CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 INTRODUCTION

Increasing population growth and industrialisation in the past decades has caused a considerable rise in wastewater generation worldwide. The common practice to cope with the large volume of wastewater is the discharge to surface waters either untreated or after some preliminary treatments. However, the need to preserve existing water resources has led to a re-evaluation of this practice focusing on more environmentally sound methods. Various studies have shown that land application of treated municipal wastewater as water and/or nutrient source for agricultural crop production can represent a sustainable alternative. This study deals with assessment of impacts due to the reuse of sewage for agriculture which is practised near Madurai city for the past 85 years. In order to understand the environmental impacts of the urban sewage irrigation, surface and ground waters and soil samples were analysed and compared with the standards so as to assess the migration of the contaminants. The main objective of this study is to understand the environmental impacts of urban sewage irrigation and to predict the contaminate movement for different management strategies of southern part ofMadurai, keeping the Avaniapuram Sewage Farm (ASF) as the epicenter.
7.2 SUMMARY

The study area is near Madurai, in the Southern part of Tamil Nadu and one of the ancient cities of India. The city is divided into North and South Zones by the River Vaigai, which is a seasonal river occasionally carrying fresh water, otherwise only city wastewater. The population of the city was 9,40,989 as per 1991 Census and is 9,22,913 as per 2001 Census. The total area of the Corporation is 51.83 km². Madurai Local Planning Area, comprising of Madurai City Corporation and its environs, extends over an area 726.34 km². The total population of the planning area is 15,24,027 as per the 2001 Census of which 9,22,913 persons live in the Madurai City Municipal Corporation area and 2,55,033 in the surrounding urban settlements and the remaining 3,46,081 in the rural settlements around Madurai City Municipal Corporation.

The water supply requirements are catered by the Vaigai dam located 70 km away from the city. The Madurai Corporation receives the raw water from Vaigai dam, which is built across River Vaigai, through a pipe line and treated it at Pannipatti. Around 68 Mld is supplied to the South Zone and 45 Mld to the North Zone using over head tanks. On an average, the city consumes 120 to 130 Mld of water for its domestic purposes. Apart from that, people used to tap ground water through open and bore wells for their day to day activities. On an average, the Madurai Corporation and its urban agglomerations are consuming approximately 150 to 175 Mld of water (Corporation supply and ground water). Hence, as per CPHEEO norms, the city generates 120 to 140 Mld of wastewater.

Madurai city has one of the oldest, systematic wastewater collection and disposal system in the world. The original city was at the Southern Bank of the River Vaigai and has expanded to the North Bank due to
the population growth. The sewerage system was initially established as early as in 1924 in South Bank. This scheme was designed for an ultimate population of 2.6 lakhs in the year 1942. The collected wastewater is pumped to Avaniyapuram, where a sewage farm was established for the reuse of wastewater. Avaniyapuram Sewage Farm (ASF) was established in the year 1924 in an area of 155.87 ha. Around 87.80 ha of land is being irrigated with wastewater. Remaining land is utilised as lagoons, roads and garbage dumping sites. This cultivated area of 87.80 ha was divided into 64 plots, each measuring 20.11 m in width and 500 m to 600 m in length with an area of 1.012 to 1.21 ha per plot. This area was built up with a French Drain System (FDS) and this act as a filter media.

From the main pumping station, a portion of the sewage (15 to 20 Mld) is pumped to Avaniapuram Sewage Farm. Due to inadequacy of the pumping capacity, the pumping station could not cope up with the flow. As a result, rest of the sewage (20 to 25 Mld) enters into the nearby channels (Chottathatti and Panaiyur). The increase in population and inadequate wastewater collection system in this South Zone leads to the discharge of the wastewater into the nearby storm water drains. Basically, these drains acted as off-taking channels from the River Vaigai to feed number of irrigation tanks in that region. But due to changes in the level difference between the river and the channels, they no longer serve the purpose for which they were created. In the meantime, the wastewater generation has been increased in this zone and these channels have been converted into sewage carriers. The wastewater is drained through the above channels flowing towards the outskirts of the Madurai city and utilised for irrigation.

Considering the wastewater irrigation in ASF and in the ayacuts of these channels like Chottathatti, Paniayur, Avaniyapuram, it is estimated that 40 to 60 Mld of sewage is being generated from the South Zone. This water is used
to cultivate Guinea grass, which was planted in the sewage farm in the year 1927, later vegetables like brinjal, greens, ladies finger and coconut are also cultivated. Paddy, sugarcane, banana and all types of greens are cultivated on the outskirts of the farm and ayacuts of the channels. Fodder grasses for milk production, greens and vegetable demands of the population of Madurai city are catered by the city wastewater for the past several years.

This study was formulated with an objective of understanding the environmental impacts of urban sewage irrigation in this region keeping the ASF as the epicenter. Samples were collected for the analyses of various parameters from wastewater, ground water and soil. A socio-economic survey was also carried out in the study area to understand the social status of the people. A spatial analysis of ground water quality was carried out in a GIS environment. Apart from that, a water quality forecasting model was developed for the area surrounding the Sewage farm using an Artificial Neural Network. A ground water contaminant transport model was developed to predict the movement of contaminants using Finite Difference Method.

Rainfall analysis was carried out for 31 years (1976 to 2006) of rainfall data for Madurai Airport rain gauge station, which is the only rain gauge station available nearest to Avaniapuram Sewage farm. The analysis indicates that the average annual rainfall is 832 mm. Southeast monsoon receives 35% of annual rainfall and Northeast monsoon receives 45%. The volume of rainwater generated in the study area is 65.3 M m$^3$ (without any losses). The study area receives an average wastewater inflow of 45 Mld, which is of 16.5 M m$^3$/year. It is observed that the volume of rain water is four times the wastewater inflow, so, there is a scope on the dilution of concentration of wastewater as well as ground water in this region.
Monthly average sewage pumped from the main pumping station at Santhaipettai to Avaniapuram sewage farm varies between 17 Mld and 19 Mld. The quality of wastewater was analysed at the inlet and the French Drain Outlet of the farm for various parameters. It is clear that the inflow sewage is rich in organic matters and it contains high BOD (323 mg/l), COD (728 mg/l) and DO (Nil). It is observed that there is an improvement in the wastewater quality for certain parameters such as BOD, COD, DO, TC, FC, Oil and Grease coming out of the French Drain System. This may be due to the free movement of wastewater in both horizontal and vertical directions with plenty of air, relative humidity and an average temperature of 35°C with more than 9 hours of sunshine. Most of the heavy metals are observed below the minimum detection limit, which may be due to the dilution effect of huge volume of domestic sewage with a small amount of industrial effluent.

Ground water samples were collected in and around ASF for a distance of 5 km radius. The well locations were identified with respect to distance and Azimuth (angle) using a Global Positioning System (GPS) Survey. The total area is divided into 4 zones and the number of samples in each zone was fixed with respect to the area covered under sewage irrigation.

Zone I starts at an angle of 45° to 135°, in the Northeast and Southeast directions, which is the most vulnerable zone since the topography favours the flow of wastewater in this direction. Therefore, 17 samples from 11 open wells and 6 bore wells were collected from this zone. In the same way, Zone II (315° to 45°) in the Northeast and Northwest directions covers 12 wells, which includes 7 open wells and 5 bore wells. This zone is comparatively medium vulnerable for pollution due to the natural slope as well as urban settlements. Zone III, (135° to 225°) in the Southeast and Southwest region, was covered with 9 samples, out of which 7 samples were from open wells and two were from bore wells. This is also less vulnerable
for pollution. Zone IV, (225° to 315°) is in the Northwest and Southwest directions. Around 7 samples were collected mostly open wells except one bore well. Since the slope is not in favour of this direction and most of the lands were irrigated by fresh water, it is termed as “least vulnerable region”.

The impact of the sewage water irrigation on ground water quality is noticed from the results. The parameters, which are highly influenced by the sewage, include TDS, chloride, sulphate, nitrate, calcium, magnesium, sodium and total hardness. Some of the parameters are also observed with high concentration in the ground water in the sewage irrigated areas as well as fresh water irrigated areas, which includes pH, bicarbonate and potassium. This may be due to the natural properties of the parent material. The Total and Fecal Coliforms are observed in very large number in the wells, may be due to the sewage water irrigation and solid waste dumping in and around the ASF. But some of the fresh water irrigated areas are also observed with high coliform count, which may be due to the local contamination.

Total Dissolved Solids (TDS) range of 500 to 1500 mg/l is seen in Zones II, III and IV. The TDS values are high in wells situated inside Zone I, especially near to ASF at 2.5 km circle. It is nearly 3000 mg/l, which is higher than the zone average of 2475 mg/l. This value of TDS exceeds the irrigation standards of 2000 mg/l. This may be due to the result of parental material of the area as well as the addition of salts in the form of fertilisers. This clearly shows that distance, direction and slope are playing a major role in the ground water pollution in the study area.

High concentration of chloride (750 to 1250 mg/l) is observed in and around the ASF and in Zone I during the pre monsoon. A value of 1173 mg/l is observed in 2 km radius in Zone I against the drinking water standard of 250 mg/l. This higher range may be due to the continuous addition of
sewage water over the years for irrigation as well as due to the typical absorption property of chloride ions.

It is observed that there is a very high accumulation of sulphate in the pre monsoon period in certain wells in Zone I within 3 km limits. The average sulphate content in this region is 445 mg/l as against the permissible limit of 200 mg/l. The influence of sulphate accumulation is noticed in Zones I and IV of the study area. The leachate from the farm might have led to higher sulphate content, which resulted in the accumulation in the near low lying areas of these zones. Rain water plays a major role in the dilution of sulphates and leach out readily, moved out further in the direction of flow.

Higher concentration of nitrate is noticed within 1 km radius of the ASF (196 mg/l) as well as upto 3 km in Zone I of the study area. This may be due to the continuous addition of sewage water over the years, which might have led to leaching of nitrate into the ground water. The reason for the higher concentrations of nitrates in the ground water might have been due to nature of the source, i.e. wastewater, which contains night soil and detergent solutions used in domestic/ industrial purposes of Madurai city.

In the cases of calcium and magnesium, it is apparent that substantial amount of residues is accumulated in the top layers of soil. This explained on the basis of calcium and magnesium ions applied through the wastewater and present in soil are in the form of non soluble compound such as carbonate, which tend to precipitate and adhere to the soil granules as the wastewater leaches downwards through the soil pores. The observed accumulation of calcium and magnesium in the top layers is a clear indication of the soils ability to purify the applied wastewater. At the same time, this accumulated salt gets diluted during the rainfall and moves out of the soil profile and reaches the surface or subsurface waters.
Higher concentration of sodium is observed in the entire Zone I from the farm to 5 km distance. An average concentration of 480 mg/l is observed as against the limit of 150 mg/l in Zone I. The reason for high sodium content observed in the wells in Zone I are only the released sodium by the influence of sewage water irrigation from its native origin. The slope of the area may also be one of the factors involved, which is evident from the higher sodium content in the low lying Zone I. In general, sodium is a dominant cation in most mineralised ground water. High concentration of sodium in the effluent might exchange the calcium and magnesium in the soil and thus release them into ground water. High concentration of chlorides in wastewater is often found in conjunction with sodium concentration.

Total coliforms are observed as unaccountable quantum in the wastewater source at the inlet of ASF, which has been slashed into an accountable quantity of 5000 MPN/100 ml at the outlet of the ASF. In the whole study area, only very limited number of wells are noticed with low coliforms. The open wells are located very near to the field channels which carry wastewater. There is a chance for seepage of this wastewater into these wells.

The effect of wastewater irrigation on the adjoining ground water levels are observed by using a Global Positioning System (GPS) survey. The altitude of well locations at the ground level were found out. Continuous flow of wastewater into the farm and draining into the near by tanks make the ASF and its surrounding as a water flourished area, even though its quality is poor.

There are many tanks in the study area within 5 km radius. But the tanks in Zone I (upto 5 km) and some part of Zones II and III (up to 2 km) are influenced by the city sewage. Surface water samples were collected from seven tanks in the study area. Most of the parameters like pH, nitrogen, BOD,
calcium, potassium and sulphate are within the acceptable limits of the irrigation standards of FAO. BOD is the most important parameter to be considered when irrigated with wastewater. Here the BOD in the surface water samples is less than 100 mg/l, within the limit of FAO standards. The quality of this surface water influences each and every parameter of ground water a lot, since the sub surface of this region is conducive for the vertical movement of water through percolation to raise the water table. The results of ground water quantity also clearly show that the region is a water flourishing region.

Soil samples were collected in each zone as well as in sewage farm to study the influence of sewage irrigation. Zone I were sampled with 10 samples in both pre and post monsoon seasons since this zone was identified as the most vulnerable region for pollution due to natural slope and intensity of irrigation. However, Zones II, III and IV were considered with 5, 6 and 4 samples respectively in both pre and post monsoons. The number of soil samples in a zone was fixed based on the intensity and frequency of sewage utilised for irrigation.

Soil samples, as mentioned above, were collected, separately labeled and processed for the analysis and tested for pH, EC, texture, lime, nitrogen, phosphorus, potassium, copper, manganese, iron and zinc.

The organic nature of liquid sewage used for irrigation could have led to the build up of high organic content in those soils. The nitrogen content of the soil in the first and second km circles is high, except in Zone IV. Zone I is heavily accumulated with nitrogen and the concentration decreases with respect to distance. The results clearly indicate that the organic source of nitrogen released gradually from the sewage may be the reason for high concentration of nitrogen in Zone I.
The liquid sewage contains phosphorus mostly in organic bound form, which in combination with high amounts of plant residues left in the soil could have promoted the P status of the sewage farm soils. The P held in organic form can be mineralised subsequently by microbes releasing soluble P compounds. K content of the soil is observed to be very high in all zones except Zone IV. There is a higher concentration of micro nutrients, which are observed in the sewage irrigated soils of Zone I though the contents in the sewage effluent are low. The concentration of all micro nutrients is very high in the vicinity of the ASF, however, they tend to decrease away from the farm as the distance increases.

In order to study the changes in soils due to the continuous application of untreated urban wastewater, a soil profile study was carried out. Pits were excavated in a size of 2 m x 2 m for a depth of 150 cm. Two pits were considered, one inside the sewage farm and the other in a private land in the Southeastern direction at a distance of 1.75 km, where the excess wastewater from the farm is used for paddy cultivation for the past 25 years. Soil samples were collected in different layers in each pit to understand the accumulation of nutrients at different depths. Finally, the profile results were compared with the standard profiles published in the Soil Atlas. This clearly shows that the vertical profile of the soil does not change with respect to its texture due to continuous sewage irrigation.

The forecasted concentrations of wastewater were estimated using an ANN model for 40 observation wells around the sewage farm, which are located within 5 km radius. The calibration results are presented for sodium, bicarbonate, potassium, sulphate, nitrate and chloride. The correlation coefficients of the model calibration for each parameter or relation among the water quality parameters are presented in Table 5.14. It is evident that the Pearson’s coefficient of correlation is more significant for the parameters
Total Dissolved Solids, Total Hardness, sulphate and nitrogen. In all the cases, the predicted extreme values are lower than the actual in case of high values and higher than the actual in case of lower values. This clearly indicates a tendency of the ANN to keep its predictions close to the global mean. This characteristic could be interpreted as a weakness of the network or may be due to the relatively low number of extreme values used for training. However, it is possible to quickly judge the water quality of a particular location by implementing this model to assess its suitability for different land uses.

Ground water modeling was performed using Finite Difference Method to simulate and forecast the contaminant plume for different management strategies. There are three different management scenarios considered for the disposal system in the study area.

Irrigation using untreated urban sewage in the farm and the tanks filled with wastewater is referred to as Scenario I. No further sewage irrigation is practised in the study area and the existing tanks are renovated and filled up with rain water, which is referred to as Scenario II. Treated sewage (as per BIS irrigation standards) used for irrigation in the farm and the study area with the existing tanks renovated and filled up with rain water is referred to as Scenario III.

The result of Scenario I indicates that if the present disposal system is continued, the contaminations will spread in the entire Zone I and reach the river within the 15 years. Moreover, all the parameters will increase in their concentration levels and reclamation would be a difficult task.

The result of Scenario II is in favour of reclamation of this study area towards a normal level. This could be achieved by stopping the
wastewater disposal through irrigation and renovating the tanks to hold fresh water for recharge. All the parameters around the farm are within the limits after 5 years and this extends to the entire study area in 15 years. But it has some difficulty in practical implementation. A disposal site has to be identified in some parts of the city as well as a systematic treatment should be implemented in the new site. Otherwise, the present condition may prevail upon the new site as well as after some years. Therefore, suggestion of an alternate site may not be appropriate. Instead, a proper disposal system may be developed as suggested in Scenario III.

Therefore, Scenario III was considered with the wastewater treated to BIS irrigation standards and tanks filled with fresh water for recharge. All parameters except bicarbonate and potassium are within limits around the farm after 5 years. Decline in concentrations is observed even at further distances of sewage farm after 10 or 15 years. But the rate of reclamation is not as quick as that of Scenario II, where fresh water is involved, whereas Scenario III involves treated wastewater.

Wastewater use may either be the only source or an economically viable option available to many groups of people. Therefore, the socio economic perspective of this natural capital was studied in the study area using a questionnaire survey. The survey covered the preference of wastewater for irrigation, application of fertilisers and pesticides, social status and health aspects of wastewater users. The results indicate that the wastewater is a preferred option by farmers, which provides a better socio economic status. But at the same time there are plenty of health hazards and issues for the workers involved in wastewater irrigation.
7.3 MAJOR OBSERVATIONS

Reuse of urban wastewater for agriculture for more than 80 years is a unique experience. Keeping that in mind, the environmental impacts and possible remedial measures were analysed by considering various management strategies. The studies made here lead to the following major observations:

(i) The rainfall analysis carried out for the study area indicates that the volume of water generated by rainfall is four times the wastewater inflow to the sewage farm and hence, there is a scope on the dilution of concentration of wastewater as well as ground water in this region.

(ii) The wastewater analysis indicates that the inflowing sewage is rich in organic matters but heavy metals are observed to be below the minimum detection limit, which may be due to the dilution effect of huge volume of domestic sewage with a small amount of industrial effluent.

(iii) It is observed that the French Drain System plays a major role and very effective in reducing the concentrations of most of the water quality parameters. This may be due to the free movement of wastewater in both horizontal and vertical directions with plenty of air, relative humidity and an average temperature of 35°C with more than 9 hours of sunshine.

(iv) Dividing the study area into zones and selecting wells for water quality samples with respect is natural slope, area covered under
wastewater use and existence of urban settlement is a logical approach for water quality analysis in a study like the present one.

(v) Total Dissolved Solids (TDS) indicate that their values are high in the wells situated in a zone where the distance, direction and slope are critical in ground water pollution.

(vi) Spatial variation of chloride concentration is high in and around the sewage farm during the pre monsoon, may be due to the continuous addition of sewage water over the years for irrigation as well as due to the typical absorption property of chloride ions.

(vii) Presence of high concentration of sulphate is noticed during pre monsoon in areas where there is continuous accumulation of sewage water stagnation, which may prevent or slow down the leaching process of ions.

(viii) Higher concentration of nitrates is noticed in and around the sewage farm. This may be due to the continuous wastewater irrigation, which contains night soil and detergent solutions used in domestic/industrial uses of water.

(ix) Excess amount of calcium has been noticed towards the slope as well as in the upper region of the sewage farm. This observed accumulation of calcium and magnesium in the top layers is a clear indication of the soils ability to purify the applied wastewater. These accumulated salts, at the same time, get diluted during the rainfall and moves out of the soil profile and reaches the surface or subsurface water.
(x) High concentration of sodium is observed in places where wastewater irrigation is practised continuously. The released sodium by the influence of sewage water irrigation from its native origin may lead to higher concentrations. It is observed that in the study area, most of the wells are traced with higher coliforms may be due to the seepage of these wastewater into these wells.

(xi) Most of the water quality parameters of the tanks, which are influenced by the city sewage, are within the acceptable limits of the irrigation standards of FAO. Surface water influences the ground water quality where the sub surface of the region is conducive for the vertical movement of water through percolation.

(xii) Continuous grass cultivation and large amount of plant residues left on the soil surface with the application of organic rich sewage for irrigation lead to the accumulation of macro nutrients (nitrogen, phosphorous and potassium) in the soil matrix to exceed the prescribed standards.

(xiii) Organic sources of nitrogen released gradually from the sewage lead to high concentration of nitrogen. The concentrations of all micro nutrients are very high in the vicinity where sewage is used for irrigation. However, they tend to decrease away from the farm as the distance increases.

(xiv) Continuous application of untreated urban wastewater for irrigation does not change the vertical profile of soil with respect to its texture.
(xv) An ANN model is an effective tool to predict the water quality and can be advantageously used to assess the water quality parameters at a particular location and to assess its suitability for different land uses.

(xvi) A Flow and Contaminant Transport model is useful to study the movement of ground water flow and contaminants.

(xvii) Containment of plume and remediation of ground water resources can be achieved by making use of the recharge potential of the existing irrigation tanks.

(xviii) Reuse of wastewater is not a matter of choice but a fact of life and therefore, safe disposal of urban wastewater with minimum impacts to the environment would be an alternate water source.

(xix) The result of socio economic study indicates that the social status of the farmers practicing wastewater irrigation is far better than other farmers working with fresh water. On the other hand, premature abortion, mineral deficiency and anemic are the major diseases for women, which may be due to their poor food habits and exposure to this wastewater. It is also observed that diseases like cholera, typhoid and entri fever are prominent in a region where wastewater irrigation is going on.

(xx) Estimated income of Rs.1.90 crores / year from the portion of wastewater generated from the city is the proven record that reuse of wastewater could lead to the increased agricultural production as well as urban employment with enough economical benefits.
7.4 CONCLUSIONS

Those major observations made out of the present study and investigation lead to the following conclusions:

(i) The places where rainfall is high or where there is a natural of fresh water can be chosen for the disposal of wastewater such as the urban sewage as the scope for dilution is high.

(ii) In general, urban wastewater will be a mix of domestic and industrial effluents. Domestic wastewater is rich in its organic matters, whereas the industrial effluents are rich in heavy metal contents. Therefore, collection of these effluents in separate streams might help in their economic and efficient treatment and disposal.

(iii) French Drain System is very effective in reducing the concentrations of the wastewater quality parameters and hence it can be beneficially used in urban wastewater treatment and management. This technology can be further investigated to study its worth in using for the municipal wastewater treatment plants.

(iv) Any study to analyse the water qualities of surface and ground waters should be based on the following approach: (i) the area has to be divided into zones on the basis of natural shape; (ii) number of sampling wells has to be fixed on the basis of the area covered by the waters under investigations; and (iii) any existence of urban settlement.
Continuous use of wastewater for irrigation over the years increases the concentrations of TDS, chloride, sulphate, nitrates, calcium, magnesium and sodium. Distance, direction and shape all play major roles in controlling the concentrations of the above parameters.

Water quality parameters of the tanks influenced by urban wastewater are within the acceptable limits of the irrigation standards of FAO. Hence, this urban wastewater can be used for cultivation of crops. But continuous use of wastewater for irrigation may pollute the ground water of the location through percolation and vertical movement.

Continuous grass cultivation with the application of organic rich urban wastewater and large amount of plant residues left on the soil surface will lead to heavy accumulation of macro nutrients such as nitrogen, phosphorous and potassium in the soil matrix, which may exceed the prescribed standards. Hence, continuous use of urban wastewater has to avoided as far as possible.

However, continuous application of untreated urban wastewater for irrigation does not change the texture of the vertical soil profile.

Water quality parameters at a particular location can be assessed by a suitably trained ANN model. Such a model will be useful to study the contaminant movements in a region where urban wastewater is used for irrigation. It can be an effective tool in a wastewater treatment plant and its management.
Ground water flow and contaminants movements can be studied with the help of a flow and contaminant transport model. This model can also be an effective tool in wastewater treatment and management.

However, a combination of ANN and Contaminant Transport Models will be useful to study the quality and quantity of ground water and contaminant movements.

Urban wastewater has to be treated before its application for irrigation continuously, else the environment will be degraded to a level, beyond redemption.

Safe disposal of urban wastewater with minimum impacts to environment will become an alternate source of water. It may become the fact of life in a place where water is a scarce commodity.

The social status of the farmers using wastewater irrigation is far better than those using fresh water. Wastewater is a perennial source, whereas fresh water is seasonal. Hence, crop production will not fail with wastewater. There is a reasonable amount of social acceptance of crop produces with wastewater. Availability of water, market for the produce and social acceptance are all in support of wastewater irrigation.

However, there are some noticeable health hazards and risks for the farm workers dealing with urban wastewater irrigation. Premature abortion, mineral deficiency and anemic are prevalent among the
women workers, whereas cholera, typhoid and entric fever are prominent in a region of wastewater irrigation.

Urban wastewater has a potential and scope to be an alternate source of water, particularly in water starved places such as in Tamil Nadu. French Drain System proves to be an effective mechanism in treating the urban wastewater. Hence, wastewater treated through a FDS and used for irrigation will go a long way in supporting the socio-economic status of the people involved in farming with this water.

7.5 FUTURE RESEARCH

This research study has established a foundation for the possibility of remediation for an urban wastewater disposal site. However, future research for the enhancement of this work may include the following:

- The state of wastewater irrigated crops with respect to its physiology and its uptake of heavy metals into the plants and accumulation of these metals to the human body have to be investigated.

- For a better performance of the developed ground water flow model, more number of observation wells may be selected in the most vulnerable region.

- French Drain System concept may be converted into a laboratory model and different combination of soil and plant may be worked out to find out the optimum uptake of the contaminants.
A separate study can be taken up on the health aspects of the wastewater workers to assess the long term and short term impacts.

Optimisation of recharge quantum of water required for the remediation of the site may be carried out using an evolution algorithm.

Other remediation techniques like bioremediation, phytoremediation etc., may be studied for the economical reclamation of the wastewater irrigated land.

The accuracy of the ANN model could be improved further by quantifying and incorporating the parameters such as the soil characteristics and climatic parameters.