Assessment of Approaches for Eliminating Use of Fresh Water in Tanneries at Jajmau, Kanpur

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By

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Environmental Engineering and Management Programme
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CERTIFICATE

This is to certify that the work contained in the thesis titled: ***Assessment of Approaches for Eliminating Use of Fresh Water in Tanneries at Jajmau, Kanpur***, by Mr Rajat Verma has been carried out under my supervision.

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Dedicated To

The Toughest Yet The Best Two Year Experience Gained

And

The Future That Lies Ahead

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RAJAT VERMA

List of Contents

List of Figures

List of Tables

Abstract

Industrial development is vital for the economy of a country. However, it should not occur at the cost of the environment. A major contributor to the Indian exports is the leather and leather goods but at the same time it is one of the most polluting industries. Though a lot of money and effort has been spent towards the treatment facilities for tannery effluent, overall achievement has been limited and the treated effluent is often found not complying with the current effluent discharge standards, especially for total dissolved solids (TDS). Conventional practice of treatment has no provision for removal of TDS and thus the levels are often much higher than the discharge standard of 2100 mg/L. Subsequent use of partially treated or untreated effluent for agriculture or disposal in inland water bodies has very serious effects on the users of such resources. Encouraging more recycling/reuse of effluent with application of advanced treatment technologies will limit the unsustainable exploitation of fresh water resources.

The present study aims at estimating the expenditure for reusable water inclusive of costs of complete segregation of effluents, proper collection and conveyance, complete treatment of effluent and distribution of treated effluent. Energy and land footprint are also important along with the expenditure incurred, and hence are also estimated separately. The study also aims at estimating the tariffs for recyclable water with the financial options available for provisioning infrastructure facilities with such high capital and operational expenditures.

The proposed approach is illustrated through a case study of Tanneries in Jajmau, Kanpur. Two options considered include zero discharge into water bodies using multi effect evaporator for recovery of salts from the reject of reverse osmosis (RO reject) process and controlled discharge of accumulated RO reject in lagoons during high flows in monsoons. Results indicate that the approximate land and energy footprint for CETP facilities with MEE and lagoon is 0.16 hectare per MLD & 18.82 MW-h per MLD per day and 2.08 hectare per MLD & 2.33 MW-h per MLD per day respectively. The approximate land and energy footprint considering common beam house (CBHF) facilities with MEE and Lagoon is 0.24 hectare per MLD and 25.94 MW-h per MLD per day & 2.17 hectare per MLD and 9.61 MW-h per MLD per day. The approximate tariffs for recycled water with MEE and Lagoon (at 30% equity and 70% loan at 5% interest rate for 20 years) ₹ 290 per KL and ₹ 144 per KL respectively. The approximate tariffs of de-limed skins in CBHF facilities with MEE and Lagoon is ₹ 57 per sq. m. and ₹ 47 per sq. m. respectively.

Proper effluent treatment and reuse/recycle is aesthetically good and have many other benefits as well. The tariffs for recycled water though may appear high in comparison to existing freshwater tariffs but it is important that the cost of abatement is truly borne by the polluter and the over exploitation of the under-priced public resources for private financial gains is stopped.

Keywords: Tannery Effluent Treatment, Zero Liquid Discharge, Common Beam House Facility, MEE, Jajmau Tanneries.

1. Introduction

National Ganga River Basin Authority (NRGBA) is an empowered planning, financing, monitoring and coordinating body formed on 20 Feb 2009 under the Environment Protection Act, 1986 for cleaning the river Ganga. A consortium of 7 Indian Institute of Technology has been engaged by the Government of India to prepare an action plan for "Un-polluted Flow" or "Nirmal Dhara" in all the rivers of Ganga River Basin (GRB). The main approach to achieve the ultimate objective of "Nirmal Dhara" has been to identify the type of polluting wastes, their sources of generation (point and non-point sources), and the techno-economic feasibility of collecting and treating them for their safe environmental discharge and/or possible recycle or reuse.

Among the point sources, industrial wastewaters are significant sources of pollution affecting the water quality in the Ganga basin and require expeditious remediation. The leather tanning industry though contributes significantly to Indian exports, poses severe threat to the environment. Leather and leather goods manufacturing industries located in Jajmau, Kanpur and Unnao in Uttar Pradesh and Kolkata in West Bengal, are major contributors to pollution in Ganga River Basin (Figure 1.01).

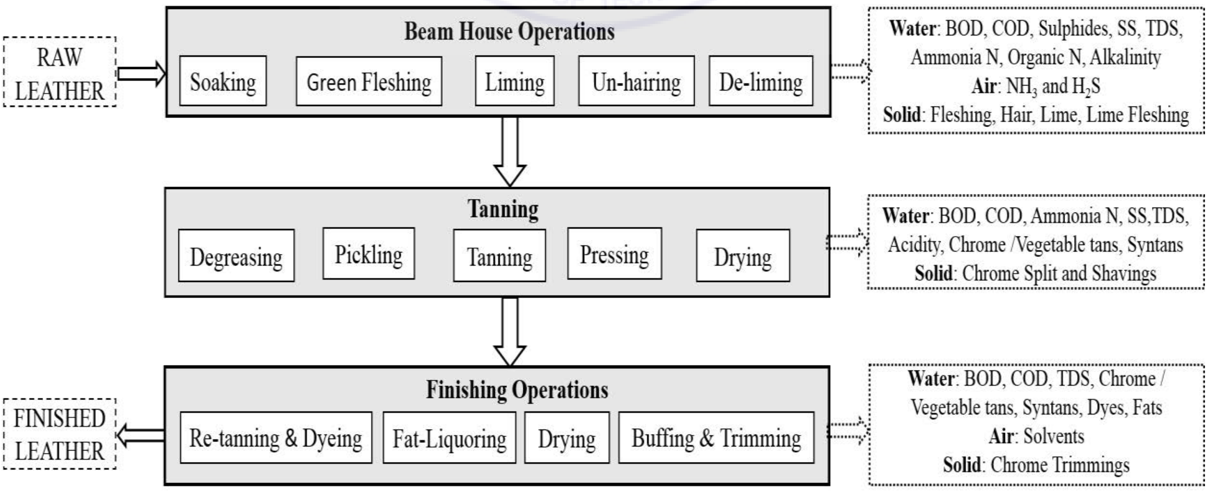

Figure 1.01: A Typical Process Flow Sheet in An Integrated Leather Tanning Industry with Types of Pollutants Generated in Leather Processing

The current practise at Jajmau, Kanpur, of primary treatment of tannery effluent at individual units followed by secondary treatment at a central facility is insufficient primarily due to under-design of the central facility to handle the current potential discharge and poor operation and maintenance practices. Hence a major portion of tannery effluent flows untreated into the Ganga River. The industry being a repeated offender often faces the fear of heavy fines and closure notices. Hence the problem is three-fold, firstly it causes the rampant pollution of valuable surface water sources, secondly it exerts a severe pressure on ground water resources, and third it limits the growth of the industry. The following steps are considered essential for solving the problem.

1. Complete stoppage of either treated or un-treated wastes into any rivers of GRB or at most extremely regulated discharge of concentrated salt streams when river flows are very large.
2. All tannery effluent should be segregated and collected into two categories, namely ‘chrome stream’ and ‘composite stream’. The ‘chrome stream’ should be physico-chemically treated to precipitate chrome and to bring Total Chromium < 2 mg/L in the supernatant. The ‘composite stream’ should be first treated to secondary level with treated effluent standards of: Bio-chemical Oxygen Demand < 30 mg/L, Suspended Solids < 5mg/L, COD < 250 mg/L, Total Chromium < 2 mg/L.
3. This should be followed by tertiary treatment including Dual Media Filtration and Activated Carbon Filtration. The tertiary treated water should be passed through the multi-stage Reverse Osmosis plant to bring down Total Dissolved Solids and permeate should be recycled and reused by the tannery industry for manufacturing of leather. The concentrate water may be stored in lined lagoons and discharged into rivers during the high flow monsoon periods or can be condensed using multi-effect evaporators.

The above measures are essential to overcome the declining state of industrial wastewater management and declining groundwater levels in GRB. Although much money and effort have been spent in Ganga Action Plan over the past few decades, the overall achievement has been limited. And, yet, the same approach has persisted over the years, leading to general disillusionment and cynicism.

But such despondency and cynicism can be easily overcome if wastewater is considered as “resource” rather than as “dirt” and the “Polluter Pays Principle” is rigidly adhered to. By adequately treating wastewater and re-using it instead of dumping the untreated or partially treated wastewater to sully the environment, industrial/urban wastewater treatment can achieve “Zero Liquid Discharge” (or ZLD) and recover the value of water as a “resource”. However, costs and benefits of such strategies need to be delineated in quantitative terms to convey policy makers. It is to satisfy this end that the present study was initiated.

2. Background and Review of Literature

2.1 General

The genesis of this study has been the recommendations of the Environment Quality and Pollution (EQP) Group of the Consortium of 7 IITs preparing the Ganga River Basin Management Plan to have "un-polluted flow" in the rivers of the basin and addresses one of the aspects which is adoption of complete water recycling by water polluting industries in National River Ganga Basin (NRGB). Prior to recycling of water it is important to have an appropriate framework for complete treatment of industrial effluents and sewage so as to ensure that the treated water is fit for recycle and/or reuse. A complete treatment facility includes effluent collection and conveyance, effluent treatment and recycled water distribution system. It is also important to have appropriate ballpark estimates of expenditure on construction and operation and maintenance of these facilities.

2.2 Tanning Process

The process of converting raw hides and skins into finished leather by following a series of physical and chemical operations is called tanning of leather. The industries which house the facilities for carrying out these operations are referred as tanneries. A typical flowchart of the operations and the description of phases carried out in tanneries are presented in Figure 2.01. The list of pollutants generated in the composite effluent of these processes, their concentrations assuming water consumption of 25 m^3 per tonne of raw hide and their permissible limit of discharge in inland surface water bodies is presented in Table 2.1.

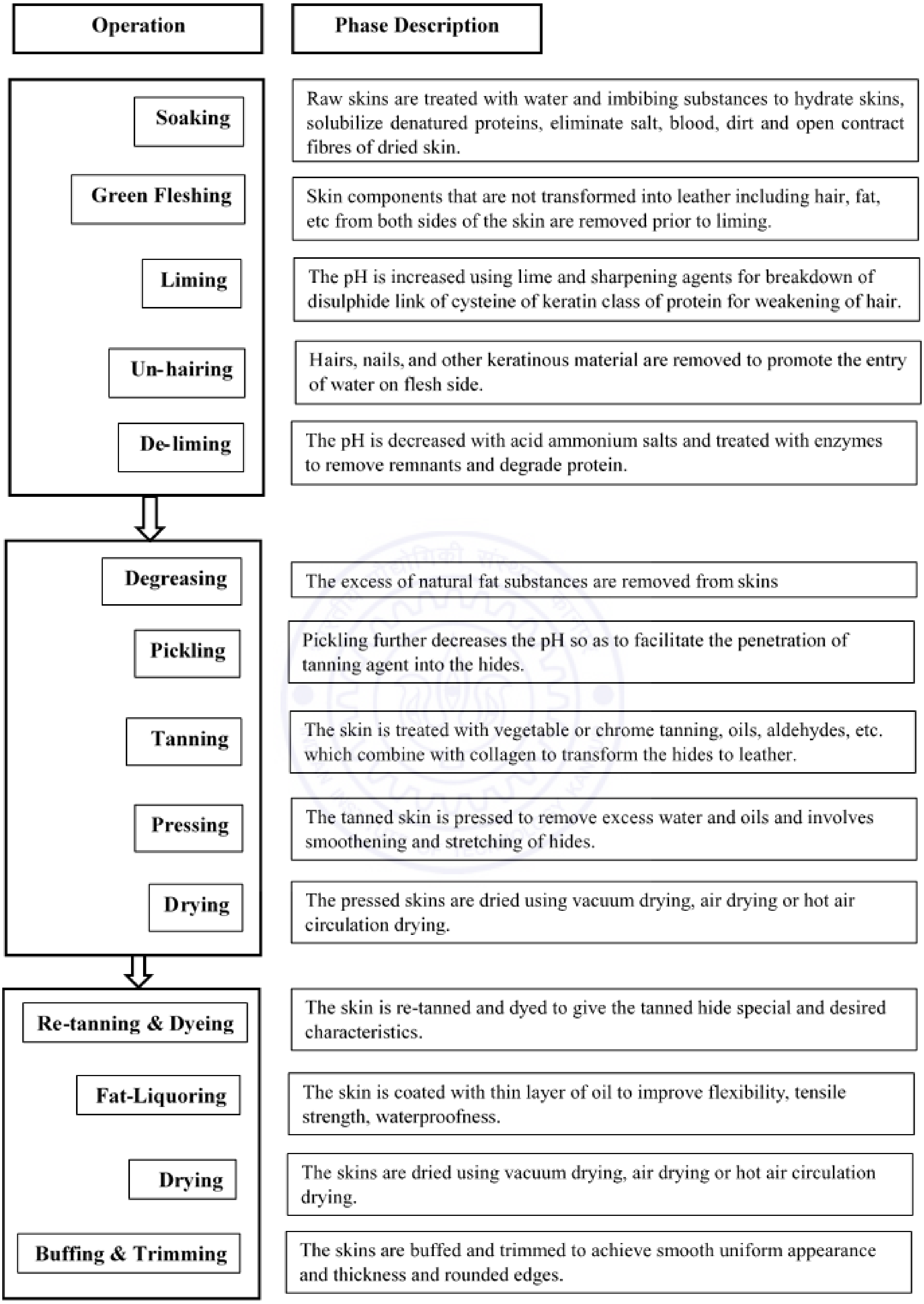

Figure 2.01: Flowchart of operations and brief description of various operations carried out in tanneries

Table 2.01: Typical average pollutant concentrations in combined raw tannery effluent based on conventional process using water 25 m^3 per tonne of raw hide (modified: UNIDO, 2011)

S No	Parameter	Unit	Average Total Pollutant Concentration	Typical Limits for Disposal in Surface Waters
1	BOD (3 Days at 27 ^oC)	mg O_2/L	3600	30-40
2	COD	mg O_2/L	7200	125-250
3	Suspended Solids (SS)	mg/L	3600	35-100
4	Cr^{+3}	mg Cr/L	270	1.5-2.0
5	Sulphide	mg S/L	290	1.0-2.0
6	Total Nitrogen (TKN)	mg N/L	290	100
7	Chloride	mg Cl/L	9000	Locally specific (India -1000)
8	Sulphate	mg SO_4/L	2500	Locally specific (India -1000)
9	Oil and Grease	mg/L	235	Locally specific India- 10
10	TDS	mg/L	18000	Locally specific (India- 2100)
11	pH		6-9	5.5-9.5

2.3 Treatment of Tannery Effluent

Conventional methods of tannery effluent treatment include physico-chemical primary treatment of tannery effluent followed by secondary treatment mostly by aerobic activated sludge process and in some instances by anaerobic processes. The tanneries are often located into clusters, and the primary treatment is often done in individual units called Primary Effluent Treatment Plants (PETPs) to decrease the pollutant load on secondary treatment facilities, followed by secondary treatment at Common Effluent Treatment Plant (CETP) facility motivated by the economies of scale.

The main objective of primary treatment of effluent is to reduce coarse material SS that could clog pumps, pipes, etc., significantly reduce BOD/COD load and reduce Cr before sending it to centralized or decentralized facility for further treatment. Conventional primary treatment facility includes i) coarse and fine screen for SS removal, ii) coagulation, flocculation and primary sedimentation facility for removal of colloidal SS, iii) chrome recovery unit to physico-chemically recover unspent chrome during the tanning process, and iv) sludge dewatering facility.

The PETPs have been reported to have varied efficiency in removal of pollutants: 30-37% (Song *et.al.*, 2004); 40-70% (Kabdasli *et al.*, 1999); >70% (Ates *et al.*, 1997); and >75% (Lofrano *et. al.*, 2006) of total Chemical Oxygen Demand (COD), 38-46% (Song *et.al.*, 2004) of Suspended Solids (SS); 74-99% of Chromium (Song *et.al.*, 2004). A report of United Nations Industrial Development Organisation (UNIDO, 2011) suggests 25-50% removal of incoming Biochemical Oxygen Demand (BOD), 50-70% of TSS and 65% of oil and grease. However in Jajmau, Kanpur often the performance of PETPs which are expected to significantly lower down grit and suspended solid load and recover chromium (Cr), is found to be poor. High concentrations (up to the order of 55 mg/L; Tare *et al.*, 2003) have been observed at the inlet of CETP. This large Cr loading in the CETPs leads to subsequent high concentrations in effluent and sludge. Subsequent use for irrigation leads to extensive Cr contamination and bio-accumulation in plants and soils (Adriano, 2001). The oxidized form Cr (VI) is class A carcinogen by inhalation, and Cr (III) has low acute and chronic toxicity (James *et.al.*, 1997).

The primary treatment is followed by secondary treatment at a centralized or decentralized facility. The main objective of secondary treatment is the removal of bio-degradable dissolved and colloidal organic matter using aerobic or anaerobic biological treatment processes. Secondary treatment is usually carried out by aerobic activated sludge process and in some instances by anaerobic processes. A conventional activated sludge plant consists of: i) equalization tank, ii) mixed liquor tank with aerators, iii) secondary clarifier, iv) sludge recirculation facility, and v) sludge dewatering facility.

Variable removal efficiency of 67% (Gisi *et al*., 2009) and 40% (Tammaro *et al*., 2014) of COD has been reported in activated sludge process pilot studies. However, many residual recalcitrant organics and micro-pollutants cannot be removed by conventional treatment method. In Jajmau, Kanpur, owing to the poor operation and maintenance practises, the plant operates at less than 70% treatment efficiency (Tare *et al.*, 2003).

No provision for removal of fixed dissolved solids (FDS) is made in the conventional primary and secondary treatment practices. Hence the practise of disposing the CETP effluent into surface water bodies or use in irrigation is violation of the discharge standards. The sustained use of high TDS water for irrigation purposes leads to salinity and decreased crop productivity. Moreover the tanning of leather uses large amounts of water (25-45 m^3/ton) and often the source of water is ground water. Thus the industry exerts huge pressure on declining groundwater resources. Thus there is a need to treat the water to remove TDS and re-use the water in tanneries, especially in areas with scarce drinking water resources.

An exhaustive tertiary treatment of secondary treated tannery wastewater followed by Reverse Osmosis (RO) treatment is imperative to render the treated wastewater fit for reuse in tanneries. The tertiary treatment is necessary to prevent the fouling of membranes. About 93-98% TDS, 92-99% sodium, and 91-96% chloride and ammonia removal efficiency with 70-85% recovery of water as RO permeate (Ranganathan *et al.*, 2011) have been reported. Another study (Bhattacharya *et al,* 2013) has shown 99% reduction of TOC and almost complete removal of metals like lead, copper, zinc and nickel, etc. Improvement in tensile strength by 19%, increased elongation by 6.2% and increased dye uptake (Bhattacharya *et al,* 2013) has been observed in leather prepared from treated effluent in comparison to that prepared from freshwater.

The next challenge which arises is the management or disposal of RO concentrate. The concentrate which has high levels of COD and TDS is not fit for discharge as per the current discharge standards. The conventional method uses multi-effect evaporators (MEE) for concentration followed by crystallization. However, the process is highly energy intensive, incurs high operational costs, and faces difficulties mainly due to corrosion, crystallization of salts, scaling of heat exchanger (UNIDO, 1998).The salt obtained after crystallization is a mixture of salts, rather than one salt, thus has low economic value, usually Indian National Rupee (INR) 4 per kg. Thus there is an urgent need to devise a cost effective environment friendly method for management of RO concentrate.

Hence another possibility of concentrate disposal in inland water bodies with relaxed discharge norms during the high flow monsoon season can be explored. The concentrate can be stored in lined lagoons and can be safely discharged with minimal effects on background concentration in the high discharge periods of the river. This method, other than having the distinct advantages of cost effectiveness and minimal damage to environment in comparison to other alternates, also helps in completing the salt cycle by assigning the river its natural function of transporting salts to the sea during monsoon season.

Another solution of effective management of waste is to create a central facility for carrying out the most polluting operations of tanning. The tanners can get partial processing of hides done from the central facility and carry out further operations in their individual units. This will provide an opportunity for good housekeeping by effective collection and handling of solid wastes like hooves, hairs, tails, etc. and will also provide an opportunity for industrial symbiosis by sharing of useful by-products.

A further challenge is the estimation of complete expenditure on these facilities and subsequent estimation on tariffs of recycled water. The Public-Private Partnership model can be explored for operating the facility. The tariffs could be determined for per KL of recycled water. The costs of: i) effluent collection and conveyance, ii) effluent treatment, and iii) distribution of recycled water can be considered for determining the tariff. Following points may be considered for cost estimates:

a) Capital expenditure (Capex) to include the cost of inventory and its installation cost, material supply, engineering design and supervision charge, interest on loan, and
b) Operation and maintenance expenditure (Opex), after the project is started, to consider the expenditure on manpower, chemicals, transport and repair work.

The tariffs will also be required for pricing of valuable fresh water resources, mainly ground water, so as to incentivise the use of recycled water and limit the rampant and unsustainable use of precious groundwater for economic gains.

3. Objectives and Scope

Ganga River Basin is one of the most densely populated regions of India and due to adequacy of vast water resources and manpower it houses a large number of industries. A major industry among these which accounts for an average 2.47 per cent share (Annual Reports, 2001-12) of total Indian exports is leather tanning industry. However, the state of effluent management infrastructure remains extremely poor. Even though stringent Central Pollution Control Board (CPCB) discharge norms of environmental pollutants have been notified, they alone fail to ensure the effluent is treated to desired levels before being discharged into rivers.

A large number of tanneries are centered in Jajmau, Kanpur. A Common Effluent Treatment Plant (CETP) was setup in 1994 under the first phase of Ganga Action Plan with bilateral co-operation of Government of India and Netherland Government. 334 units are members of the CETP. The plant however is under designed for current effluent generation capacities of the member units and thus large volumes of untreated effluent gets bypassed to Ganga River. Often the PETPs at individual units are not working properly resulting in high Cr and Suspended Solids concentration. These units are heavily fined and often closed by courts which hampers the growth of industry and economy. The CETP mixes tannery effluent with domestic sewage in ratio of 1:3 to 1:1.5 and treats the blend by anaerobic Up-flow Sludge Blanket method. The plant though operational, is poorly operated and maintained, and operates on less than 70 % treatment efficiency. The treated effluent is used for irrigation and disposed in Ganga River. No provision for removal of Dissolved Solids (inorganic) below the discharge standards of 2100 mg/L are made. Along with pollution of surface water sources, the industries put huge pressure on the declining ground water resources. Thus it is very vital that an appropriate techno-commercial frame work is developed for sustainable effluent management as well as the growth of these industries.

Tannery effluent management requires proper infrastructure, but remains mainly plagued due to indifference of the tanners to the treatment efficiency of the CETP. A major reason behind this is no immediate direct effect of the poor effluent treatment on the tanners and availability of under-priced raw ground water resource. Hence a policy change along with proper infrastructure for effluent treatment is the need of the hour. Moreover the sharing of operation and maintenance costs by the tanners and the state government has been another hurdle for the efficient operation of the CETP. The plant is in poor economic state due to irregular/ non-payment of O&M costs by the units and state government. Thus a Public-Private Partnership

(PPP) model for managing the facilities may serve as a viable option. Provisioning of effluent treatment systems and rational pricing of natural resources is necessary so that the cost of abatement is truly borne by the polluters. This necessity has been the genesis of the present study. Because of all above mentioned reasons Consortium of 7 IITs preparing Ganga River Basin Management Plan (GRBMP) is considering complete and efficient collection of tannery effluent and treatment of waste so that most of the waste could be recycled and/ or reused as we approach towards the goal of “Minimum or Zero Discharge” instead of disposal in open lands and/or water bodies.

This study is a part of the larger framework of achieving “Unpolluted Flow” in Ganga River and aims at evolving the financial plan for provisioning of industrial effluent treatment system. Following specific objectives are set for this study to achieve this goal.

1. Develop suitable methodology for efficient and complete effluent collection and treatment promoting waste reuse/recycle and distribution of recycled water.
2. Obtain ballpark estimates of capital investments and annualized expenditure towards Capex and Opex for collection and treatment of effluent and distribution of recycled water.
3. Obtain tariff rates for recycled water under different options of financing the capital expenditure.
4. Obtain ballpark estimates of land and energy footprint of these collection, treatment and distribution facilities.
5. Approach towards the goal of “Minimum Discharge” and encouraging the use of recycled water.

The scope of this study is restricted to availability of information in i) DPRs for proposed up-gradation of CETP facilities at Jajmau, ii) thesis report on design and cost estimation of sewerage network and pumping for urban centres, iii) secondary data and reports on design and cost estimation of effluent treatment facilities, and iv) secondary data for land and energy footprint of effluent treatment facilities.

4. Methodology

4.1 General

The production of tanned leather can be broadly classified into following set of operations i) Beam-house operations: soaking, fleshing, liming, un-hairing and de-liming; ii) Tanning operations: pickling and tanning; and iii) Finishing and other operations: re-tanning, dyeing fat liquoring, drying, buffing and trimming. A typical buffalo hide weighs 25 kg and has an average area of 37.5 square feet and uses a total of 25 litres per kg of hide processed. The nature of the effluent for the three operations with respective percentage share of water (Italprogetti Engineering, 2014) is shown in Table 4.01.

Table 4.01: Typical Share of Water in Various Tanning Operations with Effluent Characteristics

Name of Operation	Water Share, Percent	Effluent Quality	
		TDS, mg/l	COD, mg/l
Beam-house operations	40	25667	10000
Tanning operation	4	150000	10000
Finishing and other operations	56	4286	2143
Total	100	18667	5600

An efficient treatment of tannery effluent up to tertiary treatment may reduce all other environmental pollutants except Total Dissolved Solids (TDS) below the CPCB discharge standards. The current practise of using this water for irrigation will would lead to soil salinity. Hence in order to control TDS levels use of Reverse Osmosis (RO) treatment and subsequent reuse of RO permeate as recycled water for industrial use is suggested in this study. The loss of water as RO concentrate is made up by purchasing treated domestic wastewater (DWW) of similar grade from Kanpur Nagar Nigam at the same tariff rates as that of recycled water. Since the cost of treating the DWW will be much lower than the tariff, the excess amount will help in cross subsidizing the treatment of city's domestic waste. The government in return can co-operate by providing loans and land for the construction of such CETPs.

Tannery effluent treatment infrastructure includes: i) effluent conveyance network, ii) effluent pumping, iii) effluent treatment plants, iv) reverse osmosis concentrate treatment or disposal, and v) distribution of recyclable water. A schematic flow sheet for treatment of tannery effluent is shown in Figure 4.01. The effluent treatment plants are proposed to be built in modules of recycled water generation capacity of 16 MLD. For this study the cost estimations of 32 MLD and 64 MLD facilities has been considered. Estimation of capital (Capex) and operation and maintenance (Opex) costs for the five components has been worked out for Jajmau tannery cluster in the Ganga River Basin (GRB) using the following two approaches:

a) Effluent treatment without Common Beam-House Facility
b) Effluent treatment with Common Beam-House Facility

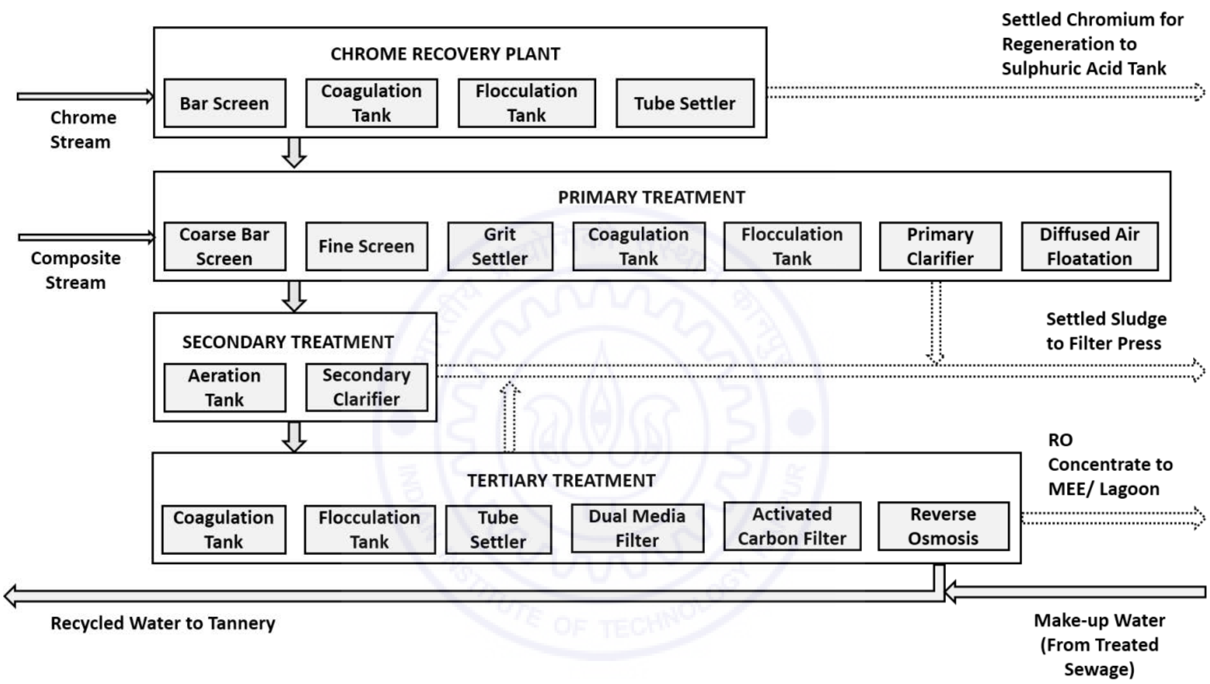

Figure 4.01: Schematic Flow Sheet for Treatment Facility of Tannery Effluent

4.2 Effluent treatment without Common Beam-House Facility

This approach assumes that all the operations are carried out in individual tanneries. Hence, two separate effluent conveyance lines, one for tanning operations and the other for effluents of all other operations. The share of water for tanning is assumed at 6.25 percent, a conservative estimate, for cost estimation purposes. Chrome stream has been separated so as to recover chrome by physico-chemical treatment in Common Chrome Recovery Plant (CCRP) and reused for tanning process. The supernatant of the CCRP will be treated in common effluent treatment plant (CETP).

4.2.1 Estimation of Capex and Opex of Effluent Conveyance Network

This involves estimation of length of conveyance pipes of different diameter and cost of laying unit length including the supply of materials, barricading the area, timbering in trenches, excavation of earth, laying, jointing of conveyance lines, surface relaying, cost of manholes, labours, dewatering etc.

An earlier study (Shukla, 2013) using data of 45 different urban locations where sewer networks have been laid or designed was gathered from various local bodies and consulting firms. This data included population, area covered, lengths of various diameter pipes, bill of quantities (BOQs), cost estimates and total cost of the project. The BOQs and cost estimates had all the details which are required for the estimation of sewerage network costs.

The unit cost (average per meter length of sewer laid including all items in BOQs) is taken as the total cost of the sewerage network project divided by the total sewer length (all diameter sewers). This cost comes around ₹ 4,000 to 5,500 per meter of the sewer length. In general this unit cost could be considered for green field projects i.e. for newly developed areas or colonies where there are no obstructions (rail lines, roads, buildings, other infrastructure networks such as water supply lines, cable networks, etc., encroachments and/or monuments of historical or religious importance, etc.). This unit cost increases to ₹ 6,000 -10,000 when some miscellaneous items like crossing of railway lines, crossing through drains etc., some extra sewer lines due to uncertainties in estimation of total sewer lengths, adoption of trenchless technology for some area, dismantling of roads, relaying of roads, etc.

However, considering low to moderate level of hindrances average unit costs is considered to be ₹ 6000 per m length of trunk sewers on a gradient of 1 in 80 metres for both composite and chrome stream for estimating the expenditure on tannery effluent sewerage network. The diameter for rising mains of the composite and chrome stream is calculated using the Manning's equation as 2000 mm and 700 mm respectively. The unit cost of laying the pipes is ₹ 12,000 per m length and 4000 per m length on an almost flat gradient of 1 in 1000 meters respectively.

Operation and maintenance (Opex) costs are estimated based on thumb rules and taken as 1.5 % of Capex as per the survey conducted by Water and Sanitation Program, (WSP Flagship Report, 2011)

The cost of effluent collection and conveyance network 19.2 MLD and 32 MLD CETP facilities has been estimated for 38.4 MLD and 64 MLD CETP facilities respectively. The reason behind this is that in case of further increase number of modules in the future, no fresh cost of laying a new conveyance network is incurred.

Another approach of conveyance of chrome waste water using tankers has also been used for estimating the Capex and Opex. However the option was rejected owing to higher cost.

4.2.2 Estimation of Capex and Opex for Effluent Pumping

Effluent pumping involves pumps, pumping stations and some miscellaneous material supplies such as valves, inlet and outlet pipes, pipe fittings, etc. Pump capacity is estimated based on (i) total daily effluent flow, (ii) average 12 hours pumping in a day, (iii) pumping head assuming 1 in 80 slope of the trunk sewer and 1 in 1000 slope of rising mains and the length of the trunk sewer and rising mains as 20.62 km and 2.3 km respectively as per the Detailed Project Report (Revised Draft) for Proposed Up-gradation of CETP Facilities (IL&FS Limited, 2011) for Tannery Cluster at Jajmau, Kanpur. Power of pump is calculated assuming 12 hours of operation of pumping stations. Costs of the pumps is estimated based on market survey and information provided by practicing engineers as ₹ 25,000/KW. Cost of miscellaneous material supplies such as valves, inlet and outlet pipes, pipe fittings, etc. generally varies in the range 1-2 % of the pump cost. To have conservative estimates, a value of 2 % is assumed in this study. Estimated cost of pumping stations is assumed as 10 % of the cost of pumps based on thumb rule generally used by practicing engineers and consulting firms.

Opex cost of effluent pumping is computed based on energy consumption for running the pumps for twelve hours on a daily basis considering prevailing average electricity tariff (₹ 6 per KW-h or a unit of electricity consumed). In addition, 10 % of energy bill for running the pumps is considered as other miscellaneous Opex for effluent pumping based on thumb rule generally used by practicing engineers and consulting firms.

4.2.3 Estimation of Capex and Opex of Effluent Treatment Plants

The two segregated streams bring the chrome effluent and composite effluent form individual tannery units to the common effluent treatment plant. The chrome stream is physico-chemically precipitated to recover chrome, which has a high commercial value and can be reused for tanning purposes. The common chrome recovery plant (CCRP) effluent after recovering chrome can be mixed with composite stream for further treatment. For cost estimation bar screen, coagulation flocculation followed by sedimentation in tube settler and recovery by dissolving the precipitate in coated civil tanks with H_2SO_4 to obtain $CrSO_4$ is considered for chrome recovery process. The Opex has been estimated using the energy, manpower and chemical demands for the operation of the treatment plant. The inventory required for treatment per MLD of chrome stream at CCRP is listed in Table 4.02

Table 4.02: Details of Inventory Considered for Treatment per MLD of Chrome Stream

S No	Inventory	Specifications	Quantity
01	Bar Screen	6mm	1
02	Sewage Pump	14 litre per second, 15 m head	2
03	Equalisation Tank	500 m^3	1
04	Dosing tank	1 cu. m. with agitator	2
05	Dosing Pump	10-26 litre per hour	2
06	Flash Mixer	4.5 cu. m., MS made FRP lined	1
07	Flocculation Tank	20 m^3, MS made FRP lined	1
08	Tube Settler Tank	50 m^3	1
09	Filter Press	32’x32’, 51 plates	1
10	Coated Civil Tanks	4 m^3	3
11	Sludge pump	1.7 litre per second, 50 m head	2

Estimation of cost of effluent treatment has been done considering that the common effluent treatment plants will use effluent as source of water and produce industry grade water that would be suitable for reuse in tannery industry for production of leather. Typically the treatment will be done in four stages, namely primary, secondary, tertiary followed by membrane treatment/ reverse osmosis (RO) treatment of the tertiary treated water. Since a fraction of water will be rejected as the RO concentrate, for cost estimation purposes the costs for these four stages are over estimated for higher capacities such that the goal of recycling of 100 % water is achieved.

For cost estimations coarse bar screen, grit settlers, drum screen, Konica fine screen, primary clarifier followed by coagulation-flocculation and diffused air floatation (DAF) is considered in the primary treatment. For low density wastes an oil skimmer is also considered for cost estimation purposes. The inventory required for primary treatment per MLD of composite stream is listed in Table 4.03.

Table 4.03: Details of Inventory Considered for Primary Treatment per MLD of Composite Stream

S No	Inventory	Specifications	Quantity
01	Bar screens	20mm, 10mm and 6mm	1 each
02	Drum screen	4 mm	1
03	Konica fine screen	1.5 mm	1
04	Submersible pump for Konica fine screen	100 m^3 per hour, 10 m head, $D_p \leq 10$ mm	1 1
05	Grit settler(with sluice gates)	14 m^3	1
06	Equalisation tank with venturi-pump	500 m^3, 1400 rpm	1
07	Dosing tank	2000 litre with agitator	6
08	Dosing pump	10-26 litre per hour	6
09	Coagulation tank (with agitator)	4.5 m^3	2
10	Flocculation tank (with agitator)	9 m^3	1
11	Primary clarifier with scrapper	100 m^3	1
12	DAF with oil skimmer	40 m^3	1
13	Sewage pump	14 litre per second, 15 m head	2
14	Sludge pump	1.7 litre per second, 50 m head	1
15	Filter press	32'x32', 31 plates	1

Moving bed bio-film reactor (MBBR) is considered at the secondary level. Filter press is adopted for sludge dewatering purposes in both primary and secondary treatment. The inventory required for secondary treatment per MLD of composite stream is listed in Table 4.04.

Table 4.04: Details of Inventory Considered for Secondary Treatment per MLD of Composite Stream

S No	Inventory	Specifications	Quantity
01	MBBR aeration tank	520 cu. m.	1
02	Root blowers	1120 cu. m. per hour, 50 HP	2
03	Air diffusers	63 mm diameter bubble air diffuser, 1000 mm long	139
04	MBBR media	BF-22, Float type	45
05	Secondary clarifier with scrapper	100 m^3	1
06	Sewage pump	14 litre per second, 15 m head	2
07	Sludge pump	1.7 litre per second, 50 m head	1
08	Filter press	36'x36', 51 plates	1

At the tertiary level, coagulation-flocculation followed by sedimentation in tube settler, and filtration through dual media filter (DMF) and activated carbon filter (ACF) followed by multi-stage Reverse Osmosis (RO) is considered for cost estimation purposes. The inventory required for secondary treatment per MLD composite stream is listed in Table 4.05.

Table 4.05: Details of Inventory Required for Tertiary Treatment per MLD of Composite Stream

S No	Inventory	Specifications	Quantity
01	Flocculation tank with agitators	9 m3	1
02	Tube settler	45 m3	1
03	Dual media filter	MS made FRP lined, 50 m^3 per hour	1
04	Activated carbon filter	MS made FRP lined, 50 m^3 per hour	1
05	Storage tank	250 m^3	2
06	Sewage pumps	14 litre per second, 15 m head	2
07	Dosing tanks		4
08	Multi-stage pump	14 litre per second, 30 m head	1
09	Reverse osmosis plant	80 % recovery, TDS 13000 ppm	1

Much of the information used for cost estimation is adopted from the report prepared by Tirubala Tri Environment Pvt. Ltd. submitted to IIT Kanpur (Tannery Zero Liquid Discharge Report, 2014). An additional amount of 40 % of the cost of the inventory has been considered as installation costs for calculation of the capital expenditure. The cost of civil work wherever required is calculated at the rate of ₹ 8000 per m^3. The Opex has been estimated using the energy, manpower and chemical demands for the operation of the treatment plant.

4.2.4 Estimation of Capex and Opex of Treatment/Disposal of Reverse Osmosis Concentrate

Estimation of cost of treatment/ disposal of RO concentrate has been done using two approaches, outlined as follows by which unit costs could be worked out.

Approach I: The concentrate of reverse osmosis is further concentrated using multi-effect evaporators (MEE) and the salt will be reused in the tannery industry or for other commercial purposes. The information for cost estimation is adopted from the report prepared by Tirubala Tri Environment Pvt. Ltd. (Tannery Zero Liquid Discharge Report, 2014).

Approach II: The concentrate of reverse osmosis is stored in geo-membrane lined lagoons during the lean flow periods and can be safely discharged into river Ganga during high flow monsoon periods. A study to assess the assimilation and transport capacity of river using daily discharge and monthly concentration data over a period of 30 years from 1980 to 2010 is used. Ninety per cent dependable flows are calculated and change in TDS, BOD and Total Chromium levels is computed by simulating the concentrate discharge during the monsoon period. The discharge period is considered to starts on 15 July and ends on 15 October. A provision for storage for extra 30 days has also been provided. Loss due to evaporation at the rate of 186 cm per year by Central Water Commission (CWC, 2006) from a suitably assumed average top width of 9 meter of the water surface for the trapezoidal section described later has also been incorporated. The costs of earthwork, concreting and lining of lagoon, conveyance from CETP to lagoon and lagoon to river, and cost of pumps is considered for the Capex. The lagoon is assumed to be of trapezoidal section with a bed width of 4 metre, side slope of 1 H: 1 V, depth of 4 metre and free board of 0.5 metre. Cost of an additional concrete cover of 0.3 metre thickness and geo-membrane lining for rendering the lagoon seepage free is also considered. The rates of the following have been worked out using a Detailed Project Report of Vadodara Solid Waste Management (SENES Consultants India (P). Ltd., 2007): i) earth work is assumed to be ₹ 150 per m^3, ii) rate of concreting at ₹ 4000 per cubic meter, and iii) rate of HDPE and geo-membrane lining at ₹ 500 per square meter. The cost of conveyance from CETP to lagoons and lagoon to river is considered to be ₹ 6000 per m length and the respective lengths to be 200 m and 500 m respectively. The cost estimation of pump has been done as stated in Section 4.2.2.

Opex cost of concentrate pumping during the monsoon period is computed based on energy consumption for running the pumps for twelve hours on a daily basis considering prevailing average electricity tariff (₹ 6 per KW-h or a unit of electricity consumed). In addition, 10 % of energy bill for running the pumps is considered as other miscellaneous Opex for effluent pumping based on thumb rule generally used by practicing engineers and consulting firms.

4.2.5 Estimation of Capex and Opex of Distribution of Recycled Water

Estimation of cost of distribution of recyclable water has been done considering that the water treated for reuse in leather industry will be distributed back at a uniform rate for 12 hours on a daily basis. The total area is divided into five zones such that the length of distribution mains and the discharge for each zone is equal for each zone. The total length of the distribution pipes in the five zones is worked out to be 21 km similar to effluent conveyance network.

Capex cost of the distribution system included the cost of construction of the overhead tank, cost of pumping of the recycled water to the overhead tank and cost of the pipe distribution system. The head of the overhead tank is calculated using i) a slope of 1 in 1200 metres for distribution mains, ii) a residual head of 5 metres at the terminal end of the distribution mains, and iii) calculation of head loss in the distribution mains by calculating friction slope using modified Hazen William's formula. The diameter of the pipe was chosen such that the total annualised cost of the distribution system was minimised. The cost of the distribution system was then calculated by using data for cost of per unit length of the pipe of the specified diameter. The capital cost of the pumps is estimated similar to the Capex of pumping stations for effluent pumping. The capital cost of overhead tank was calculated using Capex of ₹ 20 per litre after consulting engineers and studying DPR's of related projects.

Opex cost of recyclable water pumping is estimated based on energy consumption for running the pumps considering prevailing average electricity tariff (₹ 6 per KW-h or a unit of electricity consumed). In addition, 10 % of energy bill for running the pumps is considered as other miscellaneous Opex for effluent pumping based on thumb rule generally used by practicing engineers and consulting firms.

4.3 Effluent treatment with Common Beam-House Facility

This approach uses a common beam-house facility (CBHF) for the purpose of carrying out beam-house operations and a tariff will be charged that will be inclusive of the treatment of wastewater generated as well as the cost of carrying out the operations. The CBHF will have its own effluent treatment facility which will be designed for 40 percent of total wastewater generated in the complete tanning process. Thus 32 MLD and 64 MLD CETP facilities will be replaced by combination of 12.8 MLD CBHF & 19.2 CETP facility and 25.6 MLD CBHF & 38.4 MLD CETP facility respectively. For cost estimation purposes an additional amount to compensate for the loss as RO concentrate is also considered. A large amount of organic solid waste is generated in the beam house operations and the effluent generated also has higher levels of chemical oxygen demand (COD) and total dissolved solids. Separating the beam house operations provides an opportunity for good housekeeping, reuse of solid wastes of commercial value and better handling of the high TDS and high COD effluent.

De-limed hides at the end of beam-house operations will be used by industries to carry-out other operations. Two separate effluent conveyance lines i) chrome stream (6.25 percent of the total wastewater) and ii) all other streams (53.75 percent of the total waste water) will carry the effluent from the tanneries to the CETP. The CETP will be designed for handling 60 percent of the total effluent generated. For cost estimation purposes an additional amount to compensate for the loss as RO concentrate is also considered.

Estimation of cost of operations has been done considering that soaking, green fleshing, liming, un-hairing and de-liming operations will be carried out at CBHF. The Capex included the cost of the wooden drums for liming and de-liming, dry salt-shaker, fleshing machines, hair filters, and factory shed for the facility centre and miscellaneous electrical and other expenses. The Opex is estimated based on consumption of electricity and chemicals, and the manpower required in the beam-house operations. The inventory required for common beam-house operations per 30 ton of raw hide is listed in Table 4.06.

Table 4.06: Details of Inventory Required for Common Beam-House Operations per 30 Ton of Raw Hide

Sl. No.	Inventory	Specifications	Quantity
01	Dry hide shaker		1
02	Fleshing Machine	150 hides per hour	2
03	Soaking Drums	200 hides	3
04	Liming De-liming Drums	200 hides	7
05	Hair Filters		7
06	Factory Shed	1800 sq. m.	1

All the Capex and Opex for the effluent treatment of CBHF, except reverse osmosis, has been done similar to cost estimation in Section 4.2. The Capex and Opex of the reverse osmosis process have been estimated using sea water membranes and high pressure pumps respectively for the purpose.

4.4 Estimation of Tariff of Recycled Water

A large capital and operation expenditure is incurred in the construction and operation of these effluent treatment facilities. Hence various financing options using a public private partnership model are considered.

The equity is assumed to be 30 % of the Capex, and the rest of the Capex is obtained in the form of debts at: i) Interest rate of 3 %, Duration of 20 years, Moratorium period of 5 years; ii) Interest rate of 13 %, Duration of 12 years, Moratorium period of 1 year. The following assumptions have been made for calculation of tariffs at an internal rate of return of 18 %: i) Plant utilization factor as 90 %, ii) Default rate as 10 %, iii) Depreciation rate is 13.90 %, iv)

Residual Value as 10 %, v) Tax rate as 30 %, vi) Price escalation of tariff rates and Opex as 5 %, vii) Debt service reserve account (DSRA) as 50 % of average principal payment, and viii) Interest on DSRA as 1.5 % . The construction of the project is assumed to be completed in one year.

Also a policy change of pricing the freshwater for industrial use at 1.5 times the tariff will incentivise the use of recycled water. The current tariff of freshwater is excessively under-priced at ₹ 2 per KL.

The tariffs for 32 MLD, 64 MLD, 19.2 MLD and 38.4 MLD CETP facilities were estimated as ₹ per KL of recycled water. However the tariff for CBHF for 12.8 MLD and 25.6 MLD CBHF facilities were estimated as ₹ per sq. m. and ₹ per sq. ft. for hides as well as ₹ per KL of recycled water.

4.5 Estimation of Land and Energy Footprint

Estimation of land footprint has been done considering areal requirements for pumping station, primary treatment, secondary treatment, tertiary treatment, CBHF operations, management of RO reject and distribution of treated effluent. In addition, 100 % of the primary, secondary and tertiary treatment is considered for the construction of offices, control rooms, etc.

Estimation of energy footprint has been done considering the energy requirements for pumping station, primary treatment, secondary treatment, tertiary treatment, CBHF operations, management of RO reject and distribution of treated effluent.

Much of the information used for land and energy footprint estimation is adopted from the report prepared by Tirubala Tri Environment Pvt. Ltd. submitted to IIT Kanpur (Tannery Zero Liquid Discharge Report, 2014).

5. Results and Discussion

5.1 General

An appropriate frame work is a prerequisite to provide solutions for effluent generated in leather tanning industries. The treatment of effluent up to secondary level alone and subsequent use for irrigation and disposal in Ganga River may appear to be a low cost solution, but the secondary treatment does not ensure removal of dissolved solids and total chromium up to CPCB standards and thus can have detrimental effects on crops and aquatic life. So having a plan for complete treatment and reuse with near zero discharge policy is the need of the hour. It ensures a complete treatment up to a tertiary level by interlinking the interests of the polluter and end user of treated effluent, as well as reduces the pressure on scarce ground water resources.

The first and foremost step towards this is to have an assessment of the management plan in economic sense. The present study aims at estimating the expenditure on treatment of tannery effluent with provision of segregation and conveyance of different type of effluents, their treatment, and distribution of treated effluent for reuse and management of the reverse osmosis concentrate. The practical feasibility of the management of the concentrate by discharging in high flow periods of the river has also been explored. Since the establishment of treatment facilities incurs huge capital and operational investments, a Public Private Partnership model to run the facility is proposed. Different options of financing through loans at varied interests, moratorium period and loan period, and equity to estimate tariffs are also explored as a part of this study. The model also proposes a way of cross subsidizing the treatment of city sewage in lieu of the support provided by the local body to the tannery cluster in terms of land acquisition and other administrative support. Energy consumption and land footprint are also important along with the expenditure incurred, and hence are separately estimated.

5.2 Effluent Management

Effluent management includes i) Effluent Collection and Conveyance, ii) Effluent Treatment and Concentrate Treatment/ Disposal, iii) Common Beam-House Facility, iv) Make-up Water Treatment and Concentrate Treatment/ Disposal, and v) Distribution of Treated Wastewater (Tannery Effluent and Sewage for recycling in Tanneries). An attempt has been made to arrive at ballpark estimates of total annualized costs with percentage share of Capex and

Opex for all these components. Sections 5.2 to 5.5 describe and discuss the outcome of such an attempt based on approach and methods described in Chapter 4. All the costs in these sections are obtained by adding the annualized Capex (at 12 % interest rate for 20 years) and Opex for each process.

5.2.1 Effluent Collection and Conveyance

Cost estimations for effluent collection requires costs of conveyance lines of separate chrome and composite stream, cost of pumps and pumping, and cost of maintenance of the conveyance lines and pumping station.

The costs of conveyance of chrome stream for 32 or 19.2 MLD and 64 or 38.4 MLD CETP Facilities are ₹ 28.69 per KL and ₹ 15.13 per KL respectively. A typical pattern of distribution of expenditure on chrome stream collection and conveyance adopting the methodology in Section 4.2.1 and 4.2.2 is presented in Figure 5.01 to 5.02.

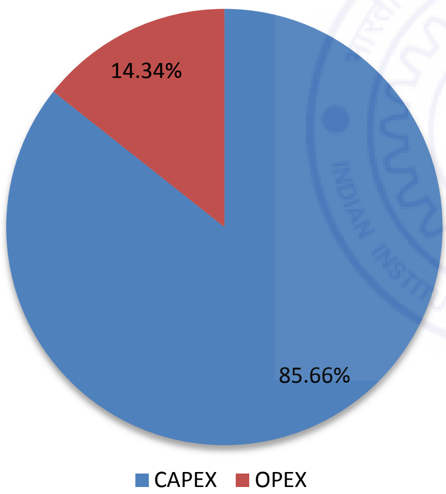

Figure 5.01: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Chrome Stream Collection and Conveyance of 32 or 19.2 MLD CETP Facility

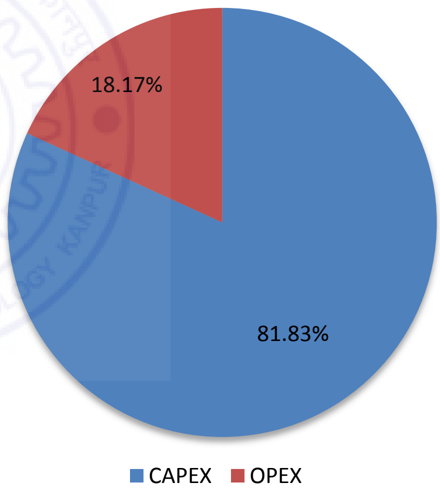

Figure 5.02: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Chrome Stream Collection and Conveyance of 64 or 38.4 MLD CETP Facility

The costs of conveyance of composite stream for 32 MLD and 64 MLD CETP Facilities are ₹ 3.62 per KL and ₹ 2.59 per KL respectively. The costs of conveyance of composite stream for 19.2 MLD and 38.4 MLD CETP Facilities with CBHF are ₹ 3.90 per KL and ₹ 2.34 per KL respectively. A typical pattern of distribution of expenditure on composite stream collection and conveyance adopting the methodology in Section 4.2.1 and 4.2.2 is presented in Figure 5.03 to 5.06.

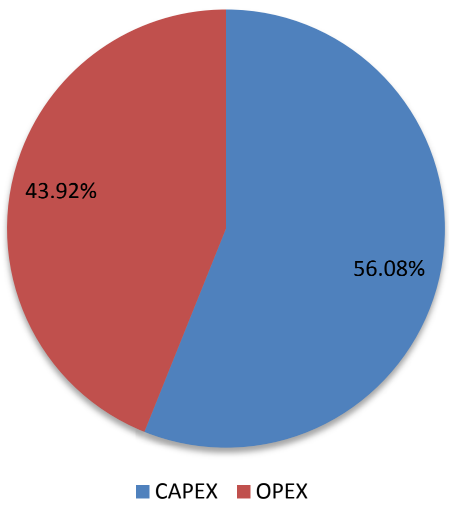

Figure 5.03: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Composite Stream Collection and Conveyance of 32 MLD CETP Facility

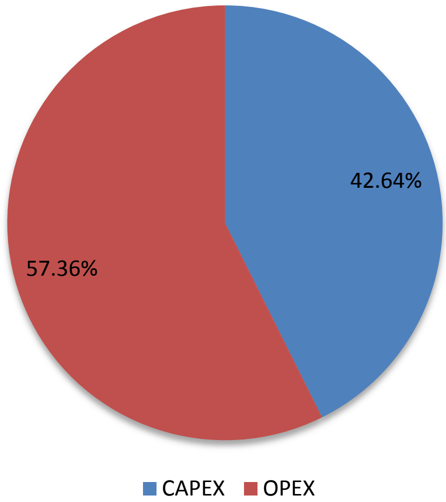

Figure 5.04: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Composite Stream Collection and Conveyance of 64 MLD CETP Facility

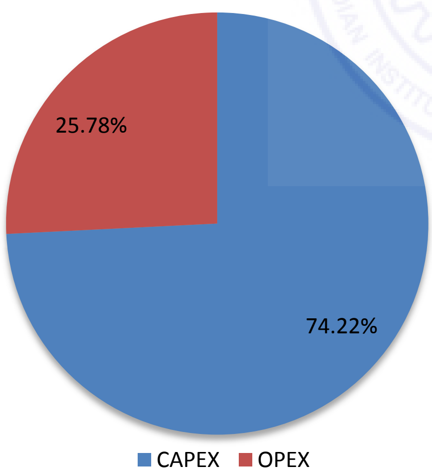

Figure 5.05: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Composite Stream Collection and Conveyance of 19.2 MLD CETP Facility

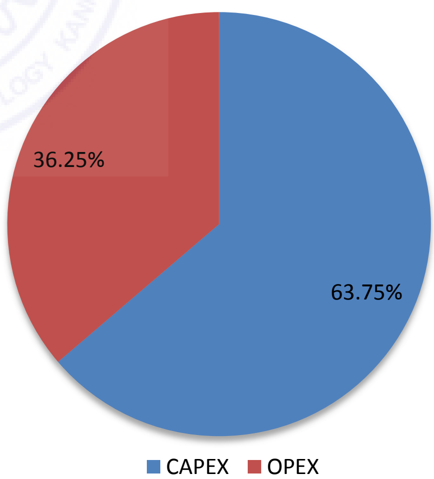

Figure 5.06: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Composite Stream Collection and Conveyance of 38.4 MLD CETP Facility

5.2.2 Effluent Treatment and Concentrate Treatment/ Disposal

Treatment of effluent includes i) Chrome Recovery Plant, ii) Primary Treatment, iii) Secondary Treatment, iv) Tertiary Treatment, v) Reverse Osmosis, and vi) Concentrate Treatment/ Disposal either through MEE or Lagoons. The capital expenditure is inclusive of the costs of the inventory, the cost of installation and the cost of civil works. The operation expenditure is inclusive of the cost of manpower, chemical and electrical energy consumed.

The chrome stream is collected and physico-chemically treated to recover chrome. The recovered chrome has high economic value and can be reused in tanning process. The cost of chrome recovery for all CETP Facilities is ₹ 227.59 per KL. A typical pattern of distribution of expenditure on chrome effluent treatment adopting the methodology in Section 4.2.3 is presented in Figure 5.07.

The cost of primary treatment for all CETP Facilities is ₹ 28.74 per KL. A typical pattern of distribution of expenditure on primary treatment of effluent adopting the methodology in Section 4.2.3 is presented in Figure 5.08.

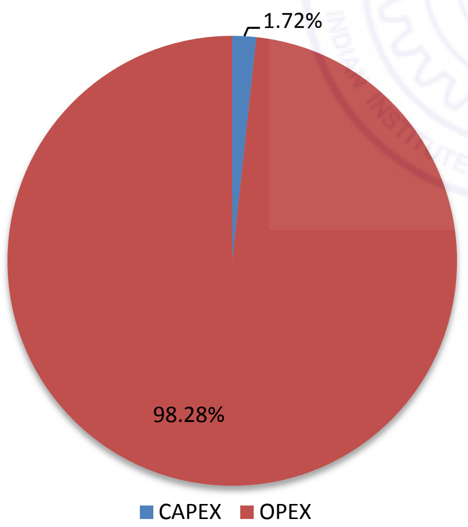

Figure 5.07: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Chrome Recovery Plant

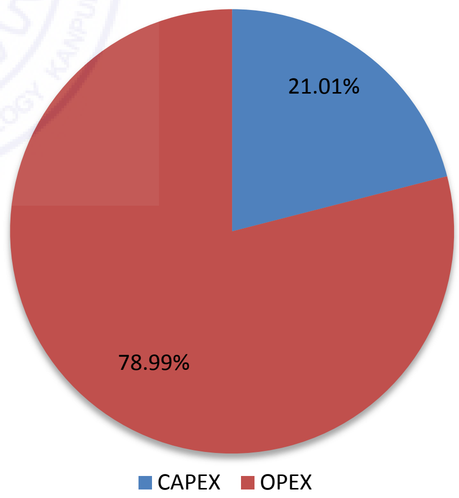

Figure 5.08: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Primary Treatment

The cost of secondary treatment for all CETP Facilities is ₹ 7.07 per KL. A typical pattern of distribution of expenditure on secondary treatment of effluent adopting the methodology in Section 4.2.3 is presented in Figure 5.09.

The cost of tertiary treatment for all CETP Facilities is ₹ 7.83 per KL. A typical pattern of distribution of expenditure on tertiary treatment of effluent adopting the methodology in Section 4.2.3 is presented in Figure 5.10.

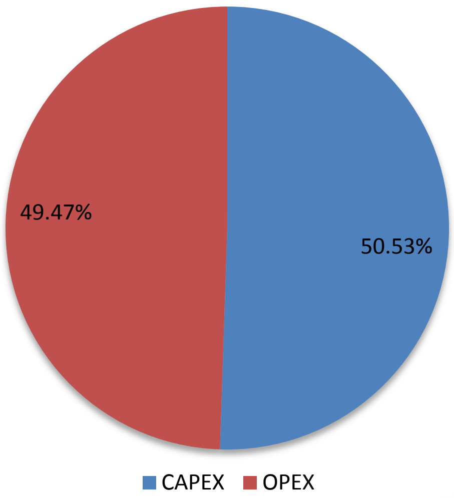

Figure 5.09: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Secondary Treatment

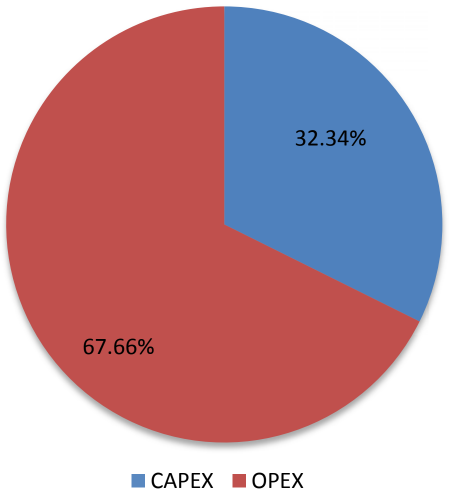

Figure 5.10: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Tertiary Treatment

The cost of reverse osmosis treatment for all CETP Facilities is ₹ 32.96 per KL. A typical pattern of distribution of expenditure on reverse osmosis treatment of effluent adopting the methodology in Section 4.2.3 is presented in Figure 5.11.

The concentrate of the reverse osmosis process can be condensed to get crystallized salts using energy intensive multi-effect evaporators or can be safely disposed in Ganga River during the high flow (monsoon) period.

The use of multi-effect evaporators though does not flout any of the current CPCB norm of disposal of effluent in surface water body, it uses large amounts of electrical energy which itself has a high carbon footprint and hence puts a burden on the environment. The cost of concentrate treatment using multi effect evaporators for all CETP Facilities is ₹ 604.63 per KL. A typical pattern of distribution of expenditure on treatment of concentrate using MEE adopting the methodology in Section 4.2.4 is presented in Figure 5.12.

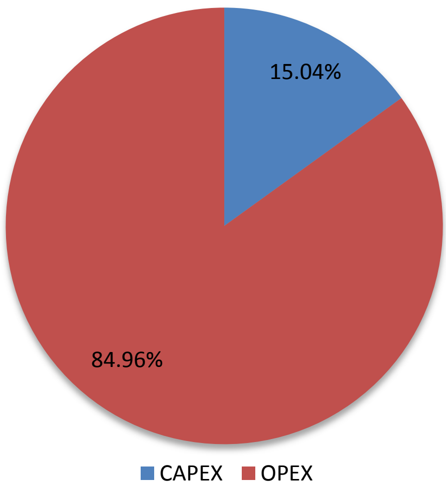

Figure 5.11: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Reverse Osmosis Treatment

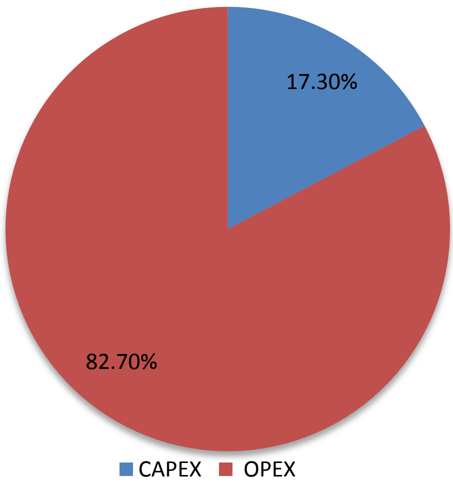

Figure 5.12: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Concentrate Treatment Using Multi-Effect Evaporators

The other option uses lagoons to store the concentrate through the lean flow period and discharges safely into the Ganga River during the high flow (monsoon) period. The period considered for discharge is decided by the increase in order of magnitude of 90 per cent Dependable Flow (90 % DF) from 15 July to 15 October from the hydrograph generated based on daily discharge measurements by Central Water Commission (CWC) at Bithoor Observation Station. This increase in flow in river offers a great assimilation and dilution capacity. Figure 5.13 shows the hydrograph generated based on Daily Discharge Measurements by CWC at Bithoor observation station during the period 1980-2009. The x-axis represents the date and y-axis represents the discharge value in cumecs.

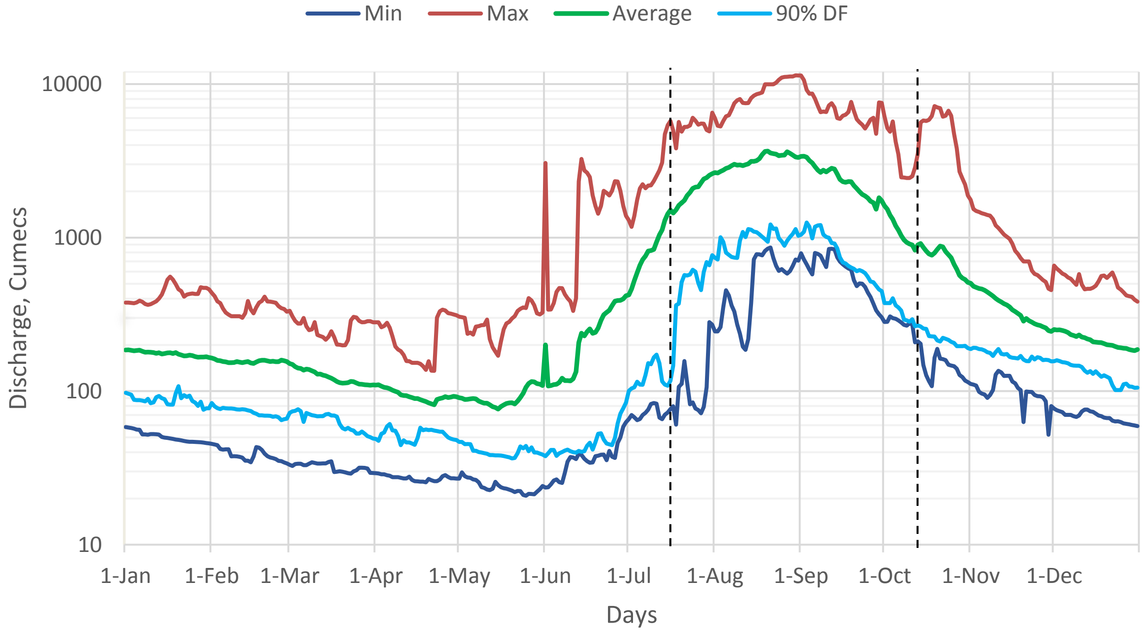

Figure 5.13: Representation of Hydrograph generated based on Daily Discharge Measurements by CWC during the period 1980-2009 at Bithoor Observation Station. The region between the dashed lines represent the period (15 July to 15 October) in which the concentrate will be discharged into the Ganga River.

The expected quality of tertiary treated effluent (prior to RO), RO concentrate (with 80 % permeate recovery and 100 % rejection of dissolved solids) and the current CPCB discharge standards in inland water bodies is presented in Table 5.01.

Table 5.01: Expected Quality of Tertiary Treated Effluent (Prior to RO), RO Concentrate and Current CPCB Discharge Standards in Inland Water Bodies

Parameter	Concentration (mg/L)		
	Tertiary Treatment Effluent (Expected)	Reverse Osmosis Concentrate (Expected)	CPCB Discharge Norms in Inland Surface Water
Total Dissolved Solids	10000	50000	2100
BOD_5 at 20^o C	10	50	30
Total Chromium	1	5	2

Final concentrations of TDS, BOD and Total Chromium in the Ganga River was calculated throughout the year using expected RO concentrate concentrations and the CPCB discharge standards for their respective discharge periods. The primary data used was i) daily discharge data for 30 years (1980-2009) at CWC Station at Bithoor for computing 90 per-cent dependable flows, ii) monthly TDS and BOD concentrations for 30 years (1980-2009) at CWC station at Bithoor. Since no data for Total Chromium concentrations in the Ganga River was available, it was assumed to be zero.

The final concentrations with disposal of stored RO concentrate were compared with average concentrations of thirty years and were found significantly low in the monsoon period than the average concentrations of lean flow period. Similarly the final concentrations with CPCB discharge standards further increase the concentrations in lean flow period. Another advantage in the use of lagoons is that it aids the completion of the salt-cycle by carrying away the excess salt into the oceans instead of accumulating in the terrestrial (agricultural fields) environment. Figure 5.14, 5.15 and 5.16 show the variation of monthly average concentrations of TDS, BOD and Total Chromium respectively in the following scenarios: i) background concentration of Ganga River, ii) concentration when RO concentrate is discharged in the high flow period, and iii) concentration if the treated effluent is discharged daily as per current CPCB discharge standards.

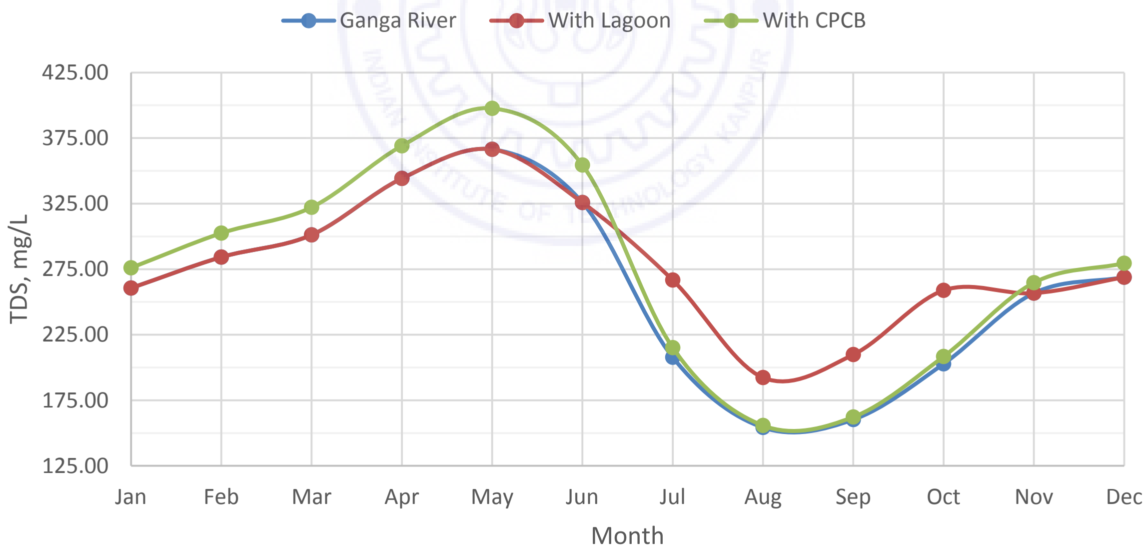

Figure 5.14: Monthly Average Concentrations in River Ganga, Post Discharge from Lagoon and Post Discharge as per CPCB Discharge Standards of Total Dissolved Solids in mg/L at Kanpur

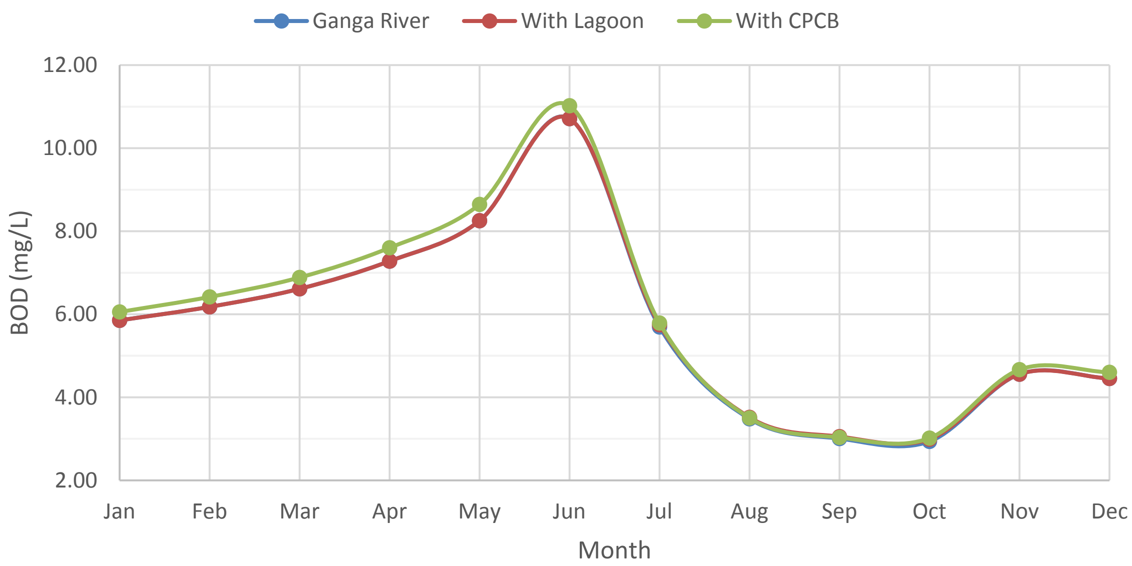

Figure 5.15: Monthly Average Concentrations in River Ganga, Post Discharge from Lagoon and Post Discharge as per CPCB Discharge Standards of BOD in mg/L at Kanpur

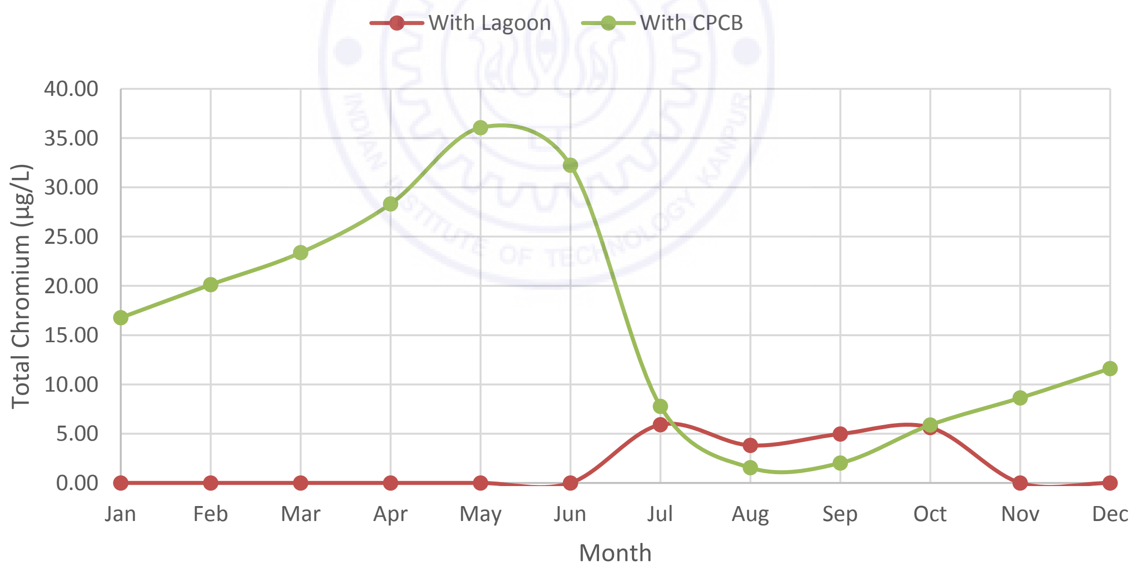

Figure 5.16: Monthly Average Concentrations in River Ganga, Post Discharge from Lagoon and Post Discharge as per CPCB Discharge Standards of Total Chromium in µg/L at Kanpur

The cost of concentrate disposal using lagoons for 32 or 19.2 MLD and 64 or 38.4 MLD Facilities with or without CBHF is ₹ 75.35 per KL and ₹ 75.25 per KL respectively. A typical pattern of distribution of expenditure on disposal of concentrate using lagoon adopting the methodology in Section 4.2.4 is presented in Figure 5.17 and 5.18.

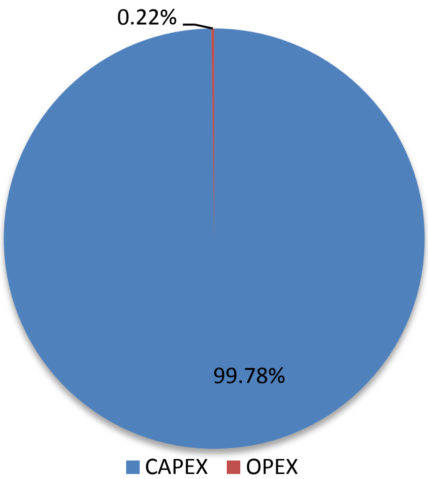

Figure 5.17: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Concentrate Disposal through Lagoon of 32 MLD and 19.2 MLD CETP Facilities

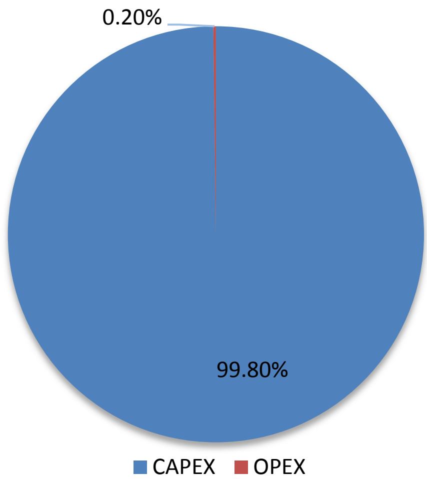

Figure 5.18: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Concentrate Disposal through Lagoon of 64 MLD and 38.4 MLD CETP Facilities

5.2.3 Common Beam-House Facility

The common beam house facility includes i) Common Beam-House Operations, ii) Primary Treatment, iii) Secondary Treatment, iv) Tertiary Treatment, v) Reverse Osmosis, vi) Concentrate Treatment/ Disposal either through MEE or Lagoons, and vii) Sewage (as make-up Water) Treatment and Concentrate Treatment/ Disposal. The capital expenditure is inclusive of the costs of the inventory, the cost of installation and the cost of civil works. The operation expenditure is inclusive of the cost of manpower, chemical and electrical energy consumed.

The cost of common beam-house operations for 12.8 MLD and 25.6 MLD CBHF facilities is ₹ 502.43 per KL or ₹ 36.06 per sq m (₹ 3.35 per sq ft) of hide processed. A typical pattern of distribution of expenditure on common beam-house operations adopting the methodology in Section 4.3 is presented in Figure 5.19.

The costs of all primary treatment, secondary treatment, tertiary treatment and concentrate treatment/ disposal are similar to the costs given in Section 5.3. The difference in costs of reverse osmosis treatment is due to use of sea water membranes and high pressure pumps. The cost of reverse osmosis treatment for 12.8 MLD and 25.6 MLD CBHF facilities is

₹ 51.91 per KL respectively. A typical pattern of distribution of expenditure on RO treatment in CBHF Facility adopting the methodology in Section 4.3 is presented in Figure 5.20.The cost of make-up water is as explained in Section 5.2.4

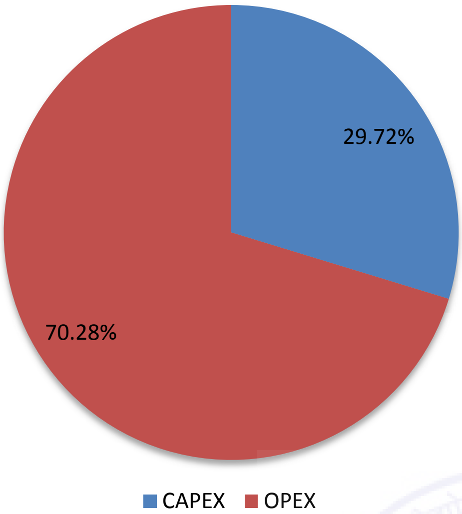

Figure 5.19: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Common Beam House Operations

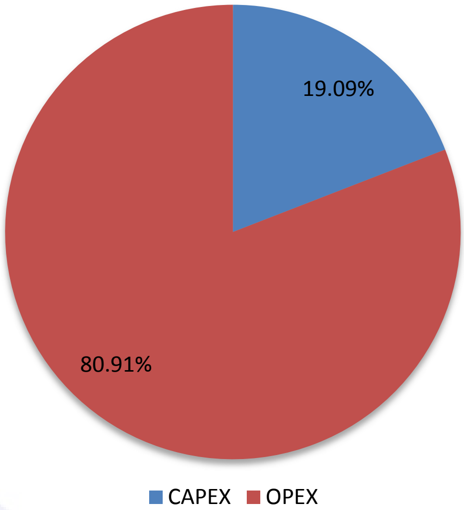

Figure 5.20: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Reverse Osmosis Treatment of CBHF Effluent

5.2.4 Make-up Water Treatment and Concentrate Treatment/ Disposal

The loss as concentrate of RO treatment will be made up by supplying the treated domestic wastewater from local sewage treatment plants at the same tariff as that of recycled water. The treatment of domestic wastewater to produce water of similar grade as that of effluent treatment plant includes i) Primary Treatment, ii) Secondary Treatment, iii) Tertiary Treatment, iv) Reverse Osmosis Treatment, and v) Concentrate Disposal/ Treatment.

The Capex and Opex for treatment of domestic wastewater up to tertiary treatment has been taken as ₹ 11 Million/ MLD and ₹ 1.4 Million/MLD/Year respectively. These values are adopted from the report prepared by Consortium of 7 IITs preparing GRBMP (IIT_GRB Report, 2010). The total cost for primary, secondary and tertiary treatment is ₹ 7.87 per KL. A typical pattern of distribution of expenditure on primary, secondary and tertiary treatment of sewage is presented in Figure 5.21.

However for cost estimation purposes the total expenditure of all stages except conveyance and distribution has been over-estimated such that the goal of 100 percent recycling of water is achieved. The cost estimates are hence similar to those described in the Section 5.2.2.

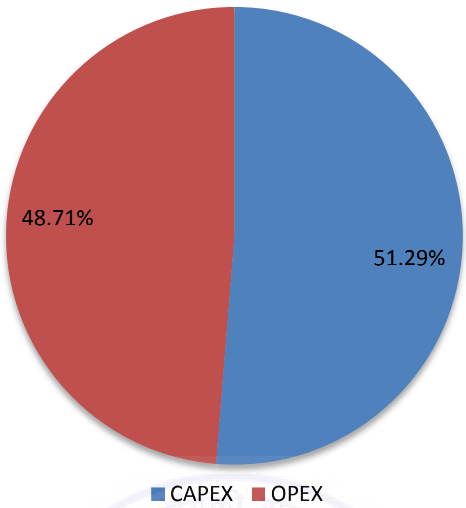

Figure 5.21: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Primary, Secondary and Tertiary Treatment of Make-Up Water

5.2.5 Distribution of Recycled Water

The cost of storage and distribution of recycled water for 32 MLD and 64 MLD CETP Facility is ₹ 5.50 per KL and ₹ 5.20 per KL respectively. The cost of storage and distribution of recycled water for 19.2 MLD and 38.4 MLD CETP Facility is ₹ 5.81 per KL and ₹ 5.41 per KL respectively. A typical pattern of distribution of expenditure on storage and distribution of treated effluent adopting the methodology in Section 4.2.5 is presented in Figure 5.22 to 5.25.

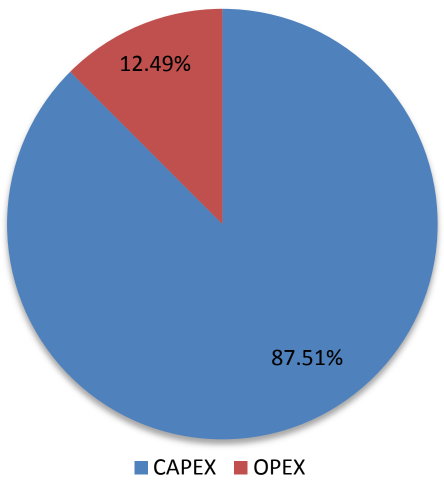

Figure 5.22: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Distribution of Recycled Water of 32 MLD CETP Facility

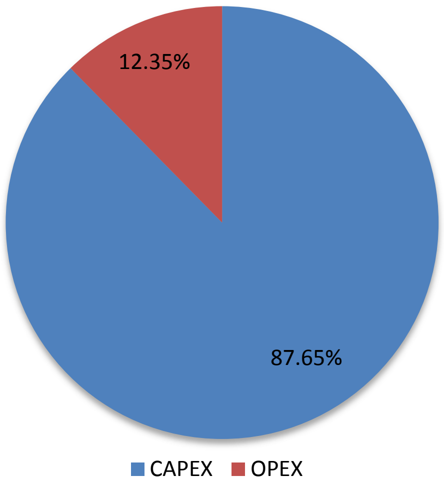

Figure 5.23: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Distribution of Recycled Water of 64 MLD CETP Facility

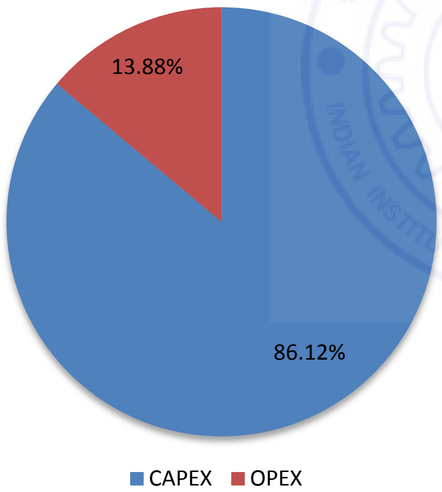

Figure 5.24: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Distribution of Recycled Water of 19.2 MLD CETP Facility

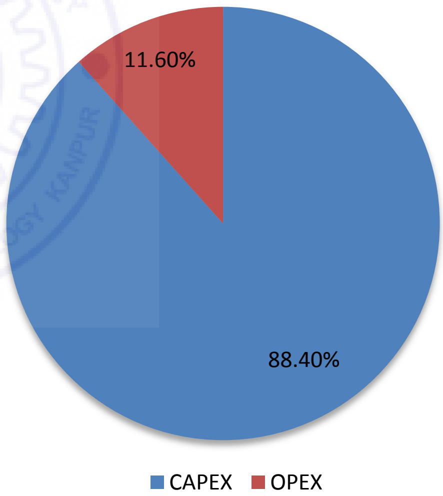

Figure 5.25: Typical Distribution of Estimated Annualized Capital (Capex) and Operation and Maintenance (Opex) Expenditure on Distribution of Recycled Water of 38.4 MLD CETP Facility

5.2.6 Total Annualized Costs

The total annualized costs of 64 MLD CETP Facility with MEE and Lagoon is ₹ 269.71 per KL and ₹ 137.37 per KL respectively. A typical pattern of distribution of total expenditure on individual operations of 64 MLD CETP Facility is presented in Figure 5.26 and 5.27.

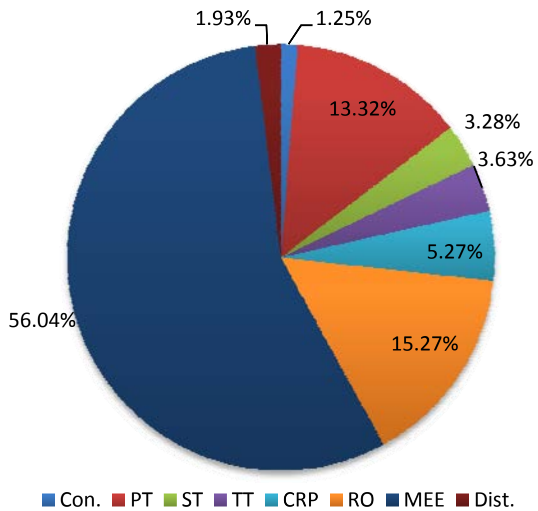

Figure 5.26: Typical Distribution of Estimated Total Annualized Expenditure of 64 MLD CETP Facility with MEE

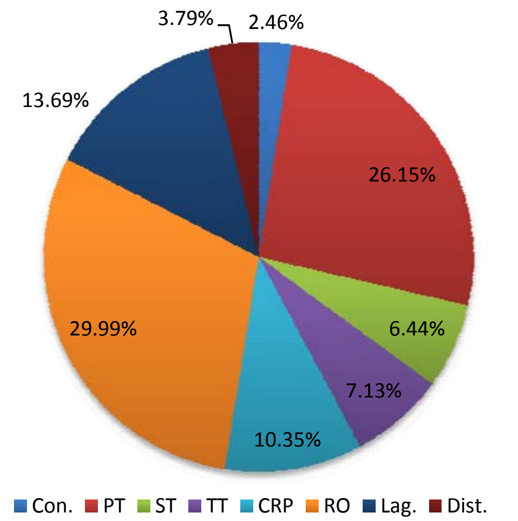

Figure 5.27: Typical Distribution of Estimated Total Annualized Expenditure of 64 MLD CETP Facility with Lagoon

The total annualized costs for 25.6 MLD CBHF Facility with MEE and Lagoon is ₹ 777.03 per KL or ₹ 55.22 per sq. m. (₹ 5.13 per sq. ft.) and ₹ 640.69 per KL or ₹ 45.96 per sq. m. (₹ 4.27 per sq. ft.) A typical pattern of distribution of total expenditure on individual operations of 25.6 MLD CBHF Facility is presented in Figure 5.28 and 5.29.

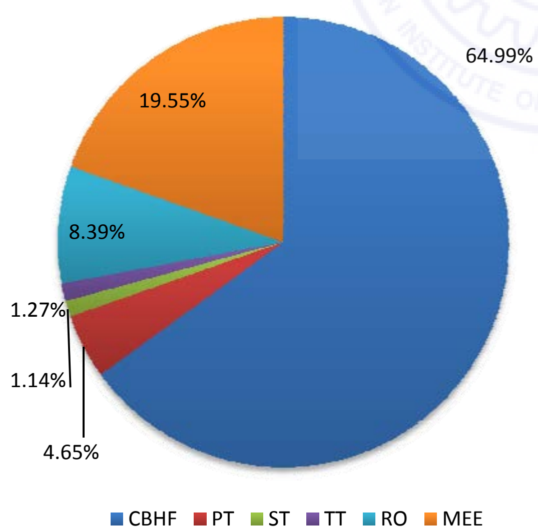

Figure 5.28 Typical Distribution of Estimated Total Annualized Expenditure of 25.6 MLD CBHF Facility with MEE

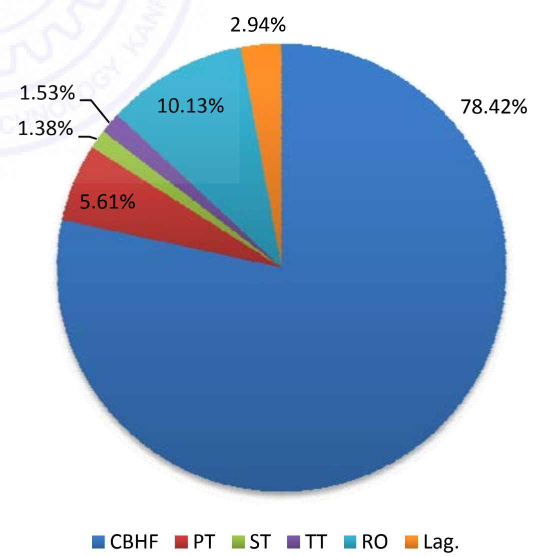

Figure 5.29: Typical Distribution of Estimated Total Annualized Expenditure of 25.6 MLD CBHF Facility with Lagoon

The total annualized costs of 38.4 MLD CETP Facility with MEE and Lagoon is ₹ 279.94 per KL and ₹ 147.60 per KL respectively. A typical pattern of distribution of total expenditure on individual operations of 38.4 MLD CETP Facility is presented in Figure 5.30 and 5.31.

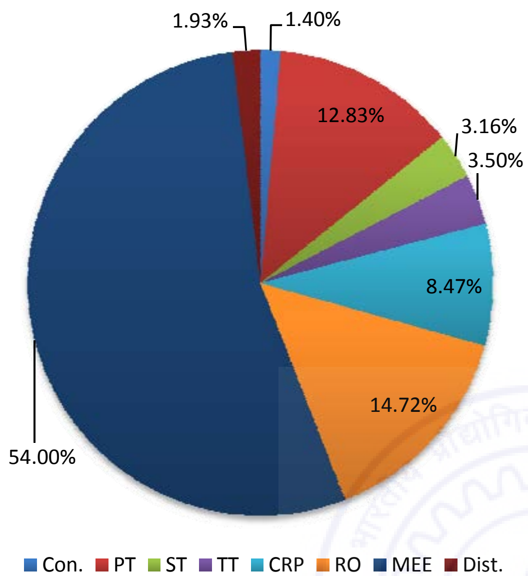

Figure 5.30: Typical Distribution of Estimated Total Annualized Expenditure of 38.4 MLD CETP Facility with MEE

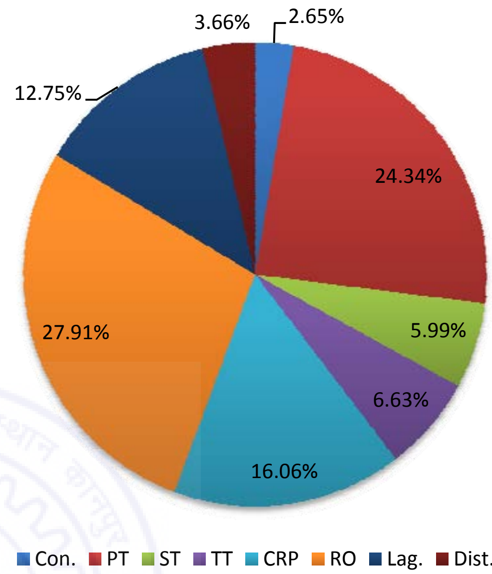

Figure 5.31: Typical Distribution of Estimated Total Annualized Expenditure of 38.4 MLD CETP Facility with Lagoon

5.3 Tariff Estimation

The tariffs have been estimated for all CETP and CBHF facilities with the following debt options.

i) Scenario 1-Equity: 30 %, Debt 1: 70 % at interest rate of 3 %, 20 year duration, 5 year moratorium period

ii) Scenario 2- Equity: 30 %; Debt 1: 50 % at interest rate of 3 %, 20 year duration, 5 year moratorium period; Debt 2: 20 % at interest rate of 13 %, 12 years duration, 1 year moratorium period

iii) Scenario 3-Equity: 30 %; Debt 1: 70 % at interest rate of 13 %, 12 year duration, 1 year moratorium period

The recycled water and hides will be charged at the estimated tariffs for the tanneries. The make-up water purchased from local STPs will also be at the same tariff. The cost of any fresh water source should be priced at 1.5 times the tariff of recycled water.

A typical pattern of distribution of expenditure of Capex and Opex of 32 MLD CETP facility with MEE and Lagoons on individual operations is presented in Figures 5.32 to 5.35. The Capex (per MLD), Opex (per KL) and Tariffs in the three scenarios (per KL) for the same are given in Table 5.02.

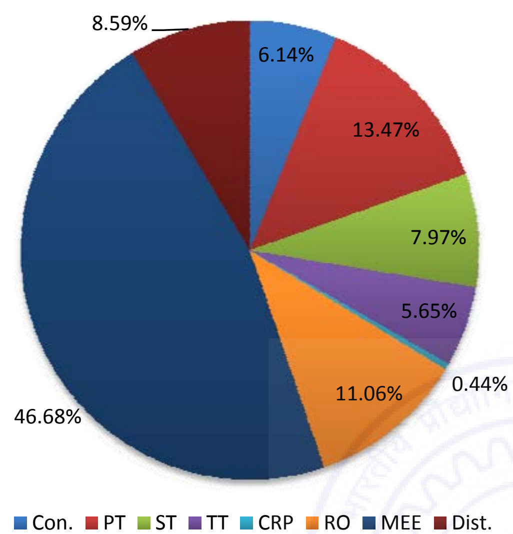

Figure 5.32: Typical Distribution of Total Capex of 32 MLD CETP Facility with MEE

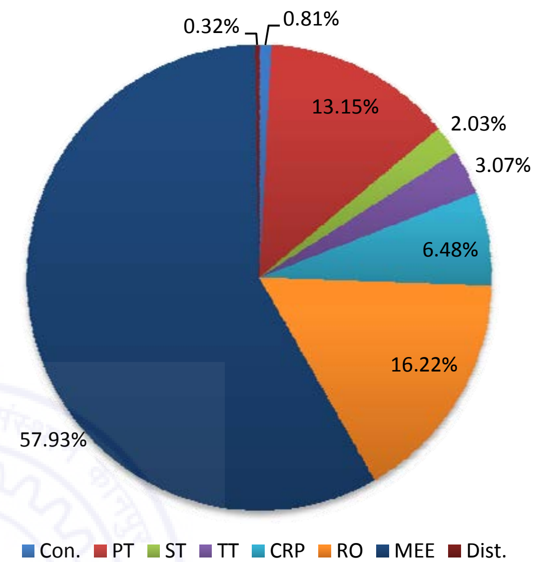

Figure 5.33: Typical Distribution of Total Opex of 32 MLD CETP Facility with MEE

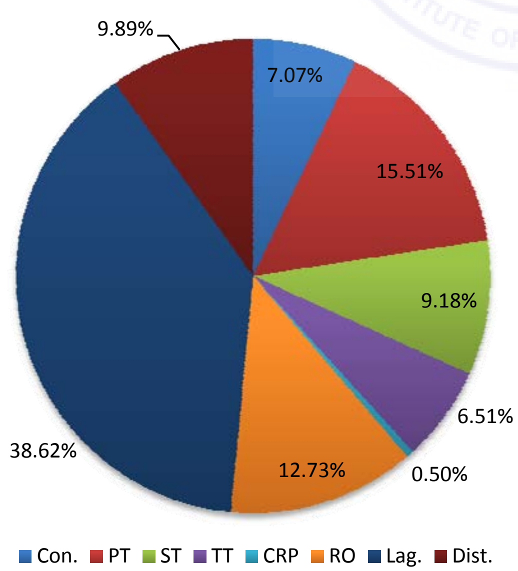

Figure 5.34: Typical Distribution of Total Capex of 32 MLD CETP Facility with Lagoon

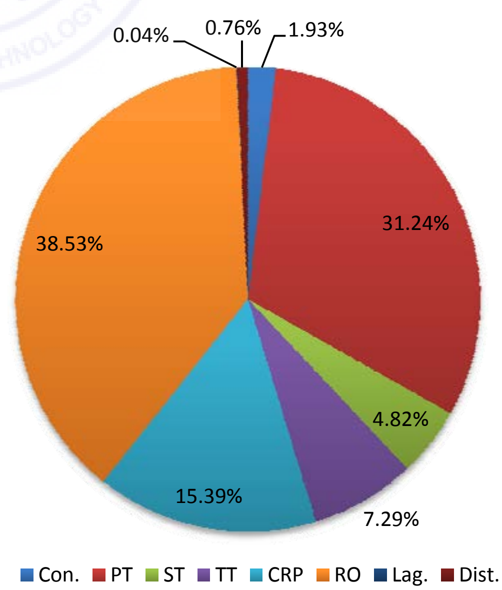

Figure 5.35: Typical Distribution of Total Opex of 32 MLD CETP Facility with Lagoon

Table 5.02: Estimated Capex, Opex and Tariffs in Three Scenarios for 32 MLD CETP Facility

Concentrate Handling Option	CAPEX	OPEX	Scenario 1	Scenario 2	Scenario 3
	₹ Cr./MLD	₹/KL	₹/KL	₹/KL	₹/KL
MEE	15.26	215.79	284.27	296.48	327.42
Lagoon	13.26	90.83	139.57	150.20	177.07

A typical pattern of distribution of expenditure of Capex and Opex of 64 MLD CETP Facility with MEE and Lagoons on individual operations is presented in Figure 5.36 to 5.39. The Capex (per MLD), Opex (per KL) and Tariffs in the three scenarios (per KL) for the same are given in Table 5.03.

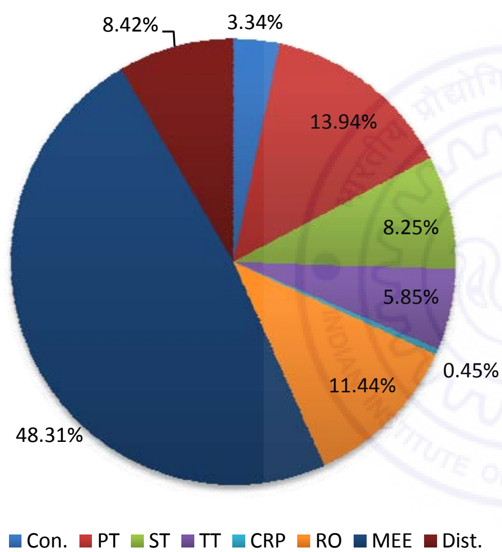

Figure 5.36: Typical Distribution of Total Capex of 64 MLD CETP Facility with MEE

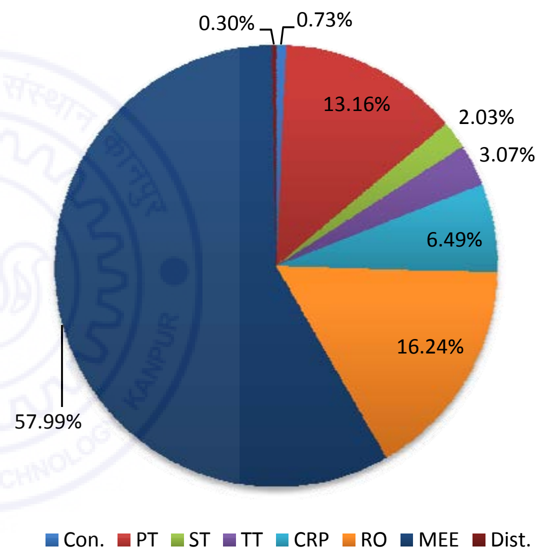

Figure 5.37: Typical Distribution of Total Opex of 64 MLD CETP Facility with MEE

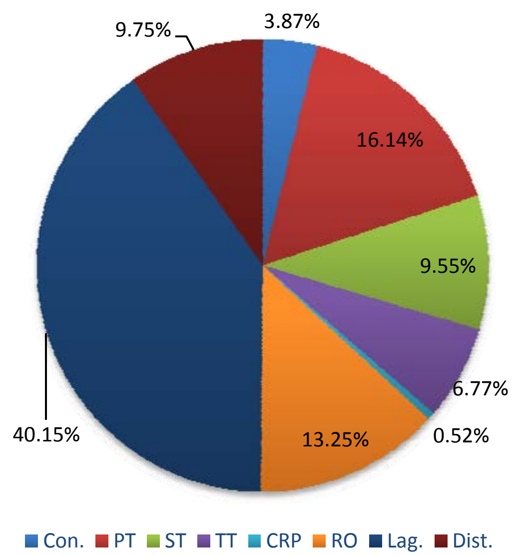

Figure 5.38: Typical Distribution of Total Capex of 64 MLD CETP Facility with Lagoon

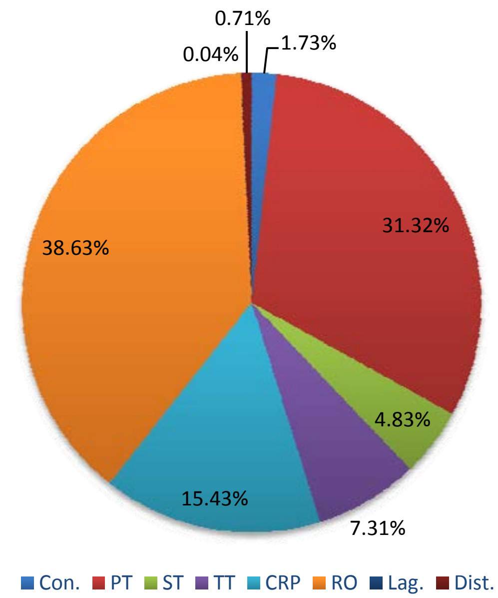

Figure 5.39: Typical Distribution of Total Opex of 64 MLD CETP Facility with Lagoon

Table 5.03: Estimated Capex, Opex and Tariffs in Three Scenarios for 64 MLD CETP Facility

Concentrate Handling Option	CAPEX	OPEX	Scenario 1	Scenario 2	Scenario 3
	₹ Cr /MLD	₹/KL	₹/KL	₹/KL	₹/KL
MEE	14.75	215.56	282.51	294.32	324.22
Lagoon	12.74	90.60	137.80	148.00	173.85

A typical pattern of distribution of expenditure of Capex and Opex of 12.8 or 25.6 MLD CBHF Facility with MEE and Lagoons on individual operations is presented in Figure 5.40 to 5.43. The Capex (per MLD), Opex (per KL) and Tariffs in the three scenarios (per KL and per unit area) for the same are given in Table 5.04.

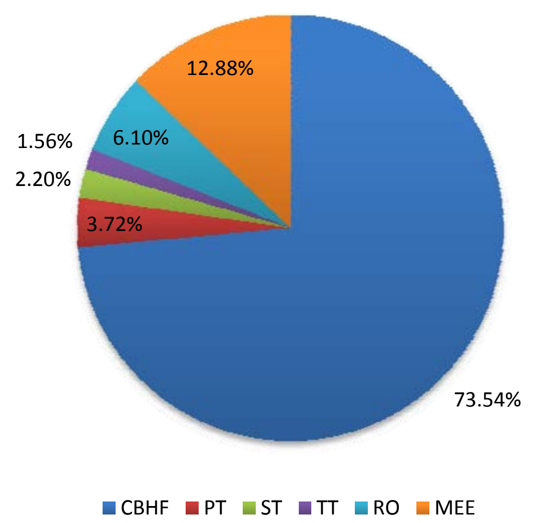

Figure 5.40: Typical Distribution of Total Capex of 12.8 MLD and 25.6 MLD CBHF Facility with MEE

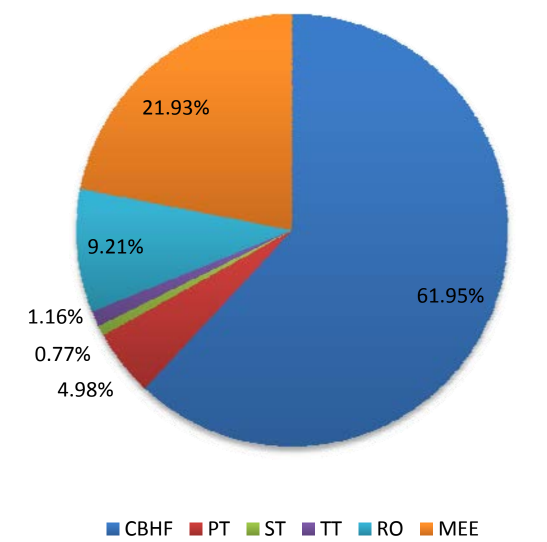

Figure 5.41: Typical Distribution of Total Opex of 12.8 MLD and 25.6 MLD CBHF Facility with MEE

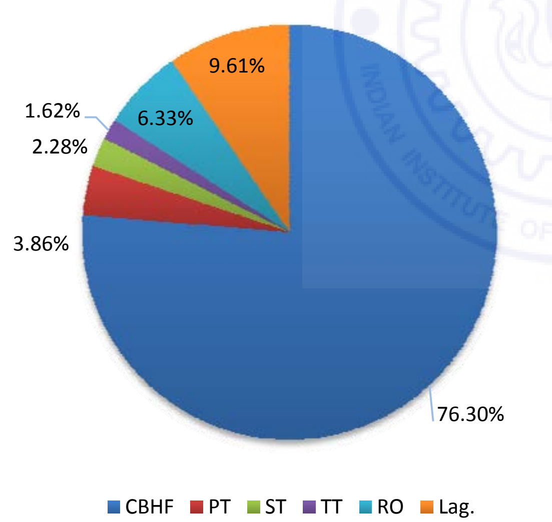

Figure 5.42: Typical Distribution of Total Capex of 12.8 MLD and 25.6 MLD CBHF Facility with Lagoon

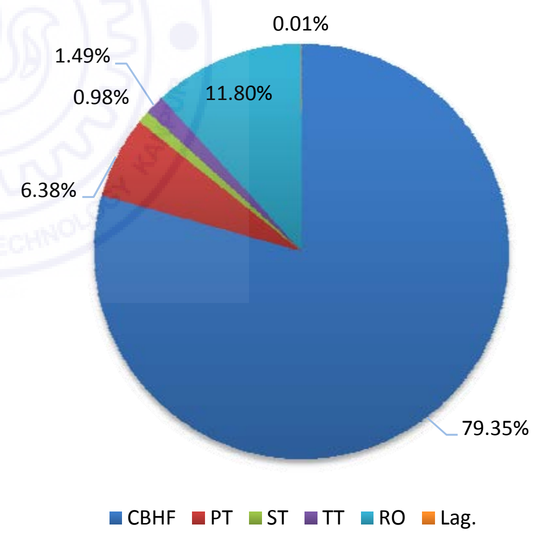

Figure 5.43: Typical Distribution of Total Opex of 12.8 MLD and 25.6 MLD CBHF Facility with Lagoon

Table 5.04: Estimated Capex, Opex and Tariffs in Three Scenarios for 12.8 MLD and 25.6 MLD CBHF Facility

Concentrate Handling Option	CAPEX	OPEX	Scenario 1		Scenario 2		Scenario 3	
	₹ Cr/ MLD	₹/KL	₹/KL	₹/sq m (sq ft)	₹/KL	₹/sq m (sq ft)	₹/KL	₹/sq m (sq ft)
MEE	55.31	570.00	794.55	57.05 (5.30)	838.85	60.17 (5.59)	951.00	68.24 (6.34)
Lagoon	53.30	445.04	649.90	46.61 (4.33)	692.55	49.73 (4.62)	800.70	57.4 (5.34)

A typical pattern of distribution of expenditure of Capex and Opex of 19.2 MLD CETP Facility with MEE and Lagoons on individual operations is presented in Figure 5.44 to 5.47. The Capex (per MLD), Opex (per KL) and Tariffs in the three scenarios (per KL) for the same are given in Table 5.05.

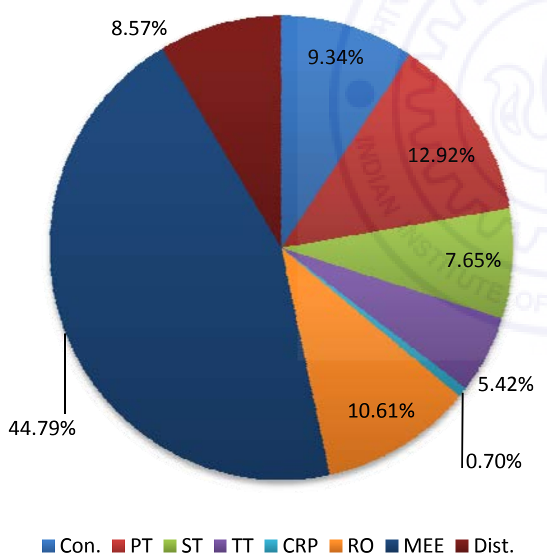

Figure 5.44: Typical Distribution of Total Capex of 19.2 MLD CETP Facility with MEE

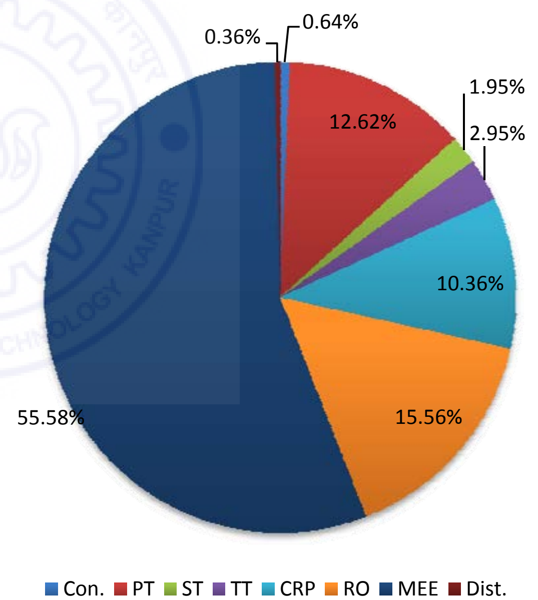

Figure 5.45: Typical Distribution of Total Opex of 19.2 MLD CETP Facility with MEE

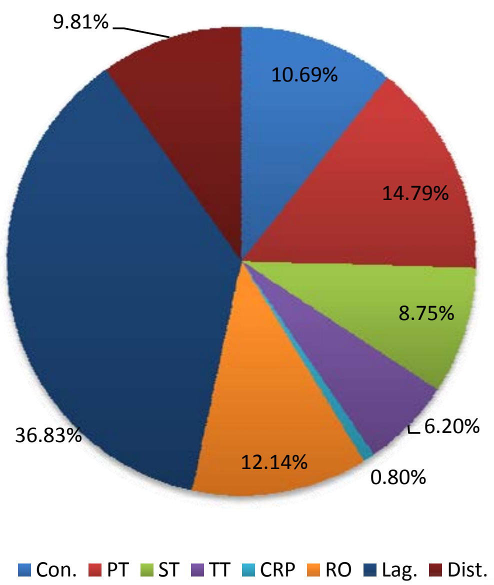

Figure 5.46: Typical Distribution of Total Capex of 19.2 MLD CETP Facility with Lagoon

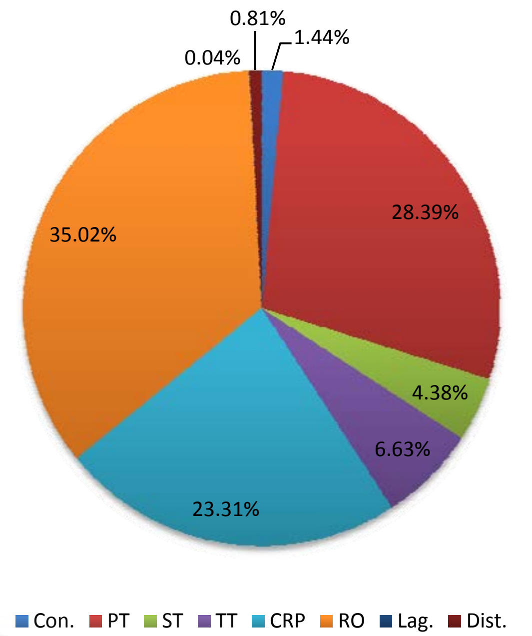

Figure 5.47: Typical Distribution of Total Opex of 19.2 MLD CETP Facility with Lagoon

Table 5.05: Estimated Capex, Opex and Tariffs in Three Scenarios for 19.2 MLD CETP Facility

Concentrate Handling Option	CAPEX	OPEX	Scenario 1	Scenario 2	Scenario 3
	₹ Cr /MLD	₹/KL	₹/KL	₹/KL	₹/KL
MEE	15.91	224.92	296.30	309.00	341.30
Lagoon	13.90	99.96	151.60	162.75	190.92

A typical pattern of distribution of expenditure of Capex and Opex of 38.4 MLD CETP Facility with MEE and Lagoons on individual operations is presented in Figure 5.48 to 5.51. The Capex (per MLD), Opex (per KL) and Tariffs in the three scenarios (per KL) for the same are given in Table 5.06.

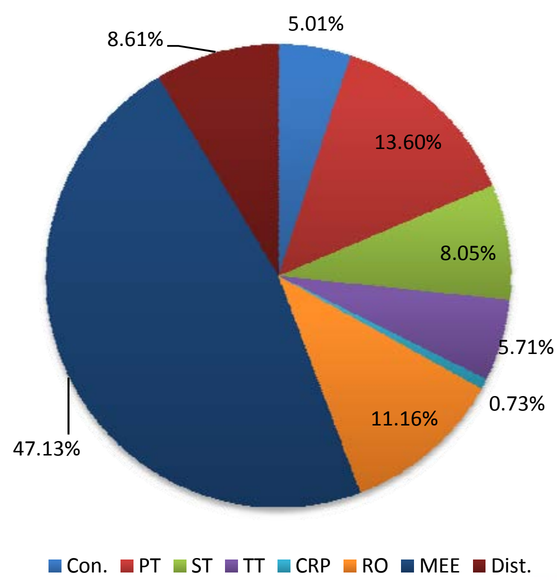

Figure 5.48: Typical Distribution of Total Capex of 38.4 MLD CETP Facility with MEE

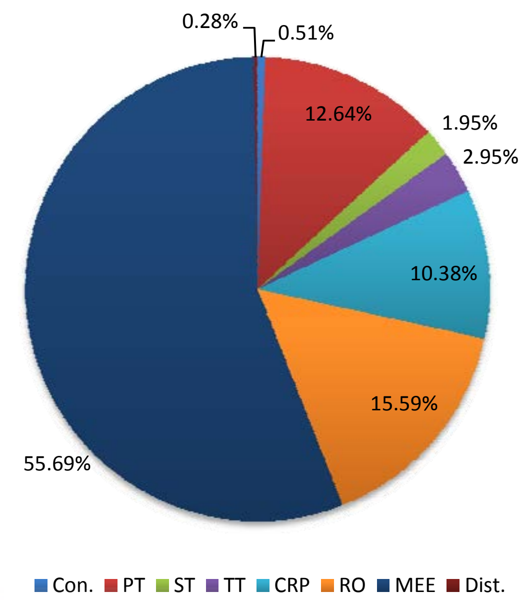

Figure 5.49: Typical Distribution of Total Opex of 38.4 MLD CETP Facility with MEE

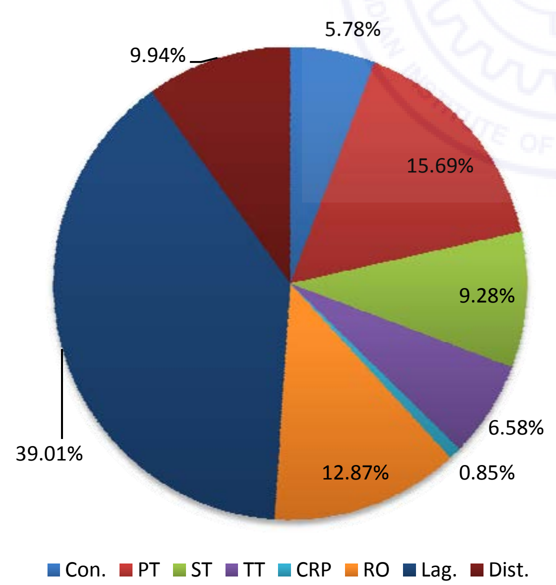

Figure 5.50: Typical Distribution of Total Capex of 38.4 MLD CETP Facility with Lagoon

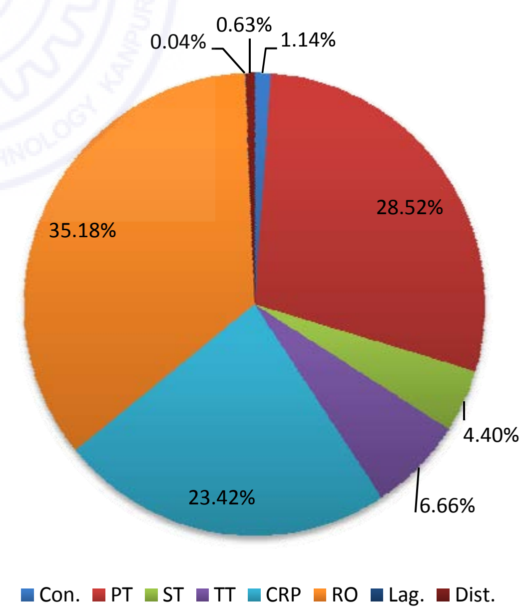

Figure 5.51: Typical Distribution of Total Opex of 38.4 MLD CETP Facility with Lagoon

Table 5.06: Estimated Capex, Opex and Tariffs in Three Scenarios for 38.4 MLD CETP Facility

Concentrate Handling Option	CAPEX	OPEX	Scenario 1	Scenario 2	Scenario 3
	₹/MLD	₹/KL	₹/KL	₹/KL	₹/KL
MEE	15.12	224.44	293.45	305.55	336.23
Lagoon	13.11	99.48	148.75	159.25	185.82

5.4 Land and Energy Footprint

The land and energy footprints of 64 MLD and 38.4 MLD CETP and 25.6 MLD CBHF has been calculated and shown as follows.

The total land footprint of 64 MLD and 38.4 MLD CETP Facility with MEE is 10 hectare and 6 hectare respectively. The daily energy footprint is 1210 Mega Watt hour (MW-h) and 720 MW-h respectively. A typical pattern of distribution of land and energy footprint of individual operations of 64 and 38.4 MLD CETP Facility is presented in Figure 5.52 and 5.53.

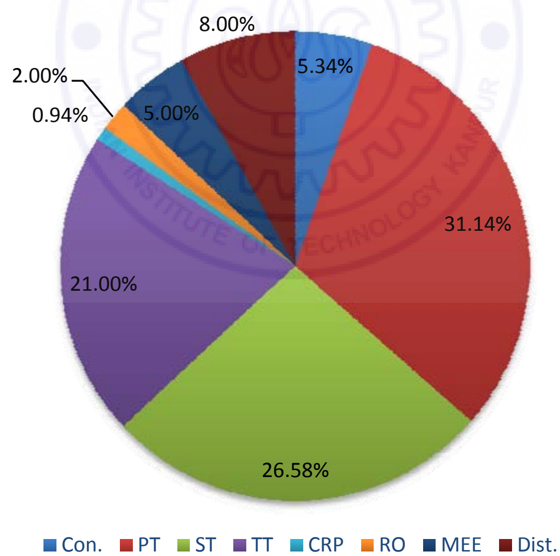

Figure 5.52: Typical Distribution of Total Land footprint 64 MLD and 38.4 MLD CETP Facility with MEE

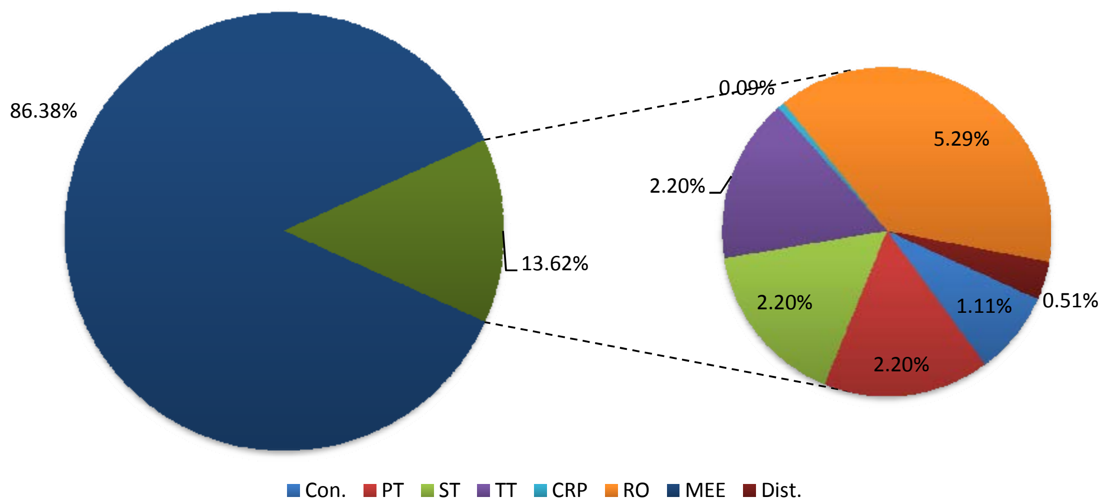

Figure 5.53: Typical Distribution of Total Energy footprint 64 MLD and 38.4 MLD CETP Facility with MEE

The total land footprint of 64 MLD and 38.4 MLD CETP Facility with Lagoon is 133 hectare and 80 hectare respectively. The daily energy footprint is 165 MW-h and 94 MW-h respectively. A typical pattern of distribution of land and energy footprint of individual operations of 64 and 38.4 MLD CETP Facility is presented in Figure 5.54 and 5.55.

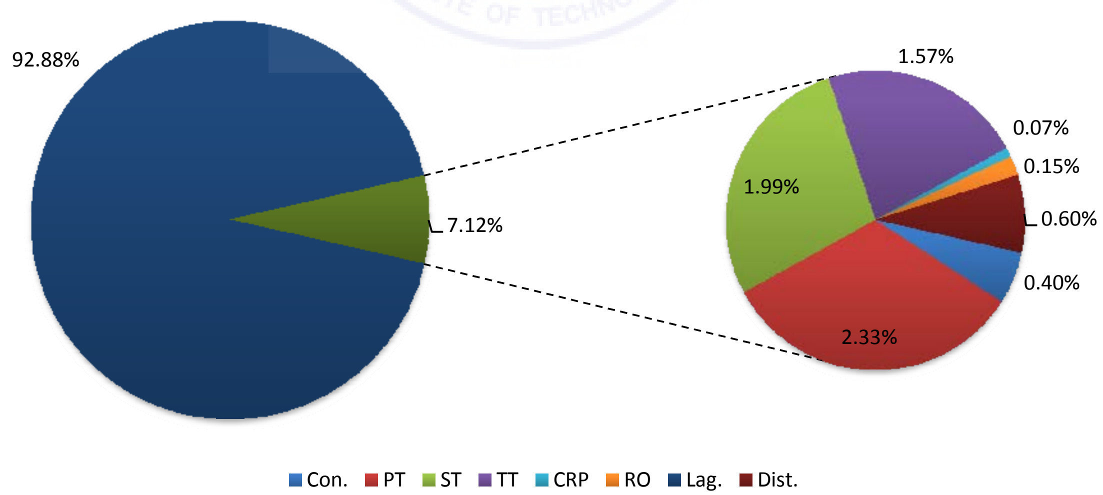

Figure 5.54: Typical Distribution of Total Land footprint 64 MLD and 38.4 MLD CETP Facility with Lagoon

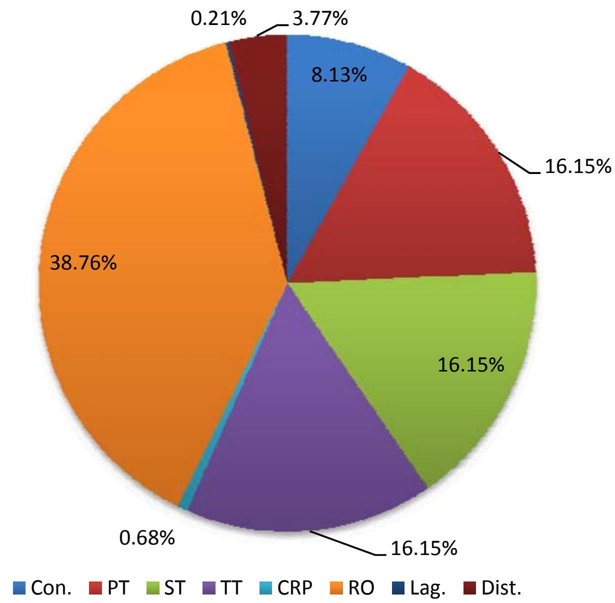

Figure 5.55: Typical Distribution of Total Energy footprint 64 MLD and 38.4 MLD CETP Facility with Lagoon

The total land footprint of 25.6 MLD CBHF Facility with MEE and Lagoon is 6.24 hectare and 55.56 hectare respectively. The daily energy footprint is 664 MW-h and 246 MW-h respectively. A typical pattern of distribution of land and energy footprint of individual operations of 25.6 MLD CBHF Facility is presented in Figure 5.56 to 5.59.

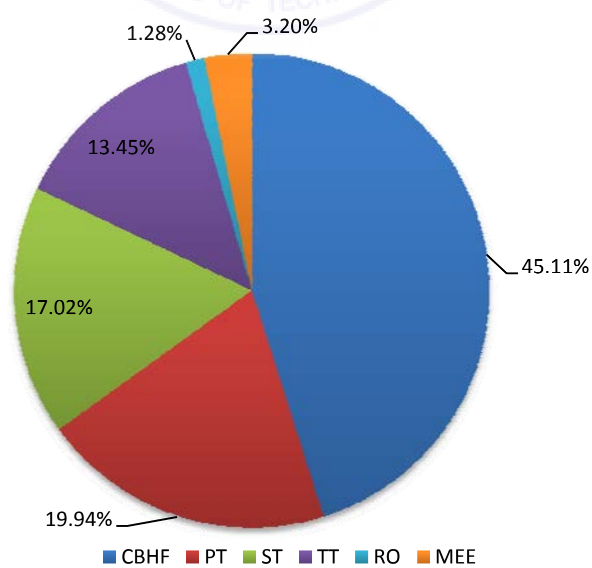

Figure 5.56: Typical Distribution of Total Land footprint of 25.6 MLD CBHF Facility with MEE

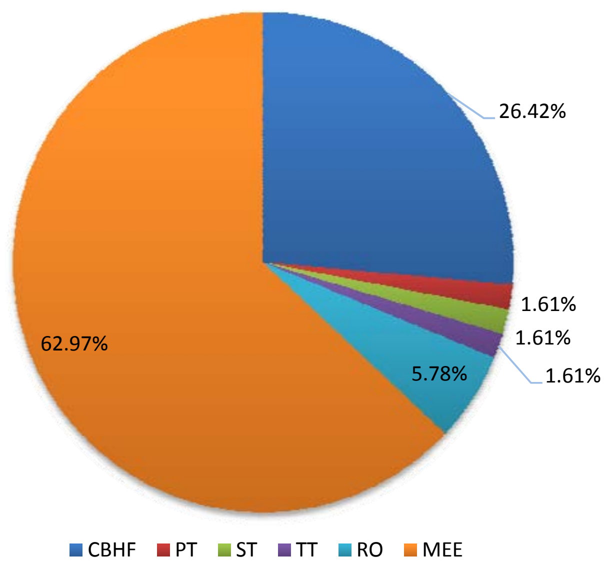

Figure 5.57: Typical Distribution of Total Energy footprint of 25.6 MLD CBHF Facility with MEE

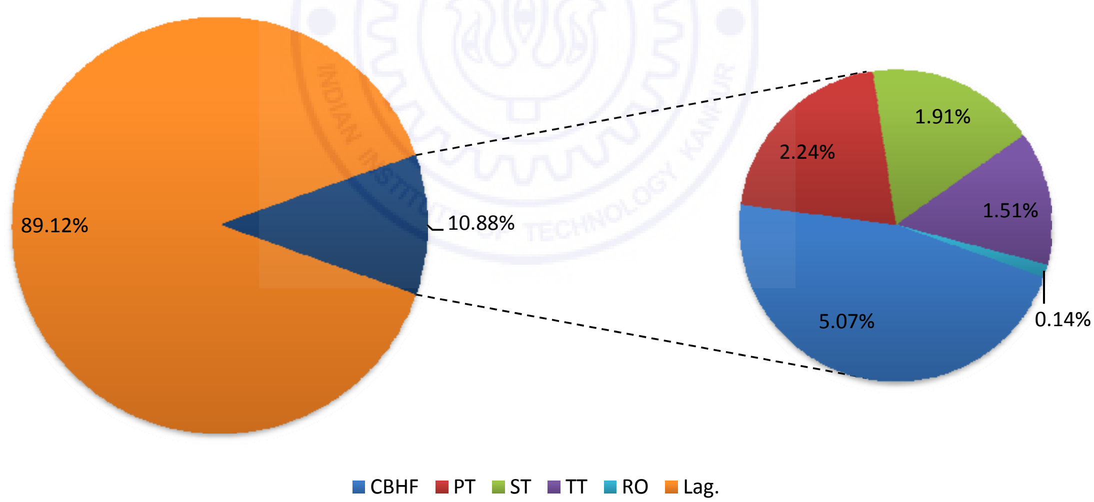

Figure 5.58: Typical Distribution of Total Land footprint of 25.6 MLD CBHF Facility with Lagoon

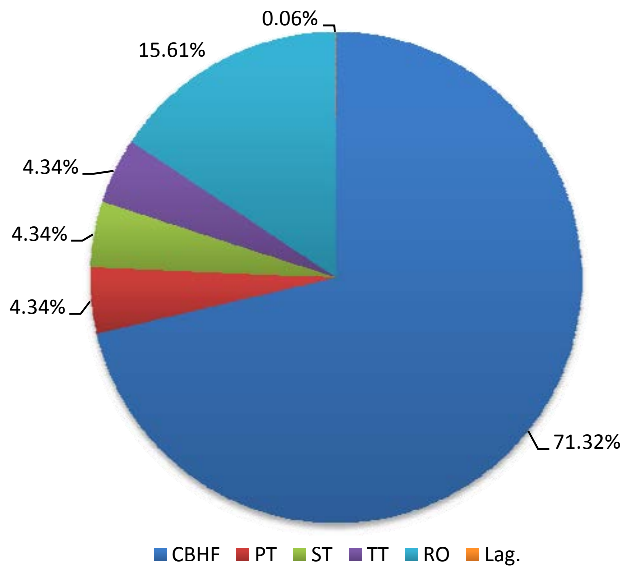

Figure 5.59: Typical Distribution of Total Energy footprint of 25.6 MLD CBHF Facility with Lagoon

6. Conclusions and Recommendations

6.1 Conclusions

Following conclusions may be drawn based on the synthesis of the information available in the literature and the results presented in this thesis.

- Tannery effluent conveyance, treatment and distribution of recycled water being common, the cost of concentrate treatment using MEE is about 800 % of the cost of controlled release of concentrate through lagoons during high flows.
- The controlled discharge of RO Reject during high flows in river Ganga at Kanpur may lead to: i) 28 % increase in the average TDS concentration during the discharge period compared to the background concentration, ii) decrease in average TDS concentration by 28% during the non-discharge period compared to discharge as per current discharge standards, iii) lower maximum monthly TDS concentration during the discharge period by 33% compared to maximum monthly TDS concentration throughout the year if the treated effluent is discharged daily as per current discharge standards, iv) lower monthly average BOD concentration throughout the year in comparison to concentrations if effluent is discharged throughout the year as per current discharge standards, v) lower average Cr concentration even in the discharge period by 77% compared to average Cr concentration in the non-discharge period if the effluent is discharged throughout the year as per current discharge standards, and vi) lower maximum monthly Cr concentration even in the discharge period by 83% compared to the maximum monthly Cr concentration throughout the year if the treated effluent is discharged daily as per current discharge standards.
- The lagoon land required for a 64 MLD CETP is 250 times the land required for MEE. The energy required for condensing the concentrate using MEE is 3000 times the energy required if controlled disposal of accumulated reject through lagoon in Ganga River.
- The use of lagoons to discharge the concentrate can be justified given the savings on capital and operational costs and low energy requirement except in areas where land is unavailable.
- The rates for carrying out beam-house operations in different tanneries have been reported to be varying from ₹ 21.53-64.58 per sq. m. (₹ 2-6 per sq. ft.). The tariffs of

CBHF in the three scenarios, namely i) Equity: 30%, Debt 1: 70% at interest rate of 3 %, ii) Equity: 30 %; Debt 1: 50 % at interest rate of 3 %, Debt 2: 20 % at interest rate of 13 % and iii) Scenario 3-Equity: 30 %; Debt 1: 70 % at interest rate of 13 %, using MEE is ₹ 57.05, 60.17 and 68.24 per sq. m. (₹ 5.30, 5.59 and 6.34 per sq. ft.) respectively and ₹ 46.61, 49.73 and 57.48 per sq. m. (₹ 4.33, 4.62 and 5.34 per sq. ft.) respectively using lagoons. The tariff is inclusive of charges of treatment of water. Thus the CBHF facility is more economic than carrying out the operations at individual facilities. However, the overall feasibility of CBHF needs to be evaluated considering challenges involved in transport of partially processed hides to individual tanneries.

- CBHF provides an opportunity of better house-keeping through better management of solid wastes, and segregation of concentrated effluents of beam-house operation. It also has the distinct advantage of economy of scale. The solid wastes in CBHF operations such as fats, grease, hooves, hairs etc. provide an opportunity of industrial symbiosis.

6.2 Recommendations

Following recommendations are made for logical continuation of the work described in this thesis based on the experience gained in conducting the present study.

- The economic reuse/sale value of regenerated chrome may be included to estimate new reduced tariffs.
- The economic value of useful by-products may be included to estimate new tariffs.
- The cost of disposal of sludge generated may also be included to estimate new tariffs.
- The possibility of mandatory completion of all operations up to production of wet blues at a central facility can be explored.

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