Impact of Point Source Contamination on Eutrophicated Water Bodies using Streeter Phelps Oxygen Sag - Reaeration Model

S.Dinesh Kumar
Adhoc Faculty, Department of Energy & Environment
National Institute of Technology, Trichy, TamilNadu, INDIA

Dr. S.Senthil Vel
Professor, Dept., of Soil & Water Conservation Engineering
Tamil Nadu Agricultural University, Coimbatore

Dr.A.Bharani
Assistant Professor, Dept., of Environmental Science
Tamil Nadu Agricultural University, Coimbatore

Abstract- The objective of the study is to address the non-linearity, subjectivity, transfer and transformation rule of the pollutants and complexity of the cause-effect relationships between water quality variables and water quality status, development and use of water quality model is of utmost importance. The main indicator of stream pollution which reflects oxygen conditions of streams are Biochemical oxygen demand (BOD) and Dissolved Oxygen (DO). In the present study, attempts have been made to use Streeter Phelps and oxygen sag curve water quality models for Sanganur stream feeding Singanallur tank and a part of Noyyal River feeding the Sulur tank in Coimbatore. The study imparts the reason for the contamination of the water storage bodies as their sources of feed system are subjected to waste disposal system from different small scale industries and residential plots. The dissolved oxygen of the stream is continuously been affected before it reaching the saturated level. This process ultimately results in the eutrophication level of water storage bodies and algal bloom growth. The physical, chemical and biological analysis of the water storage bodies are also great evident for the pollution levels of the tank system.

Keywords: Water quality, Point source contamination, Streeter Phelps model, Eutrophication.

I. INTRODUCTION

Water is important to individuals, society and natural ecosystems as life cannot exist without a dependable supply of suitable quality water. The vital component of hydrologic cycle remains the development of water resources either by way of surplus rain water harvesting through runoff or subterranean aquifer recharges through deep percolation. Harnessing water resources serves the multipurpose of irrigation, domestic water supplies and industrial water needs. The quality of water available with surface or ground water resources depends on its interaction with multi various activities such as urbanization, industrialization, domestic waste generation, crop production, drainage and sewage disposal etc in the proximity of water resources location. Lack of technical knowhow in handling the wastes and effluents generated without proper pre-treatment and post-treatment infrastructure often results in point source or non point source pollution of the water bodies. The severity of water pollution and contamination is very much felt in urban and sub urban environment where water bodies are loaded with unbelievable proportions of hazardous and infectious wastes and effluents. The point source contamination by domestic and industrial effluents discharges are carried along streams and rivers that feed a chain of system tank attached to them. In addition, these tanks will also receive non point or distributed contaminants by way of surplus runoff from the upstream catchment gushing into the water bodies bringing along the deleterious pollutant materials. The continuous ingress of multi-various pollutants in a water body leads to the eutrophication process that inflicts the survival of phytoplankton and zooplanktons within the water body making the water totally unpalatable.

Eutrophication refers to an accelerated growth of algae on higher forms of plant life caused by the enrichment of water by nutrients especially compounds of nitrogen and phosphorus and inducing an undesirable disturbance to the balance of organism present in the water and to the quality of water concerned. Eutrophication is more of a status than a trend that describes the qualitative conditions of an aquatic environment which has been disrupted more than its quantitative biomass productivity. The direct consequence is an excess of oxygen consumption near the bottom of the water body. In addition to carbon, oxygen and hydrogen that plants can find directly from water, and carbon dioxide in the atmosphere, two major nutrients are necessary for the development of aquatic life namely Nitrogen (N) and phosphorus (P). The ratio of nitrogen to phosphorus compounds in a water body is an important factor determining which of the two elements will be the limiting factor, and consequently which one has to be controlled in order to reduce a bloom. Generally, phosphorus tends to be the limiting factor for phytoplankton in fresh waters.

Water pollution is separated into two broad categories called point and non-point sources of pollutants. The term point source pollution refers to the pollutants discharged from one discrete location, such as an industry and municipal waste water treatment plant to the river and the pollution that enters the receiving surface water diffusely at intermittent intervals refers to the non-point source pollution. According to Central Pollution Control Boards data water quality of major rivers varied widely with respect to DO, BOD, TC, and FC. The pollution strength and potential demand for oxygen of effluent is indicated by the BOD concentration. The amount of oxygen that consumed by microorganisms to decompose the organic matter from a unit volume of water, during a specified period of time is termed as BOD. Another most important constituent of water systems is dissolved oxygen (DO) and a river must have about 2 mg/l of DO to maintain higher life forms. In addition to these life-sustaining aspects, oxygen is important because it produces aesthetically displeasing colours, tastes, and odours in water during chemical and biochemical reactions in anaerobic systems. The rate at which dissolved oxygen is used will depend on the quantity of the organics, the ease with which they are biodegraded and the dilution capacity of the stream. Mainly, the dissolved oxygen in water bodies is dependent upon temperature, salinity, turbulence and atmospheric pressure. Bio-depletion and re-aeration processes also control dissolved oxygen contents. If the dissolved oxygen concentration drops below that required by certain organisms living in the water, these organisms will die. This is sometimes evidenced by fish kills, and in the extreme, by the production of obnoxious gases such as methane and hydrogen sulfide.

II. MATERIALS AND METHODS

The objective of the present research is to provide information on the physio-chemical characteristics of sub-urban tank in order to discuss it's suitability for human consumption bycomparison with Water quality standards and its status of Eutrophication level to aid further reclamation of tank. The quantum of data and the number of input parameters can be collected on the basis of the objectives of the study and requirement of Streeter Phelps model for self purification study.

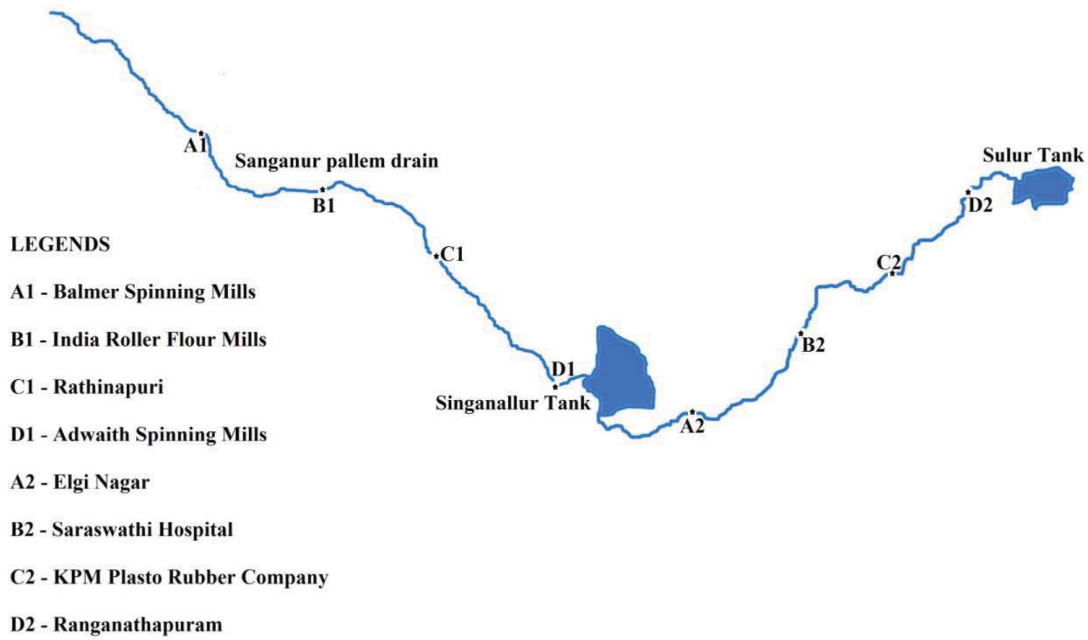

Figure 1 General plans of the sampling points in stream

To collect water quality samples of point source contamination, four sampling stations namely A1, B1, C1 & D1 at 4 km, 9 km, 11 km & 17 km locations respectively in a stretch of 21.5 km of Sanganur stream feeding Singanallur stream and four sampling stations at namely A2, B2, C2 & D2 at 5 km, 9 km, 11 km & 13 km locations respectively in a stretch of 14 km of part of Noyyal river feeding Sulur streams have been selected. A map of selected streams along with sampling stations is shown in Figure 1. The samples were collected from the point source pollution points and the DO & BOD concentration is analyzed.

The Physical, Chemical and Biological analysis of water quality were analyzed using by the Indian Standards Institution (IS 10500-1989).

Evaluation of trophic state of tank

Trophic State Index (TSI)

The trophic status refers to the level of productivity in a lake as measured by phosphorous, algae abundance and depth of light penetration. TSI rates individual lakes, ponds and reservoirs based on the amount of biological productivity occurring in the water.

The formulas for calculating TSI values are, $TSI = 14.41 \ln TP\ (\mu g/L) + 4.15$ (1)

Table.1 Carlson's trophic state index values and classification of lakes

TSI values	Trophic Status	Attributes
< 30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30 – 40	Oligotrophic	A lake will still exhibit oligotrophy, but some shallower lakes will become anoxic during the summer
40 – 50	Mesotrophic	Water moderately clear, but increasing probability of anoxia during the summer
50 – 60	Eutrophic	Lower boundary of classical eutrophy: Decreased transparency, warm-water fisheries only
60 – 70	Eutrophic	Dominance of blue-green algae, algal scum probable, extensive macrophyte problems
70 – 80	Eutrophic	Heavy algal blooms possible throughout the summer, often hypereutrophic
>80	Eutrophic	Algal scum, summer fish kills, few macrophytes

Oxygen Sag Analysis

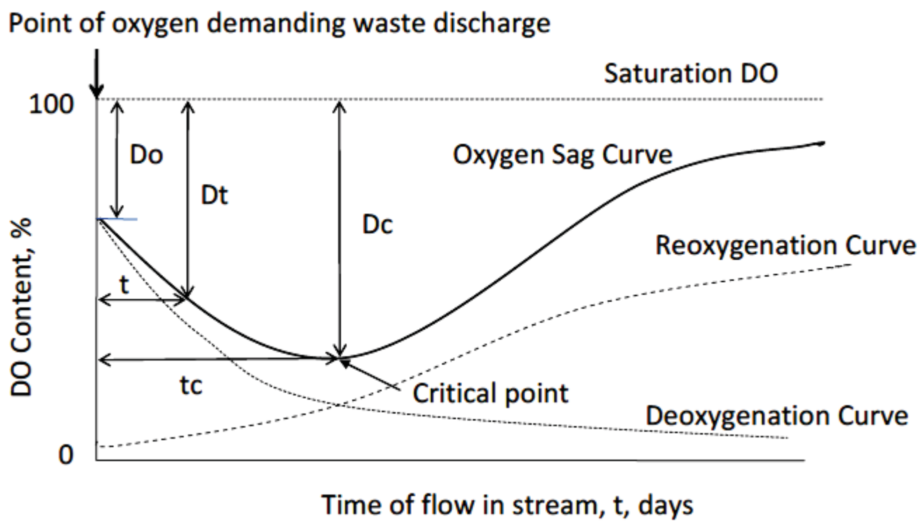

Figure 2 Deoxygenation, reoxygenation and oxygen sag curve

This is first order first degree differential equation and solution of this equation is as under

$$Dt = \frac{K'Lo}{R'-K'}\left[e^{-K't} - e^{-R't}\right] + Do.e^{-R't}$$

Changing base of natural log to 10 the equation can be expressed as

$$Dt = \frac{KLo}{R-K}\left[10^{-K.t} - 10^{-R.t}\right] + Do.10^{-R.t}$$

Where,

K	-	BOD reaction rate constant, to the base 10
R	-	Reoxygenation constant to the base 10
Do	-	Initial oxygen deficit at the point of waste discharge at time t = o
T	-	time of travel in the stream from the point of discharge = x/u
X	-	distance along the stream
U	-	stream velocity

This is Streeter-Phelps oxygen sag equation.

Results and Discussion

Trophic state of tanks

The degree to which contaminants take the toll of phytoplanktons & zooplanktons can be represented by eutrophication process. The status of eutrophication in terms is assessed by total phosphorous concentration or Cholorphyll α or secchi depth. For present study, total phosphourus concentration analysis was done which is an important indicator for trophic status of tank.

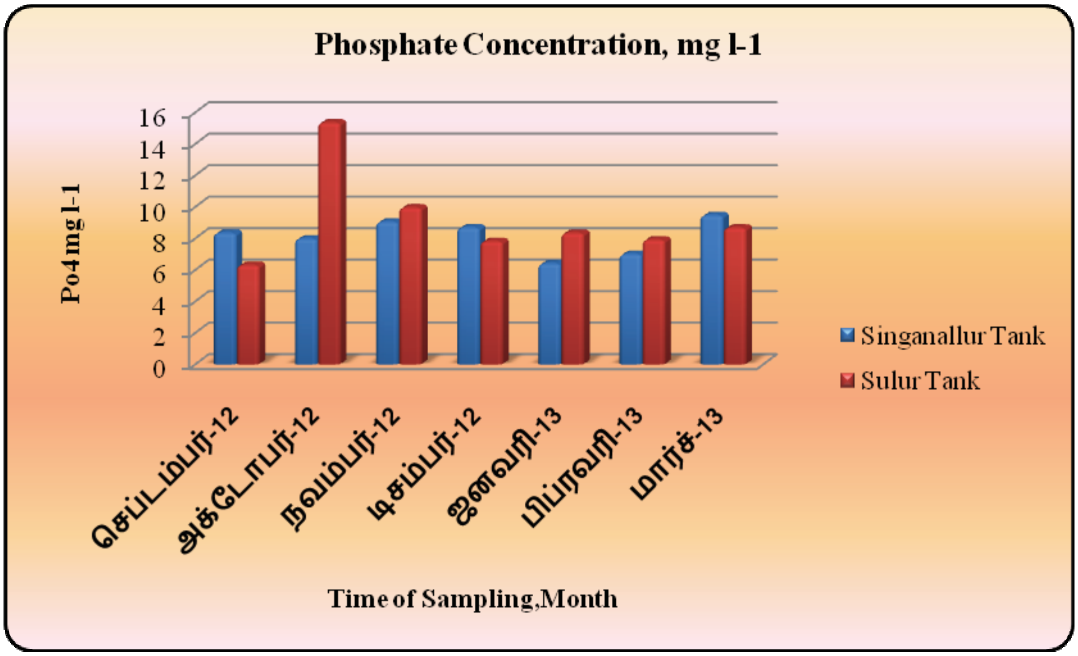

Figure 3 Comparison of Phosphate Concentration analysis for study area

Singanallur tank

From the Fig 5, the phosphate concentration at singanallur and sulur tank was found to be 8.13 mg l^{-1} and 9.2 mg l^{-1} respectively from 10 samples taken at a time. The Total Phosphorus Concentration (TP) of the tank was determined by converting for equivalent phosphate concentration based on the molecular weight given by

$$(TP) = \text{Total Phosphate concentration} \times \frac{\text{Molecular weight of Phosphate}}{\text{Molecular weight of Phosphorus}}$$

Based on the above calculation, the total phosphorus concentration at Singanallur and sulur tank was found to be 24,900µg l^{-1} and 28,200 µg l^{-1} respectively. Substituting the total phosphorus concentration (µg l^{-1}) in following Carlsons Trophic State Index formula, eutrophication state is analysed.

$$TSI = 14.41 \ln TP (\mu g\ l^{-1}) + 4.15$$

Where,

TP = Total Phosphorus concentration (µg l^{-1})

As per the analysis, the trophic state index for Singanallur and sulur tank was around 150 and 151.8 respectively. The Value indicates the hypereutrophic state of the tank water, making restoration of the tank water back to its quality inevitable.

BOD-DO Modeling for point source pollution simulation using streeter phelps oxygen sag curve

Sanganur pallam or Sanganur stream, a tributary to the River Noyyal was identified to study the real time contamination effects by the way of point source pollution at prominent points of introduction as shown in the fig 4. The Sanganur stream is an ephemeral stream drawing its stream flow mainly during the rainy seasons and acts as a sewage carrier for the rest of the year collecting a variety of pollutants and contaminants from multiple sources such as industrial outflows, domestic discharges and hospital disposals aggregating the situation of water pollution at the confluence point of Singanallur tank before joining the main River Noyyal. Apart from the non rainy season point source pollution, the Sanganur stream also contributes by way of non point source pollutions from the urban and sub urban areas through contaminated surface runoff due to rainfall.

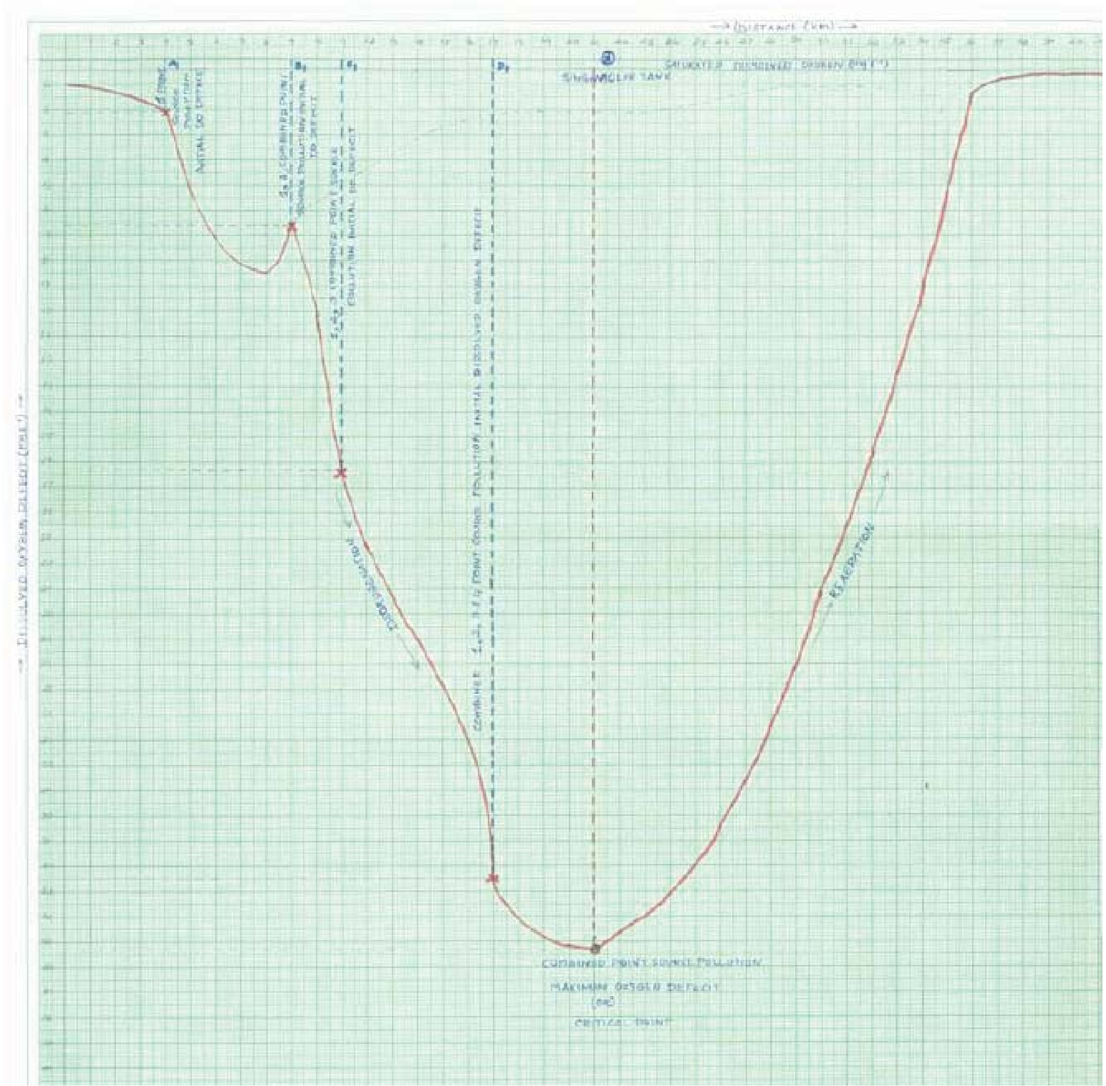

Fig 4 Cumulative point source pollution Streeter Phelps Oxygen sag – reaeration Curve for Singanallur tank

Deoxygenation and reoxygenation pattern along the contributing contaminant stream towards Singanallur and Sulur

The fig 4 & 5 depicts the locations of point source pollution and its effects on accelerating the oxygen deficits due to the successive contaminant points. The initial saturated DO content was found to be 8.64 mg l^{-1} representing the initial zero oxygen deficit. The X-axis indicates the linearly stretched distances of the contaminant points while the Y-axis is plotted with decreasing values of DO deficit concentration (mg l^{-1}) with simultaneously indicates the increasing value of oxygen deficits. It is observed that first lead distances 4 km where the first point source contaminants occurs due to the discharges of a spinning mills effluents depressing the DO as represented by the deoxygenation curves that reaches the maximum oxygen deficits at a distances of 8^{th} of the stream i.e. 4 km from the point source. There upon the deoxygenation curve get transformed to reaeration curve rising up from the point of inflection due to the atmospheric oxygen. It is observed that second lead distances 9 km where the second point source contaminants occurs due to the discharges of a flour mills effluents depressing the DO as represented by the deoxygenation curves that reaches the maximum oxygen deficits at a distances of 14^{th} km of the stream i.e. 5 km from the point source. The third lead distances occurs at 11 km where the third point source contaminants occurs due to the discharges of a residential sewage depressing the DO as represented by the deoxygenation curves that reaches the maximum oxygen deficits at a distances of 14^{th} km of the stream i.e. 3 km from the point source. The fourth lead distances occurs at 17 km where the fourth point source contaminants occurs due to the discharges of a spinning mill effluents depressing the DO as represented by the deoxygenation curves that reaches the maximum oxygen deficits at a distances of 22th km of the stream i.e. 5 km from the point source. There upon the deoxygenation curve get transformed to reaeration curve rising up from the point of inflection due to the atmospheric oxygen. If no successive point source pollution is there the complete reaeration back to the saturated DO concentration would have taken at a distance of 22.5km. But the Singanallur tank lies at a distance of 21.5 km indicating that the tank is still getting polluted with the contaminated stream. The positions of successive point source have been indicated with super position of oxygen sag reaeration curves.

The Streeter Phelps model is applied to a part of Noyyal river stream feeding the Sulur tank where the first, second, third and fourth point source contamination discharges at 5 km, 9 km, 11 km and 13 km from sources such as residential area, hospitals, rubber company respectively. The cumulative effect of the point source contamination ultimately increases the maximum oxygen deficit occurs at 21.5 km. But actually the tank is located at 13 km from stream origin. This in turn ultimately polluted the water storage bodies.

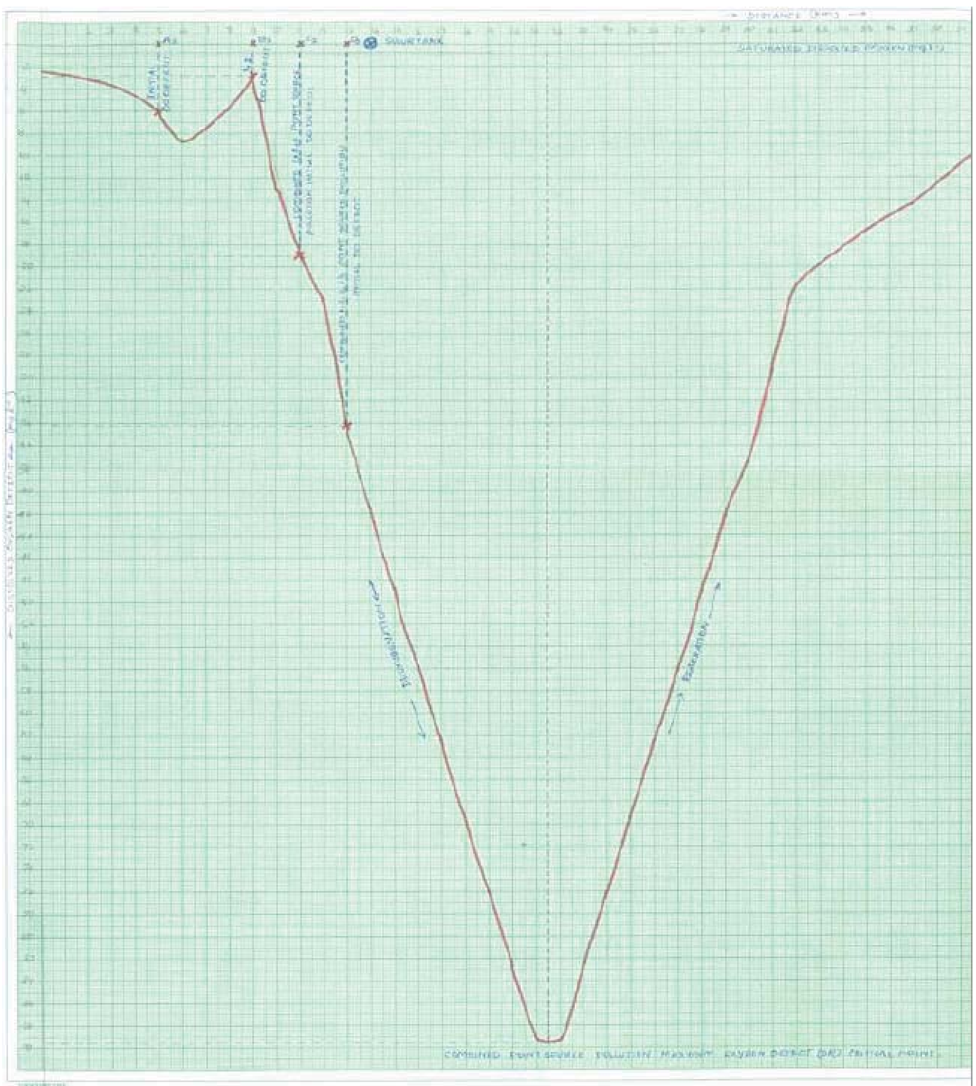

Fig 5 Cumulative point source pollution Streeter Phelps Oxygen sag – reaeration Curve for Sulur tank

Complexities in accessing the complementary deoxygenation – reaeration processes along contaminated streams

The Streeter Phelps model with appropriate model parameters values to suit the local conditions of contamination is certainly reliable tool to predict the distance or time at which reaeration back to saturated DO levels can be resumed since the point or time of introduction of contaminants at a given point source contaminated locations. However, as per the predictions by using this model, the distance at which complete recovery of DO occurs beyond the reach of water storage body connected to the stream. Further by superposition of successive point source locations, it implies that the stream water is never allowed to get back to its original saturated DO level due to the depressions of the oxygen deficit curve by successive introduction of contaminants within the domain of the previous Deoxygenation – Reaeration curve. Ultimately the oxygen deficit goes down to the level of around 35 mg l^{-1} in Singanallur tank and 84 mg l^{-1} in Sulur tank i.e. highly deleterious for any water storage body that intercepts the highly contaminated streams. Thus the stream contamination eventually leads to high degree of eutrophication within the water storage body, be it a lake or pond or a tank or a reservoir.

III. SUMMARY AND CONCLUSION

The water quality in the downstream is highly contaminated as it receives the wastewater discharge from different point source pollution than in the upper stream. The analysis of the Streeter Phelps model for different point source pollution indicated a poor dilution of the untreated wastewater with the stream discharging runoff during rainy season. Mainly the concentrations of dissolved oxygen showed an increase in oxygen deficit of stream (35 mg l^{-1} in Singanallur stream and 84 mg l^{-1} in Sulur stream) as it receives waste water discharge from point source such as Spinning mills, flour mills, Small scale industries and congested residential areas domestic sewage effluent. The higher pollution load discharged into stream was carried out to the tank ultimately resulting in deterioration of aquatic environment.

The trophic state condition of the tanks was analyzed using Carlson's Trophic State Index on considering total phosphorus as an indicator. The total phosphorus concentration of Singanallur and Sulur tank was 24,900 µg l^{-1} and 28,200 µg l^{-1} respectively. Accordingly, the trophic state index was Singanallur and Sulur tank 150 and 151.8 respectively where the index values were higher than 80 indicating the hypereutrophic state of the tanks. In this condition the heavy algal blooms were possible throughout the summer; dense macrophytes i.e. water hyacinth beds where it reduces the penetration of sunlight ultimately results in the death of aquatic organism and fresh water fish.

Ultimately the water quality in multipurpose tanks shows the drastic variations in their characteristics. The water temperature of the tanks was recorded around 30^{o} C as it was important for the metabolic activities of fresh water environments.

Turbidity of water samples was found to be within the permissible limit of < 5 NTU in Singanallur and Sulur tank as it was recorded only maximum level of 0.7 NTU and 0.6 NTU and minimum of 0.34 NTU and 0.4 NTU respectively. On comparing the average values of turbidity for both tanks was 0.5 NTU which shows the values were negligible indicating the clearness of water.

On an average, the TDS remains 1864 mg l^{-1} and 2699 mg l^{-1} for Singanallur and Sulur tank respectively showing the water unfit for multi various use like drinking, livestock watering and irrigation. Based on the above classification the singanallur tank cannot be considered safe even for irrigation purpose.

In Sulur tank, the values were under tolerance limit whereas in Singanallur tank it remains higher. The higher amount of total solids in Singanallur tank in comparison to Sulur tank was perhaps due to run off and high sewage effluent release from Sanganur drains, municipality solid garbage dump and other wastages. The higher concentration of total suspended solid in Singanallur tank is an index that shows it is more polluted.

The Dissolved oxygen level also shows the increase in the values indicates the increase oxygen required for microorganism and strong chemicals for oxidation. There also increase in the calcium, potassium, sodium, phosphate, sulphate, chloride than the permissible limit.

A potential health risk exists due to presence of microbial pathogens in water which was found to be maximum of 280/100 ml of water sample in Singanallur tank and maximum of 85/100 ml of water sample in Sulur tank.

The remedial measures suggested proper vegetative strips or mechanical filter can be installed at the confluence point of streams with water storage bodies. Even the entire stream course can be converted into swales or vegetated waterways that help in preventing the accumulation of solid wastes along the streams. Biofilters or reedbeds may also be contemplated at critical point along the streams and at the confluence point of stream before water storage body in order to minimize the contaminant loads. The study has to be continued for assessment of non point source pollution which also important to be considered for water quality assessment.

REFERENCES

[1] Addy K and L. Green.1996. Phosphorus and Lake Aging. University of Rhode Island: Natural Resources Facts; Report nr 96-2.

[2] Agarwal and Bhargava. 1977. First expanded BOD-DO Model, Basic River Water Quality Models, IHP-V Project 8.1, edited by D.G. Jolankai, pp.27-29.

[3] Agarwal, A. and S. Narain, (Eds). 1997. Dying wisdom. Rise, fall and potential of India's traditional harvesting systems. New Delhi: Centre for Science and Environment.

[4] Bhargava, D. S. _1983_. Most rapid BOD assimilation in Ganga and Yamuna rivers. *J. Environ. Eng.*, 109-1, 174–178.

[5] Boesch, D.F., R.B. Brinsfield and R.E. Magnien, 2001. Chesapeake Bay Eutrophication: Scientific Understanding, Ecosystem Restoration and Challenges for Agriculture. *Journal of Environment Quality*, 30:303-320.

[6] Carpenter SR. 2008. Phosphorus control is critical to mitigating eutrophication. *Proceedings of the National Academy of Science,* 105:11039-11040.

[7] Carpenter, S., N. Caraco, Correll, R. Howarth, A. Sharply and V. Smith. 1998. Nonpoint source pollution of surface waters with phosphorus and nitrogen. *Ecological Applications*, 8(3): 559-68.

[8] Das J., 2003. Geochemistry of trace elements in the ground water of Cuttack city, India. *Water Air Soil Pollution*, 147, pp. 129-140.

[9] Fair, G. M., 1939. The dissolved oxygen sag- and analyses. *Sewage Works J.,* Vol 11., pp. 445.

[10] Gächter, R. and B. Müller. 2003. Why the phosphorus retention of lakes does not necessarily depend on the oxygen supply to the sediment surface. *Limnology and Oceanography*, v. 48, p. 929-933.