The city of Calcutta (22°30' N, 88°30' E), as it is well known, is situated on the left bank of the river Hooghly and has its natural slope away from the river bank, i.e., in the eastern direction. In the yeaster years when Calcutta was not Calcutta but only three obscure hamlets viz. Sutanati, Gobindapur and Kalikata, it was scarcely populated but had enough lands, ponds, ditches, etc. at its disposal to receive the drainage water, and as such the problem of drainage congestion was not so acute. With the setting up of the Head Quarters of the East India Company in the year 1690 A.D. by Job Charknak, its population, for obvious reasons, began to expand at a constantly increasing rate. Consequent upon the increase in the importance as the Head Quarters of East India Company and subsequently of the British Empire and also due to its all round development as the main business and education centre of Eastern India, having a large hinterland, the landscape of Calcutta began to change rapidly. Within a short time, the natural vegetation of lush green tropical jungle disappeared to make room for the outsiders. There were numerous depressions, low-lying areas, ponds, ditches, nullas and tidal creeks even within the city limits but most of these depressions had been filled up by continuous dumping of rubbish and garbages generated during the growth of the establishment.

Despite the fact that Calcutta is not too old a city (having celebrated its tercentenary in 1990 A.D.), it is one of those cities plagued by problems requiring immediate attention. The disposal of drainage and sewerage is one of such manifold problems of Calcutta.

The city of Calcutta with a corporation area 104 sq km supports a population of 4.0 million. Fifty to sixty per cent of the city is provided with a combined system of sewers having the facility for a total population of about 2.0 million. The estimated volume of waste water during dry season including modest contribution of industrial waste water is nearly 800,000 m³/day.
There are altogether seventeen drainage pumping stations in the city of Calcutta. Out of them there are eight discharge pumping stations. These are (1) Palmer Bazar, (2) Ballygunge, (3) Topsia, (4) Kuliatangra, (5) Pagladanga, (6) Chingrighata, (7) China Town, and (8) Dhapa Lock.

Also there are three outfall channels for the city, namely,

(1) **Suburban Headcut/Storm water (S.W.) channel** from Ballygunge Drainage Pumping station to river Kulti on the East through Topsia and Bantala carrying the pumped discharge from Ballygunge Drainage Pumping Station.

(2) **Town Headcut/S.W. channel** from Palmer Bazar Pumping station to Bantala through Makalpota.

(3) **Central Lake channel** from Dhapa Lock Pumping station to Makalpota.

Besides the above channels, there are two pucca **Dry weather flow channels**, one from Dhapa Lock pumping station and the other from Topsia to Bantala. The two D.W.F. meet at Bantala and finally lead to river Kulti.

The out-fall point of Kulti is situated about 36 km away from Calcutta, as a result, the sewerage and the drainage water had to traverse this distance in the carrier channel. In course of this journey substantial quantity of suspended materials are deposited in the different reaches of the channel. Due to long traverse length, the organic and inorganic materials are also oxidised during its travel and thus the harmful effects of the raw sewage water are minimised to some extent before final discharge. Raw sewerage and drainage water carried by the **Dry weather flow** and **Storm water flow** channels are being utilised for the purpose of irrigation and pisciculture either by pumping or by gravity. Vast tracts of land (approximately 400 ha)
on both the banks of these channels have been converted into good agriculture/pisciculture centres. This has become a source of supply of vegetables and fishes to the Calcutta markets.

Selection of sites

A] As mentioned earlier, the sewage water of Calcutta city is usually discharged by drainage pumping system. The present investigation has been carried out with sewage samples collected from eight different discharge pumping stations located at the Eastern and North eastern fringes of the city of Calcutta, namely, Palmer Bazar, Ballygunge, Topsia, Kutilangra, Pagladanga, Chingrighata, China Town and Dhapa Lock. Sewages were also collected from the out-fall channel, Dry weather flow channel (D.W.F.C.) which is the chief source of water for irrigating vegetables. Sampling has been done elaborately along D.W.F.C., with the first point being chosen at Topsia Pt.-A (which is the starting point of the D.W.F.C.) and terminal point at Bantala (6 km from Topsia Pt.-A). Within the two terminal points samples were also taken from other three points at the intervals of 1.5 km.

B] Similarly sludges were collected from eight discharge points and also from D.W.F.C.

C] Sewage-irrigated soils were collected from agricultural fields situated along D.W.F.C. Samples were collected from five points starting from Topsia Pt.-A. Final point is situated at Bantala while others at the intervals of 1.5 km.

D] Mature vegetables were collected from agricultural fields situated along D.W.F.C.

E] Ground water samples were taken from sewage-irrigated areas following D.W.F.C. choosing first site at Bantala and final at Topsia Pt.-A. Other samples were collected at the intervals of approximately 1.5 km.
Collection of samples

A] Sewage water from all the discharge points and also from D.W.F.C. was collected during monsoon and winter seasons. From each point 6 samples were collected at 15 days intervals during each season. Sewages were collected by using an automatic neutral glass sampler with in-built thermometer inside the sampler device. After collection, the sewage samples were stored in neutral plastic bottles. Sludges were separated from sewage water after settling in the sampler device. Sludges were kept in plastic packets.

B] Ten composite sewage-irrigated soil samples were collected from previously mentioned sites along D.W.F.C. during both monsoon and winter seasons. Both surface (0-15 cm) and sub-surface (15-30 cm) samples were taken from the field.

C] Mature vegetables like gourd, basil, pumpkin, spinach, tomato, radish, mustard, cauliflower, amaranthus, arum, and potato were collected randomly from the above mentioned agricultural fields during monsoon and winter seasons.

D] For germination test cauliflower and tomato seeds were collected from National Seed Corporation of India.

E] For greenhouse pot experiment composite sewage sample was collected from D.W.F.C. Soils were collected from the sewage irrigated sites along D.W.F.C. Mustard and gram seeds were collected from National Seed Corporation of India.

F] Five ground water samples were taken weekly for the period of 3 months from each observation tubewell. Samples were placed directly into a sterile one litre labelled plastic beakers using a hand-operated tubewell. A refrigerated proportional sampler cooled to 5°C was used to collect 10 litres composite sample. Composite sample was drawn off for laboratory analysis.

Preparation of samples

A] Sewage water
The samples of sewage water which were collected previously,
were filtered through quantitative filter paper after settling in the laboratory.

B] **Sludges**

Sludges from various points were dried at room temperature, thoroughly mixed, subsequently ground to fine homogeneous powder and passed through 0.5 mm sieve. Samples were preserved in polythene container.

C] **Sewage-irrigated soils**

The soils (both surface and sub-surface) were dried first at room temperature, thoroughly mixed, subsequently ground in fine homogeneous powder and passed through 0.5 mm sieve.

D] **Plants**

The samples which were collected from field, were dried first in diffused sunlight and then kept in the oven at 70°C for five hours. The dried samples were ground in mortar and pestle. The crusted plant samples were passed through 100-mesh sieve. Sieved samples were preserved for various analyses.

E] **Seeds and sewages for germination test**

Healthy vigorous tomato and cauliflower seeds were selected and surface sterilized by soaking in 0.01 per cent mercuric chloride solution for five minutes, finally washed with standard distilled water several times.

Sewage water samples, which were particularly collected during the winter season, were mixed in a container and the resulting composite samples were used for germination test.
F) **Greenhouse pot experiment**

Earthen pots of 30 cm top diameter, 15 cm bottom diameter, and 25 cm of height were used in the study. Each pot was filled with 8 kg soil (collected from earlier mentioned area). Sand particles were spread at the bottom of the pot upto 5 cm depth. Leachates were collected from the bottom of the pot with the help of pipe outlets. All the arrangements were placed under polythene sheet. Pot soils were given three treatments, $T_1 =$ control, all irrigations with pond water, $T_2 =$ all irrigations with 1 : 1 diluted sewage water, and $T_3 =$ all irrigations with raw sewage water. The treatments were replicated thrice adopting randomised block design. Pot experiment was conducted with mustard and gram as test crops. Crops were regularly irrigated with the three types of water. Leachates from each pot were collected at the intervals of 20 days starting from 0 day and upto 60 days. After 60 days crops were harvested and samples were dried for subsequent analyses. Soil samples after harvesting were collected and dried for various analyses.

G) **Ground water**

Composite ground water samples were passed through filter paper to remove any suspended particles. Then the samples were directly used for various analyses.

**Laboratory studies**

A) **Analyses of sewage water**

1. **Determination of pH and EC**: pH of sewage water was determined by Systronics pH meter model No. 331 with glass electrode, while electrical conductivity (EC) was measured by Conductivity Bridge, Systronics model No. 305 (Jackson, 1973).
2. **Determination of DO, BOD, COD, TSM, and TDS**: For determination of Dissolved oxygen (DO) sewage water samples were collected in BOD bottle. Dissolved oxygen was fixed by alkaline potassium iodide and manganous sulphate and taken to the laboratory immediately for the measurement following the Winkler’s iodometric method (Trivedy and Goel, 1984). BOD, COD, TSM, and TDS were determined by the standard methods established for the examination of water and waste water (APHA-AWWA-WPCF, 1975).

3. **Determination of sodium and potassium**: Na\(^+\) and K\(^+\) were determined by flame photometric method after proper dilution (Black, 1965).

4. **Determination of calcium and magnesium**: Ca\(^{2+}\) and Mg\(^{2+}\) were determined by versenate titration method (Black, 1965).

5. **Determination of carbonate, bicarbonate, chloride, and sulphate**: CO\(_3\)\(^{2-}\), HCO\(_3\)\(^{-}\), Cl\(^{-}\), and SO\(_4\)\(^{2-}\) were determined by the methods described by Chesnin and Yien (1951) and Black (1965).

6. **Determination of NH\(_4\)\(^-\)-N, NO\(_3\)\(^-\)-N, and phosphorus**: NH\(_4\)\(^-\)-N and NO\(_3\)\(^-\)-N of the sewage water were estimated following the standard procedures as described by Black (1965). Phosphorus was determined spectrophotometrically (Jackson, 1973).

7. **Determination of micro-nutrients and heavy metals**: Micro-nutrients and heavy metals like Fe, Cu, Mn, Zn, Pb, Cd, Cr, Co, and Ni were determined by wet digestion method followed by atomic absorption spectrophotometry (AAS). The method is described as follows:
5 ml of nitric acid was added to 250 ml of the filtered sewage. The above solution was evaporated to dryness at medium heat on a hot plate. After cooling, 10 ml of digestion acid mixture [1 vol. of HClO₄ (approx. 60% m/m HClO₄) to 4 vol. of HNO₃ (approx. 70% m/m HNO₃)] was added to the solution. Then the covered beaker was placed on a thermostatically controlled hot plate maintained at approximately 100°C. When the initial reaction had subsided, the temperature of the hot plate increased sufficiently to maintain the oxidation without evaporating off nitric acid. Heating was continued for 2 hours. When the oxidation was completed, the temperature of the hot plate was increased to 200°C, allowing the excess nitric acid to evaporate from the beaker. Finally, the temperature was increased to 240°C and heating continued until all the perchloric acid volatilised leaving dry residue in the beaker. After cooling, 10 ml of 2M HCl was added to the beaker and boiled for 5 minutes. Finally, the contents of the beaker were quantitatively transferred to a 50 ml volumetric flask and diluted to 50 ml. Then the solution was filtered through Whatman No. 42 filter paper, and the filtrate retained for determination of elements in a Atomic Absorption Spectrophotometer (model - Perkin-Elmer 303).

B] Analyses of sludges

1. **Determination of pH and EC**: pH of the sludge was determined by Systronics pH meter model No. 331 with glass electrode using sludge-water suspension in the ratio 1:2.5, while conductance of the sludge suspension was measured by Conductivity Bridge (Systronics model No. 305) in 1:5 sludge-water suspension (Jackson, 1973).

2. **Determination of cation exchange capacity and exchangeable cations**: Cation exchange capacity of the sludge was determined using normal neutral NH₄OAc after washing with 40% alcohol to remove the soluble salts (Chopra and Kanwar,
Exchangeable Ca\textsuperscript{2+} and Mg\textsuperscript{2+} were determined from the extracts by versenate titration method and Na\textsuperscript{+} and K\textsuperscript{+} by flame photometric method (Black, 1965). Water soluble SO\textsubscript{4}\textsuperscript{2-} was determined by the method described by Jackson (1973).

3. Determination of chemical composition: For determination of chemical composition sludge samples were fused with HF-HClO\textsubscript{4} mixture. Solutions obtained after fusion were used for the determination of Ca, Mg, Na, K, Fe, and Al. Calcium, Mg, Na, and K were determined according to Black (1965). Aluminium concentration was estimated by the method given by Maxwell (1968), and Fe by the procedure proposed by Black (1965). Total Si was determined separately by alkali fusion (Black, 1965).

4. Determination of organic carbon, humus carbon, humic acid and fulvic acid carbon: Organic carbon was determined by Walkley and Black rapid titration method (Black, 1965). Humus carbon, humic acid and fulvic acid carbon were estimated in the 0.5 (N) NaOH extract followed by Walkley and Black rapid titration method using the procedure described by Kononova (1966).

5. Determination of total and available nitrogen, phosphorus and potassium: Total N was determined by Kjeldahl method (Black, 1965). Total P was estimated by tri-acid (HClO\textsubscript{4} + HNO\textsubscript{3} + HCl) digestion followed by spectrophotometric method, while total K by HF + HClO\textsubscript{4} digestion followed by flame photometric method (Black, 1965). Available N of the sludge was determined by alkaline KMnO\textsubscript{4} method (Subbiah and Asija, 1956). Available P was estimated by Olsen's extractant followed by using Spectrophotometer (Jackson, 1973) and available K was determined from ammonium acetate extract followed by using Flame Photometer (Jackson, 1973).
6. **Determination of total and available micro-nutrients**: Total Fe, Cu, Mn, and Zn concentrations were measured by digesting the sludges with HClO$_4$–HNO$_3$ mixture and followed by using Atomic Absorption Spectrophotometer (ADAS; London, 1986). Available Fe, Cu, Mn, and Zn were determined by AAS using Diethyline triamine penta acetic acid (DTPA) as single extractant (Lindsay and Norvell, 1978).

7. **Determination of total and available heavy metals**: Total heavy metals, namely, Pb, Cd, Cr, Co, and Ni were determined by tri-acid (HClO$_4$ + HNO$_3$ + HCl) digestion. Detail method was as follows:

2.5 g of ground sludge sample was taken in a beaker and then 25 ml of digestion acid [1 vol. of HClO$_4$ (approx. 60% m/m) to 4 vol. of HNO$_3$ (approx. 70% m/m)] was added to it. Covered beaker was allowed to stand overnight. Then the beaker was placed on a thermostatically controlled hot plate maintained at approximate 100°C. When the initial reaction had subsided, the temperature of the hot plate was increased to 180°C. The beaker was kept on the hot plate until oxidation was completed. Finally, the temperature was raised to 240°C to volatilise all the HClO$_4$. After cooling, 10 ml of 6 (M) HCl was added to the beaker and boiled for 5 minutes. The contents of the beaker were quantitatively transferred to a 100 ml volumetric flask and diluted to 100 ml. Then the solution was filtered through Whatman No. 42 filter paper and the filtrate retained for determination of Pb, Cd, Cr, Co, and Ni in a Atomic Absorption Spectrophotometer (AAS).

Available heavy metals concentrations were determined by AAS using DTPA as the extractant (Lindsay and Norvell, 1978).
C] Analyses of sewage-irrigated soils

The physical properties such as bulk density, particle density, water holding capacity, pore space, and absolute specific gravity of the soils were determined by Keen-Raczkowski box experiment (Piper, 1966). Mechanical composition of the soil was determined by hydrometer method (Piper, 1966).

Analyses of physico-chemical parameters, chemical components, organic carbon content, nutrients (macro and micro) and heavy metal contents of the soils have been conducted by the same methods as described earlier for analysis of sludge.

D] Analyses of some vegetables grown in the sewage-irrigated areas

For analyses of inorganic chemical constituents like P, K, Na, Ca, Mg, S, and heavy metals like Fe, Cu, Mn, Zn, Pb, Cd, Cr, Co, and Ni, 1 g of dried powdered plant sample was digested with tri-acid (HClO₄ + HNO₃ + HCl) mixture by the similar method as described earlier for digestion of sludge. The solutions so obtained after digestion were used for the determination of the above mentioned elements.

All the components in the solution phase were determined by the procedures as described earlier for analyses of sewage water.

Nitrogen in plant samples was determined by the method described by Ward and Johnston (1962).

E] Germinability test of cauliflower and tomato seeds using raw and 1:1 diluted sewage

Germinability test was carried out as follows:

20 ml of raw and 1:1 diluted sewage water samples from different sources were taken in previously washed culture tubes.
The inner walls (one side) of the tubes were lined with narrow strips of sterilized blotting paper. The soaked cauliflower and tomato seeds were placed on the blotting paper about 2 mm above the water level. The whole set was kept in the incubator at 25°C after covering the mouth of the culture tube with sterilized cotton. Germination percentage was calculated by observing the number of seeds germinated for each treatment after 5 days of incubation. Simple correlation coefficient calculation was carried out as per Panse and Sukhatme (1967).

F) Greenhouse pot experiment

1. Leachates were analysed in respect of pH, EC, soluble Ca\(^{2+}\), Mg\(^{2+}\), Na\(^{+}\), K\(^{+}\), Cl\(^{-}\), and SO\(_{4}\)^{-2}. Analyses have been conducted by the common methods used for analysis of sewage water.

2. Sewage-irrigated pot soils were analysed by the common methods used for analysis of soils.

3. Mustard and gram seeds were digested with tri-acid mixture as per the method given by ADAS (London) in 1986. Solutions obtained after digestion were used for the determination of Fe, Cu, Mn, Zn, Pb, and Cd with the help of Atomic Absorption Spectrophotometer.

G) Analyses of ground water from sewage-irrigated sites

Ground water samples were analysed by the method described earlier for the analysis of sewage water. Coliform counting was done using Most Probable Number (MPN) method (Black, 1965) where a series of nine tubes for each sample were used on Mankenky broth hi-media.