
Temperature	27	26	22	22	21	22	23	23	29	30	31	32	29	31
Total Coliform	110000	110000	110000	140000	110000	130000	130000	110000	130000	110000	110000	13000	130000	130000
Calcium	35.2	42.4	40.8	42.4	52	48.8	49.9	44.8	41.6	36	44	34.4	33.6	35.2
Chloride	11.99	15.65	18.59	18.59	21.53	20.1	20.1	24.88	23.93	26.99	24.99	19.57	24.46	18.19
COD	16	14	15	13	12	11	12	14	12	15	16	18	13	12
Fluoride	0.26	0.27	0.28	0.27	0.26	0.25	0.28	0.19	0.2	0.18	0.2	0.2	0.22	0.18
Magnesium	10.6	5.83	10.21	11.66	11.8	12.63	10.69	13.61	10.69	15.55	12.63	11.66	12.64	10.21
Nitrite	0.02	0.05	0.05	0.02	0.03	0.02	0.03	0.04	0.04	0.05	0.06	0.01	0.06	0.01
Phenopthaline	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Total Alkalinity	138	134	142	1.6	170	172	162	160	154	158	172	140	146	138
Total Suspended Solids	30	76	80	52	76	26	70	78	140	166	52	176	52	20
Total Dissolved Solids	198	152	70	266	156	266	164	214	170	458	280	282	160	196
Turbidity	136.33	68.43	64.8	47.27	55	26.37	40.13	32.5	44.6	68.2	36.53	89.1	31.6	19.3

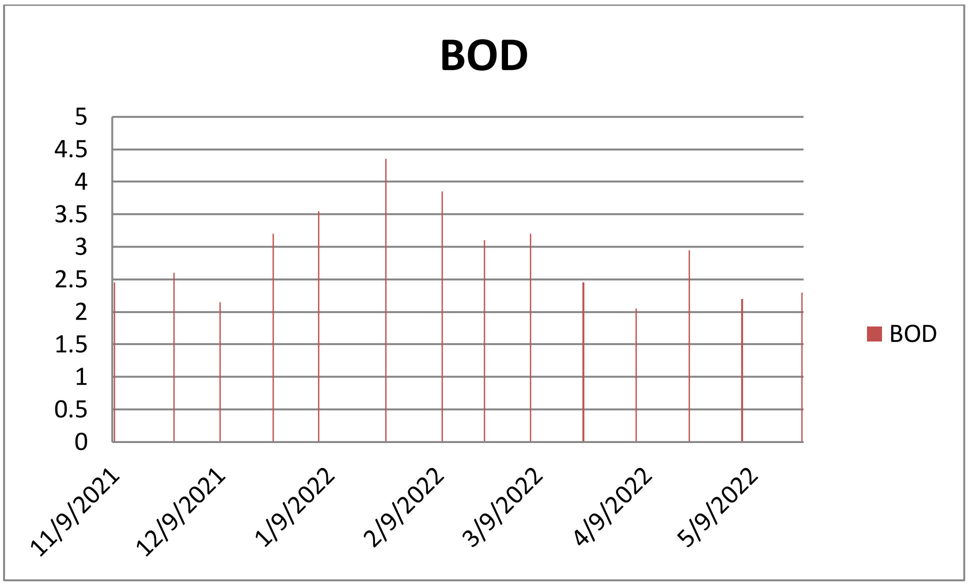


Figure 11 BOD variation frpm Nov '21 to May '22

DISCUSSION: BOD value is obserbed to be the highest in the month of January which is 4.35ppm and to be the lowest in April month which is 2.05ppm among all the months taken into consideration. The BOD value for drinking water should be nil.

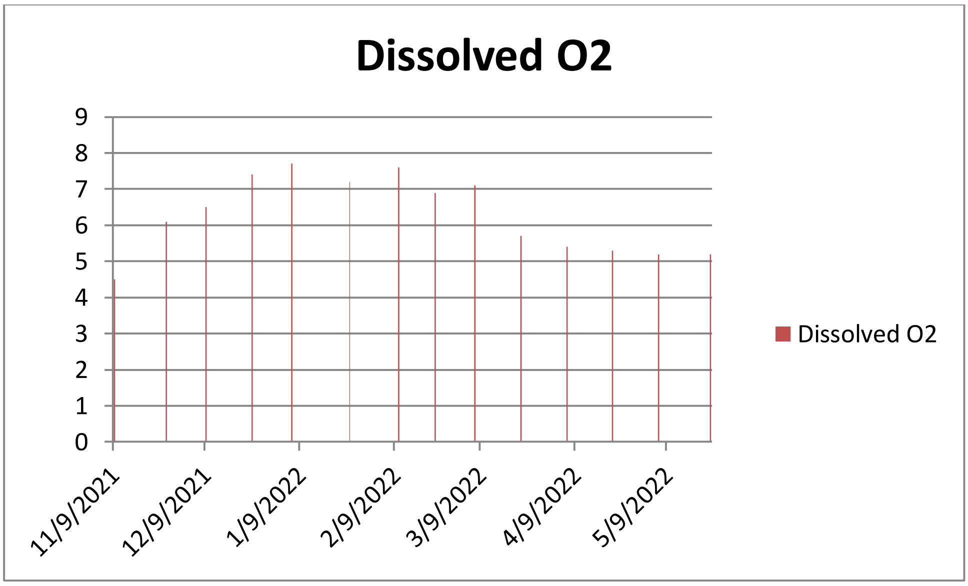


Figure 12 Dissolve O2 variation from Nov '21 to May '22

DISCUSSION: Dissolved O2 is observed to be the highest in January which is 7.7ppm and to be the lowest in November which is 4.5. The DO value in clear water should be 5ppm.

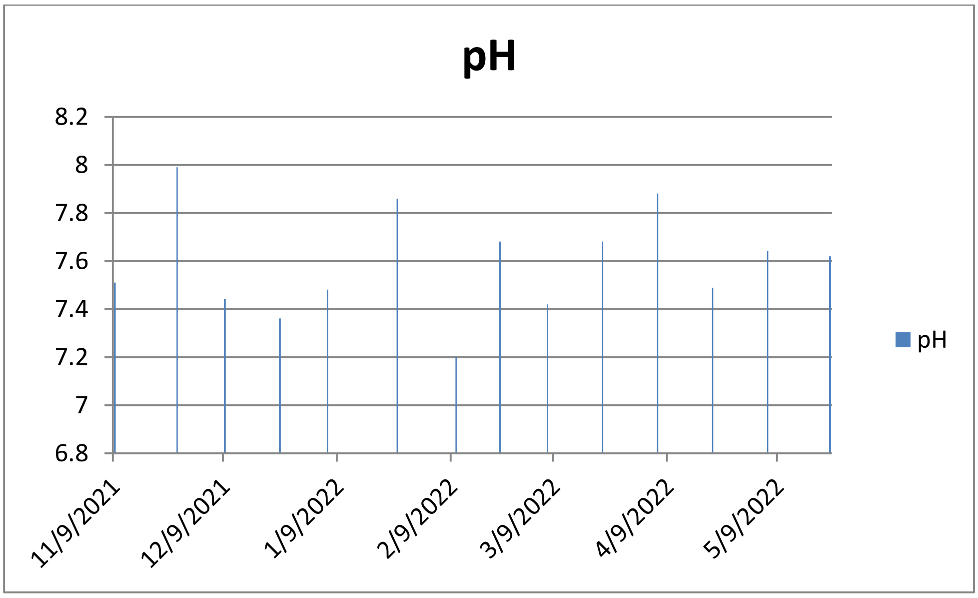


Figure 13 pH variation from Nov '21 to May '22

DISCUSSION: pH value is lowest in the month of February which is 7.2 and the highest value can be shown in April which is 7.88. The safe pH value for drinking is 6.5 to 8.5.

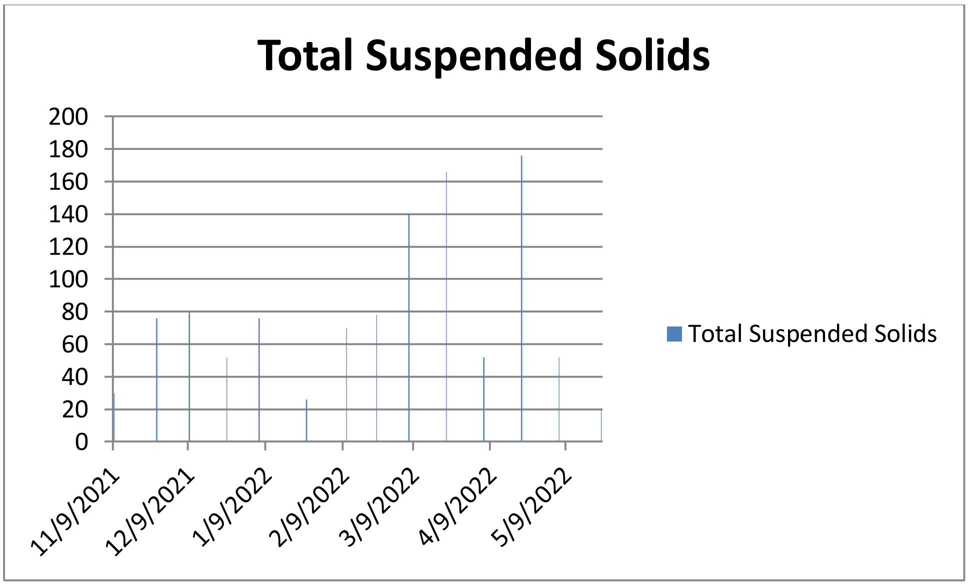


Figure 14 TSS variation from Nov '21 to May '22

DISCUSSION: TSS can be shown as high as 176 in the month of April and as low as 20 in the month of May. This value should be less than 500 as per WHO.

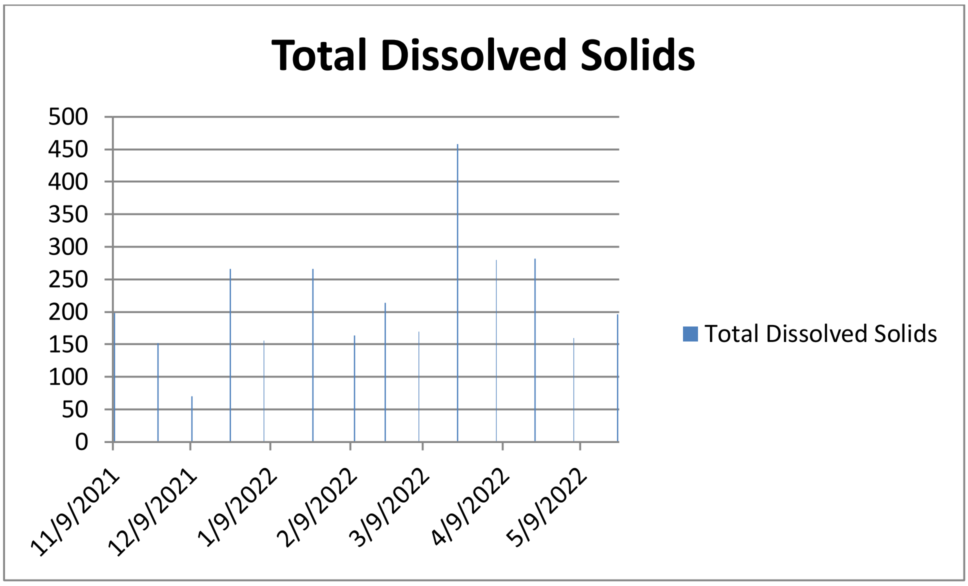


Figure 15 TDS variation from Nov '21 to May '22

DISCUSSION: TDS value can be shown as low as 70ppm in February and as high as 282ppm in April. The value of safe drinking water should be between 500 to 2000ppm as per BIS.

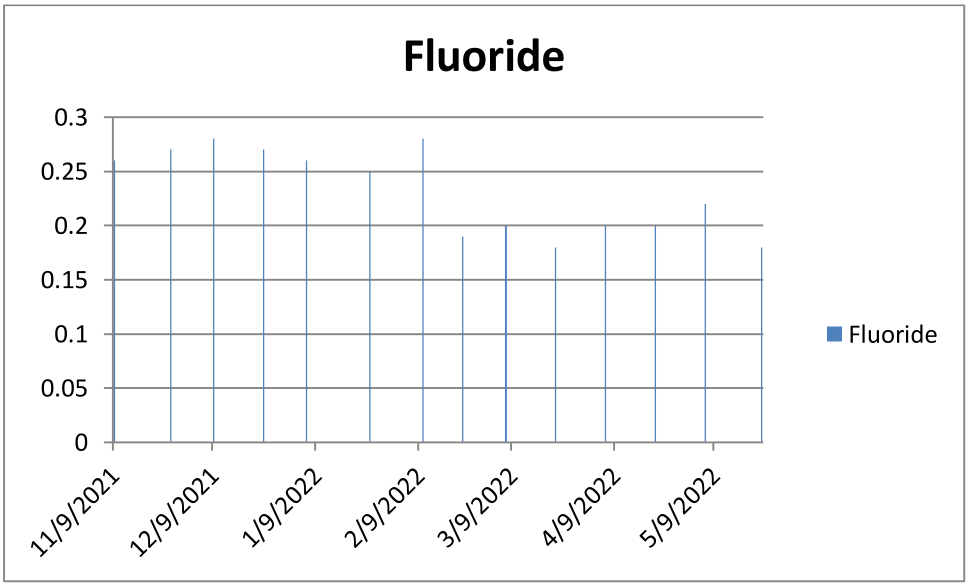


Figure 16 Fluoride variation from Nov '21 to May '22

DISCUSSION: Fluoride value can be shown more or less 0.2 ppm which should be between 1ppm to 1.5ppm as per BIS.

5.1. JAR TEST:

5.1.1. Observation:

Date: 24/06/2022

Sample used: Raw water (800 ml in each jar)

Jar no.	1	2	3	4	5	6
Alum dosage (ppm)	8	9	10	11	12	13
Turbidity (NTU)	11.9	11.3	7.9	6.5	7.7	7.6

Date: 25/06/2022

Sample used: Raw water (800 ml in each jar)

Jar no.	1	2	3	4	5
Alum dosage (ppm)	10	11	12	13	14
Turbidity (NTU)	11.5	9.3	8.4	9.2	7.6

Date: 26/06/2022

Sample used: Raw water (800 ml in each jar)

Jar no.	1	2	3	4	5
Alum dosage (ppm)	8	9	10	11	12
Turbidity (NTU)	11.7	10.5	8.5	9.3	7.9

5.1.2. Results:

From the carried out experiment the most optimum alum dosage for,

24/06/2022 is **11** ppm having a Turbidity of **6.5** NTU

25/06/2022 is **12** ppm having a Turbidity of **8.4** NTU

26/06/2022 is **10** ppm having a Turbidity of **8.5** NTU

5.1.3. Discussion:

Alum dosage of 11 ppm, 12 ppm, 10 ppm for 24th, 25th and 26th June 2022 respectively were the most optimum alum dosage for the Jar Test which was used to remove the Turbidity of Raw water.

5.2. DISSOLVED OXYGEN:

5.2.1. Observation:

Reading number	**Raw water sample burette reading**	**Clear water sample burette reading**
1	4.2	4.6
2	3.8	4.1
3	4.0	4.3
4	4.2	4.3

5.2.2. Result:

D.O of the given water sample under ambient temperature condition is found to be,

4.2 mg/l for raw water

4.3 mg/l for Clear water

5.3. TOTAL DISSOLVED SOLIDS (TDS):

5.3.1. Observation:

Sample Used	Wt of Crucible (g)	Wt of Crucible + sample (g)	Difference x 1000 (ppm)
Raw water	23.234	23.244	400
Clear water	31.950	31.962	480

5.3.2. Calculation:

Total dissolved solids (ppm)

a. Raw water = (23.244 - 23.234) x 40 x 1000 = 400 ppm
b. Clear water = (31.962 - 31.950) x 40 x 1000 = 480 ppm

5.3.3. Results:

From the above experiment, we determined that the TDS in the given Raw water sample is **400** ppm and in Clear water is **480** ppm.

5.4. pH TEST:

5.4.1. Observation:

Sl no.	Sample no.	Sample	pH value
1	I	Tap water	6.67
2	II	Tap water	6.70
3	III	Tap water	6.70

5.4.2. Result:

The pH value of sample is 6.70.

5.5. HARDNESS TEST:

5.5.1. Estimation of hardness of water:

Solution taken in the burette = given EDTA solution

Solution taken in the flask = 25 ml of hard water + 2 ml of buffer solution

Indicator used = 3 drops of EBT

End point = change the colour from wine red to blue

5.5.2. Hard water vs. EDTA (Raw water vs. EDTA):

Trail no.	1	2	3
Final B.R (ml)	6.90	13.70	20.70
Initial B.R (ml)	0	7.00	14.00
Vol of EDTA used (ml)	6.90	6.70	6.70

5.5.3. Clear water vs. EDTA:

Trail no.	1	2	3
Final B.R (ml)	7.50	15.50	23.20
Initial B.R (ml)	0	8.00	16.00
Vol of EDTA used (ml)	7.50	7.50	7.20

5.5.4.Formula:

Mg of $CaCO_3$ per litre $= \frac{vol\ of\ EDTA\ used * normality\ of\ EDTA * 10000}{ml\ of\ sample\ taken}$

5.5.5. Observation and Calculation:

Raw water:

Mg of $CaCO_3$ per litre $= \frac{vol\ of\ EDTA\ used * normality * 10000}{ml\ of\ sample\ taken}$

$$= \frac{6.70 * 0.01 * 10000}{50}$$

= 134 ppm

Clear water:

Mg of $CaCO_3$ per litre $= \frac{vol\ of\ EDTA\ used * normality * 10000}{ml\ of\ sample\ taken}$

$$= \frac{7.50 * 0.01 * 10000}{50}$$

= 150 ppm

Hardness of Raw water is **134** ppm and Clear water is **150** ppm.

5.5.6. Result:

Total hardness of the given sample of water (clear water) = **150** ppm $CaCO_3$ or its equivalents.

5.6. CHLORIDE TEST:

5.6.1. Observation and Calculation:

1. **Standardization of $AgNO_3$ solution:**

Solution in burette: Given $AgNO_3$ solution
Solution in the flask: 25 ml of NaCl solution

Indicator used: 10 drops of 5% K2CrO$_4$ solution
End point: Appearance of reddish brown tinge

NaCl vs. AgNO3:

Trail no.	1	2	3
Final B.R (ml)	28.5	57	85.5
Initial B.R (ml)	0	29	57
Vol of AgNO$_3$ (ml)	28.5	28	28.5

Strength of AgNO$_3$ solution $= \frac{25 \text{ X N1 (Nacl)}}{V1 \text{ (AgNO3)}}$

N$_2$ (AgNO$_3$) = <u>0.00012</u> N

2. **Estimation of chloride in water:**

Solution in burette: Given AgNO$_3$ solution
Indicator used: 10 drops of K_2CrO_4 solution
End point: Appearance of pale reddish brown tinge

Chloride water vs. AgNO3:

Trail no.	1	2	3
Final B.R (ml)	30	61.1	93.1
Initial B.R (ml)	0	30	62
Vol of AgNO$_3$ (ml)	30	31.1	31.1

Strength of chloride in water $= \frac{V2 \text{ (AgNO3) } X\ N2 \text{ (AgNO3)}}{25}$

N$_3$ chloride in water= <u>0.00015</u> N

Weight of chloride as NaCl = N_3 (chloride) X 58.5
Per litre of the solution = 0.0089 gm
Chloride content of water sample = 0.0089 X 1000 = 8.9 mg/l

5.6.2. Result:

Chloride presents in the given sample of **8.9** ppm NaCl or its equivalent.

5.7. RESIDUAL CHLORINE:

5.7.1. RESULT

Residual Chlorine in ppm in treated water (clear water reservoir outlet)

Date and Time	Residual Chlorine (ppm)
14.05.2022, 2pm	1.0
05.06.2022, 1.30pm	1.0
19.07.2022, 1.0pm	1.0

5.7.2. DISCUSSION:

The residual chlorine in treated water is within acceptable unit. As per IS 10500-2012 (drinking water- specification), acceptable limit of free residual chlorine, minimum is 0.2 mg/l.

5.8. BACTERIOLOGICAL ANALYSIS:

5.8.1. RESULT

Sample	Total Coliform (MPN/100ml)	Faecal Coliform (MPN/ 100ml)
Raw water (PST inlet)	2800	340
Treated water (CWR outlet)	Absent	Absent

5.8.2. DISCUSSION:

In treated water coliform organism is absent in 100ml of sample. As per IS 10500-2012 (drinking water-specification), coliform organism shall not be detectable in any 100ml sample.

CHAPTER 6: CONCLUSION

The resident population of KMC area is 45, 80,544 i.e. 4.58 million as per 2011 census. Water demand in 2012 has been shown 293 MGD which would be 402 MGD. To meet this requirement, 82% treated surface water is supplied and 10% ground water supplied. Ground water is supplied by 415 big dia. tube well which are power driven. Besides there are almost 10000 small dia. tube wells. Treated surface water after confirming to the IS 10500-2012 is supplied to domestic ends.

CHAPTER 7: REFERENCES

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