Chapter Two
Material and Methods

Study Area:

The main objective of this research work was to undertake study of drinking water pollution in Kolhapur City. The City once boasting a legacy of valour, aristocracy and graciousness, is a rapidly growing township located in south of Maharashtra (Figure-1). Geographically, it is located at an altitude of about 550 meters above MSL, at latitude 16° 40' to 16° 45' North and 74° 10' to 74° 15' East. The city has ancient history dating back almost to the beginning of the Christian era. Today, Kolhapur is an important pilgrim place and a tourist attraction on account of the famous Mahalaxmi temple built in the seventh century. Panchaganga river meanders the northern half of the city flowing from West to East.

Climatically the City enjoys dry and moderate climate throughout the year, which is generally temperate. Climate in Kolhapur may be divided into three seasons, hot weather from March to May, rainy period from June to October, and cold weather from November to February. The average rainfall of the city is around 600 mm lasting for about 60 rainy days during June to September every year.

The jurisdiction of Kolhapur Municipal Corporation (KMC) covers an area of 66.82 sq. kilometres with population of 4,85,183 with literate population of 3,86,256. (Census 2001). Expansion of the KMC boundary is long overdue, for over two decades, and once completed it would include about 48 village boundaries on the fringe of the city. This will not only enlarge the existing city limits in terms of area and by additional population, but will have tremendous stress on the existing amenities in general and drinking water supply and sewage disposal infrastructure in particular.

Presently the three major basic services of water supply, sewerage and solid waste management are handled by three different heads of department, the Hydraulic Engineer, the City Engineer, and the Health Officer respectively.

The Hydraulic Engineer is fully responsible for operations and maintenance of water supply system, whereas the sewerage operation, maintenance as well as disposal of sewage is just one of the functions carried out by the City Engineer.
As per the provisions of the Bombay Provincial Municipal Corporations (B.P.M.C.) Act 1949, water supply is an obligatory duty of Municipal Corporations and it has been specified in Schedule 12 consequent upon the 74th amendment also. However, Maharashtra Jeevan Pradhikaran (MJP) has been playing a major role in the state of Maharashtra in the development of water sources and execution of the water supply projects and even in the distribution of water. (Environmental Status Report, 2000-2001).

Raw water source of the City

Panchaganga River and Bhogawati River are the main raw water sources for the City. Panchaganga river system is developed on the eastern flank of the Sahyadri ranges. The streams namely Bhogawati, Tulsi, Dhamni, Kasari and Kumbhi originate at the elevation of about 900 m MSL and flow down to 550 MSL till all these tributaries meet at Prayag, 12 km to the north of Kolhapur city (Plate-I A). Beyond this confluence the river is known as Panchaganga.

There are 2 cities, 12 towns, and 80 villages located on the banks of Panchaganga, which today totally depend on the water from this river. There is continuous discharge of agricultural and domestic waste directly into the river. Even though sugar industry is backbone of the rural economy and main reason of socio-cultural transformation in south Maharashtra, it has also become the major sources of riverine pollution.

The sugar factories situated on the bank of Panchaganga river system are mentioned below. The effluents from them are considered to be one of the main causes of pollution in Panchaganga river.

* Bhogawati Sahakari Sakhar Karkhana Ltd. At Parite on the bank of river Bhogawati
* Kumbhi-Kasari Sahakari Sakhar Karkhana Ltd. at Kuditre, on the bank of river Kumbhi
* Shri Datta Sahakari Sakhar Karkhana Ltd at Asurle-porle on the bank of river Kasari.
* Rajaram Sahakari Sakhar Karkhana Ltd, Kasba Bawda, on river Panchaganga.

* Most of these sugarfactories have distilleries attached to them which is another polluting industry in Panchaganga basin.
The river also receives effluents from a large number of small-scale industrial units situated at Shivaji Udyamnagar in the heart of the city, which includes fabrication, tanneries, battery manufacturing, electroplating, and automobile servicing centres.

There are two large streams carrying city sewage, namely Jayanti nala and Dudhali nala, which pass through the central areas of the city and discharge their waste directly into the river Panchaganga (Plate 1 D). The river encircles and flows around the city and finely moves towards the pumping station located at the downstream of Panchaganga River at Kasba Bawda (Plate 1 C). This water intake pump house is just 2 km downstream from the point where the sewage, containing the chemical pollutants and diseases causing bacteria and viruses, is dumped. The Jayanti nala discharges on an average 50-55 MLD of sewage and Dudhali nala dumps at about 15 MLD sewage into the river.

Considering the location of the intake pump house, which is downstream of the effluent and sewage discharge, the location is not only wrong but has become permanent source of drinking water pollution in Kolhapur City for a long time. Presently the city water supply, along with eleven villages at its outskirts, is arranged through following three sources of water works.

Table 4: Water Treatment Plants of Kolhapur City and their water treatment capacity

<table>
<thead>
<tr>
<th>S.No</th>
<th>Drinking water treatment plant</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Kalamba water works (Kalamba Storage Reservoir)</td>
<td>8 MLD</td>
</tr>
<tr>
<td>2</td>
<td>Balinga water works (Bhogawati river as source)</td>
<td>41 MLD</td>
</tr>
<tr>
<td>3</td>
<td>Kasba Bawda water works (Panchaganga river as source)</td>
<td>36 MLD</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>85 MLD</strong></td>
</tr>
</tbody>
</table>
Raw water from these three sources is treated in Balinga filter house, Kalamba filter house, and Kasba Bawda filter house. The water treatment is as specified in the following flow chart.

**Raw Drinking water source**

(river, tank)

↓

**Screening**

(Use of physical methods to remove debris)

↓

**Coagulation**

(Plate- II B)

↓

**Flocculation**

(Plate- II C)

↓

**Sedimentation**

(Plate- II D)

↓

**Filtration**

(Plate- II E)

(Slow and rapid sand filters)

↓

**Disinfection**

(Plate- II F)

(chlorination to kill micro-organisms)

↓

**Distribution system**

**Balinga water works:**

This water works was commissioned in the year 1949 with a capacity of 10.90 MLD, which was increased from time to time at various stages by providing augmentation schemes. At present the total capacity of Balinga water works is 41 MLD. Source of this scheme is Bhogawati River. The water from the river is admitted in the intake chamber (Plate I E) and further conveyed through channel by gravity in jack-well.
Since 1985-86, it is observed that due to indiscriminate lifting of water from the riverbed for sugarcane crop by farmers, the water level in river did not remain to the required level to facilitate gravity flow to jack well. Every year, from October/November onwards till next year monsoon, lifting of water from river to channel becomes necessary due to this problem. From the water works water is supplied mainly to A ward, that is old Kolhapur and also parts of C& D wards.

Kalamba water works:
Kalamba water works is the oldest WTP in Kolhapur. An earthen dam, about 4300 feet long and 27 feet high, was constructed during 1881-83 on the southern side of the city at a distance of about 5 km to store 94 mcft of water. The water is brought by gravity to the filtration plant of 8 MLD capacity. The water supply from this water works is made to Mangalwar peth area (B ward) of the city. Due to excessive utilisation of water for sugarcane cultivation in the catchment, presently the dam does not get filled up to its full capacity every year. Hence, from January onwards the water supply from this water treatment plant gets reduced to 2 MLD. In the year 2000 Shingnapur water scheme was started in order to solve water scarcity problem to certain extent. Therefore these days during July to December, water distribution system slightly changes as it takes water from Shingnapur scheme. Water uplifted at Shingnapur is treated either at Puikhadi plant or from Puikhadi to overhead tanks. Some amount of water is also brought to Kalamba water works for treatment and for further distribution to B ward.

Kasba Bawda water works:
The water works was commissioned in the year 1978. Source for this water work is Panchaganga river (upstream of Rajaram K.T. weir). The capacity of water works is 36 MLD and water supply is made to E ward and six villages on eastern outskirts of the city limits.

Temporary arrangements of diverting sewage from Dudhali nala by utilising it for agriculture by pumping, and Jayanti nala sewage by admitting it in drainage dump with bandhara arrangements and further by pumping to sewerage treatment plant at Bawda have been made. But during electricity breakdowns leading to failure in sewage pumping system, the sewage overflows on the wall and makes its way to Panchaganga River creating serious pollution problem. (Plate- 1 D)
Distribution network: (Figures 23i and 4,)

Kolhapur city is divided by the Municipal Corporation into five wards as A, B, C, D, and E for the supply of drinking water. The area and population of each of the five wards is given in Table 5.

Table 5: Area and population of each Ward of Kolhapur Municipal Corporation

<table>
<thead>
<tr>
<th>S. No</th>
<th>Ward</th>
<th>Area</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>9.9 km²</td>
<td>99,850</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>10.2 km²</td>
<td>76,902</td>
</tr>
<tr>
<td>3</td>
<td>C</td>
<td>2.4 km²</td>
<td>42,551</td>
</tr>
<tr>
<td>4</td>
<td>D</td>
<td>2.9 km²</td>
<td>44,928</td>
</tr>
<tr>
<td>5</td>
<td>E</td>
<td>41.4 km²</td>
<td>220,952</td>
</tr>
<tr>
<td>Total</td>
<td>05</td>
<td>66.82 km²</td>
<td>485,183</td>
</tr>
</tbody>
</table>

Source: www.censusindia.net.in

The purpose of distribution network is to supply treated water to consumers from each ward at adequate residual pressure in sufficient quantity. Daily water supply demands of populations are different, it is worked out by KMC for immediate, projected and ultimate stage for domestic use as follows.

Table 6: Estimated water requirement for the domestic use in the next twenty years

<table>
<thead>
<tr>
<th>Population Year</th>
<th>Immediate stage</th>
<th>Projected stage</th>
<th>Ultimate stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,02300</td>
<td>6,20,500</td>
<td>8,65,200</td>
</tr>
<tr>
<td></td>
<td>2001</td>
<td>2011</td>
<td>2021</td>
</tr>
<tr>
<td>70% population @ 150 LPCD</td>
<td>52.742ML</td>
<td>65.153 ML</td>
<td>90.846 ML</td>
</tr>
<tr>
<td>30% population @ 50 LPCD</td>
<td>7.335ML</td>
<td>9.308 ML</td>
<td>12.978ML</td>
</tr>
<tr>
<td>Fire demand @ LPCD on 100% population</td>
<td>7.535 ML</td>
<td>9.308 ML</td>
<td>12.978ML</td>
</tr>
</tbody>
</table>
REFERENCES
1. RAJARAM WEIR AT KASABA BAWADA
2. HEAD WORKS AT KASABA BAWADA
3. RAW WATER RISINGMAIN FROM BAWADA H. W.
4. WATER TREATMENT PLANT AT BAWADA
5. E.S.R. AT W. T. P. AT BAWADA
6. 750 mm ø P. S. C. P. W. RISINGMAIN
7. E.S.R. AT TARABAI PARK
8. E.S.R. AT KAWALA NAKA
9. GRAVITYMAIN FROM KAWALA NAKA TO G. S. R. AT TEMBALAI HILL
10. G.S.R. AT TEMBALAI HILL
11. G.S.R. AT TEMBALAI HILL
12. C.I. GRAVITYMAIN FROM KAWALA NAKA TO RAJARAMPURI SUMP
13. BRANCH GRAVITYMAIN
14. E.S.R. AT SCHOOL NO. 9
15. G.S.R. AT RAJARAMPURI 14" LANE
16. E.S.R. AT RAJARAMPURI 14" LANE

KEY PLAN
BAWADA WATER WORKS

Figure 3
REFERENCES
1. KALAMBA TALAV
2. 400 mm-9 GRAVITY MAIN FROM KALAMBA TALAV TO KALAMBA FILTER HOUSE
3. KALAMBA FILTER HOUSE
4. E.S.R. KALAMBA FILTER HOUSE
5. 278 mm-9 GRAVITY MAIN
6. MANDHWAR Filter Q.S. II
7. PROPOSED Q.S. R AT MANDHWAR PWTH

KEY PLAN
KALAMBA WATER WORKS

Figure- 4
A. Aeration and coagulation of raw water at Bawda.

B. Coagulation tank of Balinga water works.

C. Setting water Tank.

D. Formation of flocs.

E. Sand Filtration of Water.

F. Water chamber for chlorination.

PLATE- II
A. Overhead water tank ESR 1 (T4)
B. Overhead water tank ESR 2 (T5)
C. Sampling Station of 'E' ward (HT 9)
D. House tap located near drainage system (HT3)
E. Pipeline leakage, sampling station of 'E' ward (HT10)
F. Treated water source- House tap (HT8)
A. Public tap in slum area (CT4)
B. House tap located in bathroom (HT4)
C. Bore tap of 'D' ward (TG 2)
D. Bore tap of 'B' ward (TG1)
E. Bore tap of 'E' ward (TG3)
F. Well or bin used for disposal.
A Public tap located near public toilet. (CT3)

B. House tap located in the premises of temple (HT2)

C. Sampling station having contaminated water (HT5)

D. Ground water source (HG1)

E. Ground water sampling site (HG2)

F. Ground water source of 'C' ward. (HG3)

PLATE - V
Table 7: Estimated water requirement for non-domestic use in the next twenty years

<table>
<thead>
<tr>
<th>Population Year</th>
<th>Immediate stage</th>
<th>Projected stage</th>
<th>Ultimate stage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5,02300</td>
<td>6,20,500</td>
<td>8,65,200</td>
</tr>
<tr>
<td>Immediate</td>
<td>2001</td>
<td>2011</td>
<td>2021</td>
</tr>
<tr>
<td>For industrial use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Udyamnagar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special consumer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Central bus stand, S.T. Workshop, Railway station)</td>
<td>2.00 ML</td>
<td>2.00 ML</td>
<td>2.00 ML</td>
</tr>
<tr>
<td>Total net daily demand</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Domestic + Nondomestic)</td>
<td>79.257ML</td>
<td>95.21ML</td>
<td>128.247ML</td>
</tr>
</tbody>
</table>

At present there are three Master Reservoirs and sixteen Service Reservoirs in the distribution system, which is divided in three zones. The water supply system is of intermittent type. The water is supplied for different zones varying from 2 to 8 hours duration. Though distribution system is designed to supply sufficient quantity of good quality water, there is chance for contamination of the water during its transmission. Kolhapur Municipal Corporation regularly analyses the water quality supplied at different ends and results are published for public information (KMC Environmental status report 2001).

Most of the drinking water distribution pipeline system of Kolhapur city is old and is in close vicinity with the drainage system. (Plate-VII C). Even though after commissioning, the new 29.80 MLD capacity sewerage scheme in the year 1976, no further drainage scheme was planned or executed.
As the water supply to the city has increased to 85 MLD, proportionately waste water quantity is also increased. About 60 MLD waste water is generated every day which is collected and pumped to the 29 MLD sewage treatment plant at Kasha Bawada. The resultant excess sewage therefore does not get any treatment and flows directly into the Panchaganga river through Bapat camp nallah or used in its untreated form for irrigation. In addition the excess sewage and sludge in Dudhali nallah can not be lifted completely and therefore this sewage also flows directly into the Panchaganga river.

Considering the population growth rate the generation of sludge and sewage is expected to increase still further to about 102 MLD making it necessary to augment the system further. In fact, the ultimate 2021 water supply to Kolhapur would be 154.80 MLD and the generation of sludge and sewage could increase to about 125 MLD in the year 2021. (Kolhapur Municipal Corporation Report, 1996-97). Therefore along with new scheme to supply drinking water, it is necessary to plan for the sewage treatment.

METHODS

The city has an elaborate network of drinking water distribution system, Also water of varied nature is used for drinking purpose by the people. These waters were tested in the laboratory during the studies. In addition, for the comparative study, raw as well as treated water samples were also collected and analysed. In some areas of the city groundwater is traditionally used for domestic needs, and due to water scarcity also sometimes for drinking purpose, therefore ground water samples were routinely analysed.

Considering the objectives of the study, standard water analysis methods recommended by American Public Health Association (APHA, 1985) and Bergy’s manual (1984,86) of Systematic Bacteriology volume I and volume II were used for physical, chemical and microbiological parameters respectively.

Locations of different sampling sites were carefully chosen after surveying the area physically and with the use of KMC water distribution maps. The sampling sites
were finalised after the initial pilot survey of the drinking water conditions of the city, and analysis of pilot water samples in the laboratory.

**Study Approach**

The approach adopted for the study and the sampling design was as follows

1. Primary survey of the drinking water status in Kolhapur City i.e. collection, treatment and distribution systems.

2. Water samples from river Panchaganga i.e. upstream and midstream of the river course from where there is main intake is made, water samples (n=2)

3. Water samples from each of the three filter houses namely Balinga, Kalamba and Bawda. A total number of six samples, i.e. at inlet and outlet each, (n=6)

   (Inlet water sample of Balinga filter house represents water quality of river Bhogawati. Kalamba filter house has raw water from both, Kalamba tank and river Panchaganga. In summer season and in first three months of rainy season source of water is river Panchaganga, and in rest of the season, raw water source is Kalamba tank).

   Treated water samples were from outlets of respective treatment plants. From filter house treated water is stored in Elevated Service Reservoirs (E.S.R), this water is retained for a short time period in the ESR, and subsequently supplied through the network to the respective wards of the city.

4. Water samples from representative Elevated Service Reservoirs. (ESR) from E ward. (n=2).

5. Water samples from representative house taps, stratified from each of the five municipal wards (n=10).

6. Water samples from representative public or common taps, stratified from each of the five municipal wards (n=5).

7. Representative ground water samples (n=8).
Table 8: Sample Index of 33 sampling sites used in the study

<table>
<thead>
<tr>
<th>S. No</th>
<th>Sample Location (Ward)</th>
<th>Sample Code No</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Raw water category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Prayag - Out of City area (Plate-I A)</td>
<td>R1</td>
</tr>
<tr>
<td>2</td>
<td>Shivaji Bridge - D ward (Plate-I B)</td>
<td>R2</td>
</tr>
<tr>
<td>3</td>
<td>Inlet Water Sample Balinga water Works Out of City area (Plate-I E)</td>
<td>R3</td>
</tr>
<tr>
<td>4</td>
<td>Inlet Water Sample Kalamba water Works B ward</td>
<td>R4</td>
</tr>
<tr>
<td>5</td>
<td>Inlet Water Sample K' Bawda water Works E ward</td>
<td>R5</td>
</tr>
<tr>
<td>II Treated water category</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Outlet Water Sample Balinga water Works out of City area</td>
<td>T1</td>
</tr>
<tr>
<td>7</td>
<td>Outlet Water Sample Kalamba water Works B ward</td>
<td>T2</td>
</tr>
<tr>
<td>8</td>
<td>Outlet Water Sample K’ Bawda water Works E ward</td>
<td>T3</td>
</tr>
<tr>
<td>9</td>
<td>Elevated Service Reservoir E ward (ESR1) (Plate-III A)</td>
<td>T4</td>
</tr>
<tr>
<td>10</td>
<td>Elevated Service Reservoir E ward (ESR2) (Plate-III B)</td>
<td>T5</td>
</tr>
<tr>
<td>III House tap water samples</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>House Tap - A Ward</td>
<td>HT1</td>
</tr>
<tr>
<td>12</td>
<td>House Tap - B Ward (Plate-V B)</td>
<td>HT2</td>
</tr>
<tr>
<td>13</td>
<td>House Tap - B Ward (Plate-III D)</td>
<td>HT3</td>
</tr>
<tr>
<td>14</td>
<td>House Tap - B Ward (Plate-IV B)</td>
<td>HT4</td>
</tr>
<tr>
<td>15</td>
<td>House Tap - C Ward (Plate-V C)</td>
<td>HT5</td>
</tr>
<tr>
<td>16</td>
<td>House Tap - D Ward</td>
<td>HT6</td>
</tr>
<tr>
<td>17</td>
<td>House Tap - E Ward</td>
<td>HT7</td>
</tr>
<tr>
<td>18</td>
<td>House Tap - E Ward (Plate-III F)</td>
<td>HT8</td>
</tr>
<tr>
<td>19</td>
<td>House Tap - E Ward (Plate-III C)</td>
<td>HT9</td>
</tr>
<tr>
<td>20</td>
<td>House Tap - E Ward (Plate-III E)</td>
<td>HT10</td>
</tr>
<tr>
<td>IV Public or Common tap water samples</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Common Tap - A Ward</td>
<td>CT1</td>
</tr>
<tr>
<td>22</td>
<td>Common Tap - B Ward</td>
<td>CT2</td>
</tr>
<tr>
<td>23</td>
<td>Common Tap - E Ward (Plate-V A)</td>
<td>CT3</td>
</tr>
<tr>
<td>24</td>
<td>Common Tap - E Ward (Plate-IV A)</td>
<td>CT4</td>
</tr>
<tr>
<td>25</td>
<td>Common Tap - E Ward (Plate-I F)</td>
<td>CT5</td>
</tr>
<tr>
<td>V Ground water (Handpump) sample</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Ground Water Sample (Handpump) -A Ward (Plate-V D)</td>
<td>HG1</td>
</tr>
</tbody>
</table>
Sampling Frequency

Laboratory analysis of the drinking water samples was carried out for two consecutive years from January 2000 to January 2002, all samples were analysed in each one of the three seasons i.e. summer, winter, and rainy season.

Laboratory analysis was divided into three parts as-
1) Physical parameters (n=7), 2) Chemical parameters (n=10), and 3) Bacteriological parameters (n=2 for all samples, and n=14 for bacterial identification at the species level). The total number of parameters studied were 32.

The parameters studied in each category were as follows:

I) Physical parameters:
1) Colour 2) Odour 3) Temperature 4) Turbidity as N.T.U. 5) Total Solids (TS) as mg/l 6) Total Dissolved Solids (TDS) as mg/l 7) Total Suspended Solids (TSS) as mg/l

II) Chemical parameters:
1) pH 2) Chlorides as mg/l 3) Nitrates as mg/l 4) Total hardness in terms of CaCO₃ 5) Estimation of calcium as mg/l 6) Estimation of Mg as mg/l 7) Dissolved Oxygen as mg/l 8) Biochemical Oxygen Demand (BOD) as mg/l 9) Chemical Oxygen Demand (COD) as mg/l 10) Estimation of Residual Chlorine as mg/l

III) Bacteriological analysis:
1) Estimation of Most Probable Number. (M.P.N. index /100ml)
2) Determination of Standard Plate Counts. (S.P.C/ml)
3 Detection of *E. coli*

4 Isolation of *Salmonella typhi*

5 Morphological and cultural study of some bacteria isolated on nutrient agar to identify bacteria at species level.

**IV) Water purification methods study** In all 25 traditional and new methods were studied

**V) Interview Methodology:** Household interviews (n=310) and doctor’s interviews (n=25)

I) **Physical Analysis**

1. **Colour**

   Colour determination of water was done at the sampling site immediately after collection of the sample by using visual detection method.

2. **Odour**

   Odour was determined by considering the average opinion of five people, after the contact of water sample with their receptor cell, at the site of sample collection. (APHA)

3. **Temperature 0°C**

   For determination of surface temperature, water samples were collected in clean glass bottles. Soon after the collection of the sample, a mercury thermometer with 0.1 °C graduation was inserted in the sample and reading were recorded directly.

4. **Turbidity as N.T.U.**

   When light is passed through a water sample having turbidity, some of the light is scattered by the particles. The scattering of the light is generally proportional to the turbidity. The turbidity of the sample is thus measured from the amount of the light scattered by the sample taking a reference with standard turbidity suspension, using Nephelometer. The value is measured in terms of Nephelometric Turbidity Units (NTU). Standard procedure given in APHA was used, and turbidity was calculated by using following formula.

   \[
   \text{Turbidity in NTU} = \text{Nephelometer reading} \times 0.4 \times \text{dilution factor}
   \]
5. Total Solids (TS) as mg/l

Total solids are determined as the residue left after evaporation of the unfiltered sample and its subsequent drying in an oven at defined temperature and calculated by using following formula.

\[
\text{Total solids mg/l} = \frac{A - BX1000X100}{V}
\]

Where \(A\) = Final weight of the dish in grams (g)
\(B\) = Initial weight of the dish in grams (g)
\(V\) = Volume of the sample taken in ml

6. Total Dissolved Solids (TDS) as mg/l

Total dissolved solids are determined as the residue left after evaporation of the filtered sample and calculated as-

\[
\text{TDS mg/l} = \frac{A - BX1000X1000}{V}
\]

Where \(A\) = Final weight of the dish in grams (g)
\(B\) = Initial weight of the dish in grams (g)
\(V\) = Volume of the sample

7. Total Suspended Solids (TSS) as mg/l

Total suspended solids were determined by calculating the difference between the total solids and total dissolved solids.

\[
\text{TSS} = \text{TS} - \text{TDS}
\]

II) Chemical Analysis

1. pH

pH is the negative logarithm of the hydrogen ion concentration in a solution. There are many methods for the determination of pH. During the present investigation battery operated portable pen type pH meter was used in the field for on site determination of pH of water sample.

2. Estimation of Chloride as mg/l

Chloride was estimated by titrometric method as given in APHA. Silver nitrate reacts with chloride present in water sample to form very slightly soluble white
precipitate of AgCl. At the end point when all the chlorides get precipitated free silver ions react with chromate of reddish brown colour.

\begin{align*}
\text{Chloride, mg/l} &= (ml \times N) \text{ of AgNO}_3 \times 1000 \times 35.5 \\
&\text{ml of sample}
\end{align*}

3. **Estimation of Nitrates as mg/l**

There are many methods for the estimation of nitrates. Phenol disulfonic acid (PDA) method was used during the present study, by using UV visible spectrophotometer. Standard curve was plotted with different concentrations of nitrate to determine concentration of nitrate in the sample was estimated.

4. **Estimation of total hardness in terms of CaCO}_3 mg/l**

Total hardness was estimated by titration method by using following formula

\begin{align*}
\text{Hardness as mg/l CaCO}_3 &= \frac{ml \text{ EDTA used} \times 1000}{\text{ml of sample}}
\end{align*}

5. **Estimation of calcium as mg/l**

Calcium in mg/l was estimated by titration using the following formula

\begin{align*}
\text{Calcium, mg/l} &= \frac{X \times 400.8}{\text{ml of sample}}
\end{align*}

Where \( X = \text{volume of EDTA used} \)

6. **Estimation of Magnesium as mg/l**

Magnesium can be estimated by using following formula

\begin{align*}
\text{Mg}^{++} \text{mg/l} &= (\text{Total Hardness} - \text{Calcium hardness}) \times 0.244
\end{align*}

7. **Estimation of Dissolved (DO) Oxygen as mg/l**

There are several methods to estimate DO. In the present investigation Wrinkler's iodometric method was used.

Dissolved oxygen can be estimated by using following formula.

\begin{align*}
\text{Dissolved oxygen mg/l} &= \left( \frac{ml \times N}{\text{titerant} \times 8 \times 1000} \right) \\
&\times \frac{1}{V_2 (V_1 - v / V_1)}
\end{align*}
Where $V_1 =$ volume of sample bottle after placing the stopper
$V_2 =$ volume of the part of contents titrated
$v =$ volume of $K_I$ and $MnSO_4$ added

8 Estimation of Biochemical Oxygen Demand (BOD) as mg/l
BOD incubation was done at 27 °C for three days. After completion of incubation period BOD was calculated by using following formula.

$$BOD \text{ mg/l} = (D_0 - D_2) \times \text{dilution factor}$$

9 Estimation of Chemical Oxygen Demand (COD) as mg/l
Heat reflux method was used.

$$COD \text{ mg/l} = \left( b-a \right) \times N \text{ of ferrous ammonium sulphate} \times 1000 \times \frac{8}{ml \text{ of sample}}$$

Where $a =$ ml of titrant with sample
$b =$ ml of titrant with blank

10 Estimation of Residual Chlorine as mg/l
The Residual Chlorine was estimated by using titrimetric method and starch as an indicator

$$\text{Residual chlorine mg/l} = \frac{ml \times N \text{ of titrant} \times 1000 \times 35.5}{ml \text{ of sample}}$$

(* For the physical and chemical analysis "Standard methods for water and waste water analysis" APHA,( 1985) was refereed.)

III) Bacteriological Analysis

i) Most Probable Number (MPN) estimation
This is a presumptive test to estimate most probable number of coliforms. Coliform group constitutes all Gram negative, motile bacilli, facultatively aerobic in nature belonging to family Enterobacteriaceae and able to ferment lactose at 37°C ± 2 °C with production of gas. Coliform group constitutes four genera,

1. *Escherischia coli*
2. *Enterobacter*
3. *Citrobacter*
4. *Klebsiella*
Member of coliform that is *Escherischia coli* is a intestinal inhabitant of man and animal therefore used as faecal indicator. However detection of faecal coliform as well as MPN above one per 100 ml makes water non-potable, since it is an indication of water contamination with faecal matter and possibility of presence of other intestinal pathogens.

ii) **Standard Plate Count (SPC) method**

Principle: Single microbial cell grows to form single colony. (Pelczar 1992)

For the counting of most of the micro-organisms general purpose medium like nutrient agar can be used, on which micro-organisms are able to grow. This method also gives information about types of micro-organisms in addition to their number per ml of the analysed sample. Therefore this method was selected for the enumeration of micro-organisms.

Number of micro-organisms was determined by using following formula,

\[
\text{Number of micro-organisms per ml water sample} = \text{No. of colonies} \times \text{dilution factor} \times 10
\]

iii) **Identification of isolated bacteria.**

Technique used for the isolation of different pathogens was the four quadrant method, however the media used was specific for specific bacteria.

1) Bismuth sulphite agar for the isolation of *Salmonella* group
2) Wilson and Blair's medium for *Salmonella*
3) Brilliant green agar medium for isolation of *Salmonella*
4) S-S agar, for isolation of *Shigella*
5) Mac conkey's agar for the isolation of *Klebsiella, and Proteus*
6) Endo agar for isolation and confirmation of *E. coli*
7) Baird and Parker medium for *Staphylococcus* species
8) *Staphylococcus* 110 medium for isolation of *Staphylococcus*.

For all pathogens temperature used for incubation was 37 °C for 24 hours. Cultural study was carried out and the results were recorded in following manner. Characters of a colony isolated on specific media incubated at 37 °C for 24 hours were recorded as – size, shape, colour, margin, opacity, elevation, consistency, Gram character, motility.
iv) Biochemical characteristic study-

Bacteria isolated on specific media were sub-cultured and pure cultures were prepared on nutrient agar slants. These cultures were then studied to identify bacteria at species level by using their specific biochemical behaviour pattern as mentioned in the volumes of Bergey's (1984,1986) Manual of and Systematic Bacteriology.

Different biochemical tests used during present study were as follows:
1) Pigmentation study on different media
2) Growth in presence of salt concentration gradient
   1%, 2%, 3%, 5%, 7%
3) Ability to grow at various temperatures
   4°C, 10°C, 20°C, 30°C, 40°C, 50°C, 60°C
4) Ability to grow in presence of methylene blue.
5) Ability to utilise malonate and citrate as carbon source.
6) Detection of extracellular enzymes synthesised by bacteria during growth.
7) IMViC test
8) Detection of H₂S gas produced by bacteria
9) Deamination test * Phenyl alanine * Arginine
10) Decarboxylation test * Ornithine * Lysine
11) Nitrate reduction test
12) Ability to ferment different sugars(n=12) by acid or gas production
   Hexoses- * Glucose, * Galactose, * Fructose
   Sugar alcohol- * Inositol, * Dulcitol, * Sorbitol

IV) Water purification methods study

A separate study was conducted to review the efficacy of various traditional and new drinking water purification methods (n=25) used at household level, in terms of their cost, time required for purification, convenience and reduction in coliforms that is M.P.N of raw as well as purified water sample. The various purification methods studied were as follows:

Traditional Methods:
• Exposure of water to sunlight for 2 and 4 hours.
• Sedimentation – Plain sedimentation for different time periods (24 and 48 hours)
• Sedimentation of water for 24, 48 hours treated with alum
• Treatment of alum and potassium permanganate
• Sedimentation of water treated with alum in copper and silver vessel
• Simple Cloth filtration by using five types of cloths.
  Water boiling – For 5, 10, 15 minutes.
• Sterilisation of water by using pressure cooker

Modern Methods:
• Filtration methods: - Use of 1) Aqua-guard, 2) Candle filter, 3) Zero B,
  4) Ultra purifier, 5) Microfine filtration, 6) Use of tap filter 7) Ultra violet radiation
• Disinfection methods: - Use of some disinfectants available in market such as
  1) Medichlor, 2) Purosiol, 3) Potassium permanganate.

V) Interview Methodology

In addition to water analysis in the laboratory, to study the existing drinking water use practices and people’s perceptions and attitude towards drinking water issue, a detail survey of drinking water conditions in the city was also carried out simultaneously. In order to generate the above data, interview schedule was designed with questionnaire framed with 28 questions (Annex-4 and Annex-5) covering many aspects of the drinking water issues. For the survey random disproportionate stratified sampling technique was used. A total of over 310 interviews were taken from five wards of the City with sample size as - A (n=50), B (n=56), C (n=50), and D (n=50) E (n=103) were covered.

Similarly 25 interview schedules, specifically designed for doctors (general practitioners), were also administered in the city to get idea about the effects of drinking water pollution from the health experts.