Pollution – Anthropogenic: Monitoring and Management **14**

Sustainable Algal scum Management and Wastewater treatment in Bangalore

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Bangalore has been experiencing unplanned rapid urbanisation during the last two decades evident from natural resources utilisation and waste (solid and liquid) management. The wastewater generated in the city is either partially treated or untreated enters storm water drains and ultimately reaching cascading human-made water bodies (lakes). The wastewater with nutrients has been enriching the water systems and resulting in the contamination of water affecting local people's health. In the south-eastern part of Bangalore, two large lakes, the Bellandur and Varthur receive approximately ~40 % [500 MLD] of the sewage generated in Bangalore. A strategic analysis of the causative phenomena suggests that the water bodies firstly undergo an initial anaerobic stage of wastewater decomposition where the N is largely ammoniacal and higher P in the form of condensed phosphates. A nutrient balance assessment of the two lakes suggests that microalgae are the key agents that convert and capture organic N and P found in the wastewater. A mass balance estimated for the system suggests that a large part of the nitrogen is generally in ammoniacal forms that facilitate micro-algal absorption leaving little chance for nitrification. A substantial part of the N appears to be lost due to volatilization and to some extent denitrification. The lake accounts for about 60% N capture and recovery into reusable intermediates and is therefore a candidate for evolving methods for near-100% N recovery by algal systems. The SEM–EDXA studies showed higher phosphate accumulation in case the algae as a result of luxury P uptake. With a growth rates such algae tend to accumulate lipid in their cells. Experiments conducted in the lab have also showed the potentials of these algae in heterotropically removing organic C (90%). An investigation on C allocation pattern in biomass with all variability's in environment would pave essential path for C abatement and GHG emission from the anoxic regions.

The study indicates that these water bodies do treat water, when lakes are not invested with invasive water weeds. This study brings out the strategies to recover a large part of the C, N & P in urban wastewaters through algal systems at lower costs and higher energy efficiencies. Furthermore, it is possible to capture the nutrients as well as C in algal biofuel to achieve triple benefits-namely i) water purification ii). nutrients capture and iii). algal biofuel. This study shows that given the water spread area and the levels of nutrients released in Bangalore sewage, it is possible to devise a 7,000 tonnes per day (tpd) algal biofuel system to meet the growing need of liquid fuel.

Keywords: micro algae, lakes, wastewater, treatment, nutrients, Bangalore

1. INTRODUCTION

Unplanned rapid urbanisation in Bangalore has led to the increase in population resulting in the lack of basic amenities and adequate infrastructure. Quantum of wastewater generated has been estimated as ~40 billion litres each day (CPCB Report) and less than 30% undergoes partial treatment before being let into receiving waters. Most of the developing cities do not have an infrastructure for municipal water supply and sewerage. Bangalore possesses few functional wastewater treatment plants (WWTP's), and some below the installed capacity. However sewage networks have severe shortcomings and are often inadequate to transfer sewage to these treatment units. This result in treatment of a small fraction of the total sewage generated. The major chunk of sewage bypasses these networks and flows across storm water drains and ultimately reaches the surface water bodies. The close proximity of the sewage flow paths to human settlements results in health and hygiene problems. Furthermore stagnation of sewage leaches contaminating ground water resources.

The wastewaters are rich in nutrients to grow oleaginous algae that can be used for producing biofuel as algal bio-diesel.

Bangalore city has grown spatially 10 times (69 to 741 sq.kms) since independence. The present population density of Bangalore is ~8822 persons/sq. km. The wastewater generated in the city is about 1500 MLD (million litres per day). Partially treated or untreated sewage enters the lakes of the city enriching them with nutrients and resulting in obnoxious algal blooms. Bangalore receives water from river Cauvery, situated 90 km away further south of Bangalore. The state spends about 75 MW electricity every day to supply water to Bangalore. Drinking water in the city has become a serous concern. The suggestion of Cauvery management committee of providing 9000 Cusec water daily to Tamil Nadu from KR Sagara Dam, Mysore has added miseries and panic among local residents in Bangalore. Reuse of wastewater through suitable and efficient decentralised algal wastewater treatment options seems viable, cost effective and environment friendly option to meet the growing demand of water. Cultivation of algae in wastewaters and harvest regularly ensures proper resource utilisation and rejuvenate water bodies.

Bangalore has a dependable supply of sewage throughout the year. The large volume of sewage provides great potentials if proper treatment and water management issues are carried out optimally. The wastewater can be treated efficiently and economically, which reduces reliance on the freshwater need. Treated wastewaters can be reused for non-portable domestic, industrial and agricultural use. Resource demand analyses for algal biofuel production highlight the need for sustainable wastewater treatment together with production of algal biofuel. This strategy would promote generation of biofuel with sustainable biological nutrient removal (Chanakya et al., 2012). Adopted wastewater treatment technologies in the city only remove C (carbon) and solids, leaving behind the nutrients. Conjunction of these treatment plants with HDAP (high detention algal ponds) would aid in the nutrient removal and sustained biofuel generation. Despite many benefits of using wastewater for algal biomass production, it is unknown whether there is sufficient land or wastewater available for large-scale fuel production. The use of wastewater for algal production is to be near WWTP's. Availability of wastewater effluent and land within short distances from WWTP's would help in biofuel production. There have been significantly higher numbers of studies on growth of algae under a wide variety of wastewater environments (Ip et al., 1982; Konig et al., 1987; Wrigly and Toerien, 1990). Most of these studies have focussed on efficient algal sp. in pure cultures for the treatment of sewage and artificial wastewaters (Ruiz-Marin et al., 2010). These studies have primarily looked at evaluating the potential of algae for removing N and P, and in some instances metals and other minerals from wastewater. The present study investigates the viability of wastewater algae in treatment of urban wastewaters and generation of algal biofuel through its integration to existing treatment plants in the city.

The main objective of this analysis is to devise a sustainable nutrient (C, N and P) capture mechanism for the city wastewaters and to investigate the feasibility of producing algae lipids (biofuel) in urban localities. The study was conducted for the city of Bangalore, and the nutrient dynamics studies were performed in the two big lakes of the city because of its higher detention and high algal productivities. The average algal productivity and lipid content were determined from laboratory based studies at Aquatic ecology laboratory, Centre for Ecological Sciences, IISc, Bangalore campus with the similar wastewater algal consortia. The algal lipid content and productivities were examined to create realistic baseline values to estimate the city's biofuel production potential from algal scums in surface waters. This study provides the geospatial analysis of wastewater treatment plant locations and investigations of land availability near the plants for integration of HDAP to existing treatment technologies.

2. MATERIALS AND METHODS

The wastewater generated in the city flows across three main storm water channels in the three catchments. These wastewater samples were periodically assessed for algal growth, nutrient content (HACH, Protocols) and the physico-chemical parameters following Standard Methods (APHA, 1995). Treatment plants from each catchment were investigated on the effluent discharges and their quality. For finding out the algal potentials, two lakes situated on the South of Bangalore were studied for algal growth and biomass estimations. The field level algal productivity or algal biomass production is based on the data collected from the algal growth in lakes that were tested in the laboratories. The field studies show an areal productivity of $10g/m^2/d$ and a nominal lipid content of (14%) the highest being 24 %. The studies in the lab showed an average ~$24g/m^2/d$ and lipid content closest to 30%. The total amount of oil that could be produced annually under each productivity scenario was calculated based on the land or wastewater available in the Bangalore city (land especially near the existing wastewater treatment plants) in order to determine the limiting factor of production and to assess the potential of either resource in producing algal biodiesel. A 60% overall processing efficiency was assumed for the conversion of algal lipids to biodiesel. A lipid density of 918 kg/m^3 was assumed.

The potential algal biofuel production under wastewater conditions was determined using wastewater effluent concentrations of nitrogen and phosphorus investigated earlier 2010-2011. (Unpublished data). The average total nitrogen (TN) and total phosphorus (TP) concentrations, in units of mg/l, during the study were determined for each representative treatment plant from the three catchments in Bangalore city. Average seasonal nutrient concentrations of wastewaters collected from drains, lakes etc. were investigated and the molar N/P ratio was determined during the study (Dec-May-Oct, 2010-11). The molar N/P ratio was used to determine whether the WWTP's effluents were overall nitrogen-limited (N/P<16) or phosphorus limited (N/P>16). The studies showed TN concentrations varying from 35 to 80 mg/l and TP concentration varying from 8 to 31 mg/l.

The algal nutrient uptake studies were performed in the laboratory in ambient conditions in batch cultures with a culture time of 8-10 days. Lipids were extracted by Bligh and Dyers method, and were then processed for FAME analysis by GC-MS. The potential algal biodiesel production was calculated on the basis of field level observations and laboratory studies with average N and P concentrations of the effluent, in relation to the N nad P content of algae and available wastewater loads in the three different catchments V Valley (400 MLD), Koramangla and Challaghata Valley(500 MLD) and Hebbal valley (300 MLD). The GHG emissions were calculated according to the IPCC 1996 and 2006 guidelines, taking into considerations the regional TOC, TN values and the corresponding emission factors.

3. RESULTS AND DISCUSSIONS:

Algae have proliferated in almost all surface water bodies in the city. This is evident by the green scums and thick algal blooms that is a very common occurrence in urban waters as shown in figure 1. The use of algae in nutrient removal in wastewaters is not new and has been known from 1950's (Oswald et al, 1957) in wastewater stabilisation (oxidation) ponds or raceway algal ponds (Hoffmann 1998). Wastewater treatment is a major challenge especially in developing nations. Most of the wastewaters are being generated in the rapidly urbanizing cities as Bangalore. In the city most of the C released into the sewer system and degraded anaerobically at different environments and subsequently decomposed aerobically during its flow periods in open sewers and storm water drains (Mahapatra et al., 2011b,c). The mean TOC values were ~160 mg/l and TN values were ~55 mg/l at different sampling locations in the three valleys. The TOC and TN influx into the lakes as Bellandur and Varthur lakes ranged 40-160 mg/l and 65-23 mg/l respectively. Such high C and N values in sewage are responsible for a higher emission generated from anoxic conditions in the city wastewaters. The GHG are contributed during the flow of the sewage through the UGD's, during the time of treatment at WWTP's and during their flows in storm water drains and in the lakes of the city. It has been estimated that negligible GHG (especially methane) is being captured or transformed to non-reactive forms in the city leading to higher quantum of emissions accounting to 172 tonnes of N_2O/yr; 3,10,795 tonnes of CH_4/yr. The CO_2 being generated during the bacterial activities in the WWTP's though non-fossil in origin, but contributes significantly to the city's existing CO_2 load and individual's wastewater C-footprint. However in the water bodies due to dense algal growth minimal CO_2 is absorbed during the day, but CO_2 might be released during night due to respiration.

There are ~14 wastewater treatment units in the city that could partially treat the wastewaters up to secondary levels. However the limiting nutrients as N and P are left behind in the final effluents of these treatment units (Mahapatra et al., 2011a). Most of the N present in the system is in the form of Amm-N (~45 ppm) that can be potentially up-taken and immobilised in algae (Mahpatra et al., 2011c). However the nitrate values were very less 1-5 mg/l in city sewers and ~1 mg/l in lakes (Mahpatra et al., 2011b). In a mass balance approach as high as 80 % of the total N present in such wastewaters is in the form of Amm-N. The N budget in the water bodies revealed a substantial amount that was not accounted (~40%). This could be due to ammonia volatilisation or denitrification or could be due to ANAMOX (anoxic ammonia oxidation). The algal comprise of ~5-8% N in their biomass (Mahaptra et al., 2011b). Algae have been tested in the laboratory and in the ambient conditions for its efficiency in removing N from wastewater and thence are key players for nutrient remediation particularly during the secondary and tertiary treatment phase of wastewater. The laboratory studies showed ~92 % of amm-N removal and 88% of TN removal in just 8 days batch cultures in wastewaters.

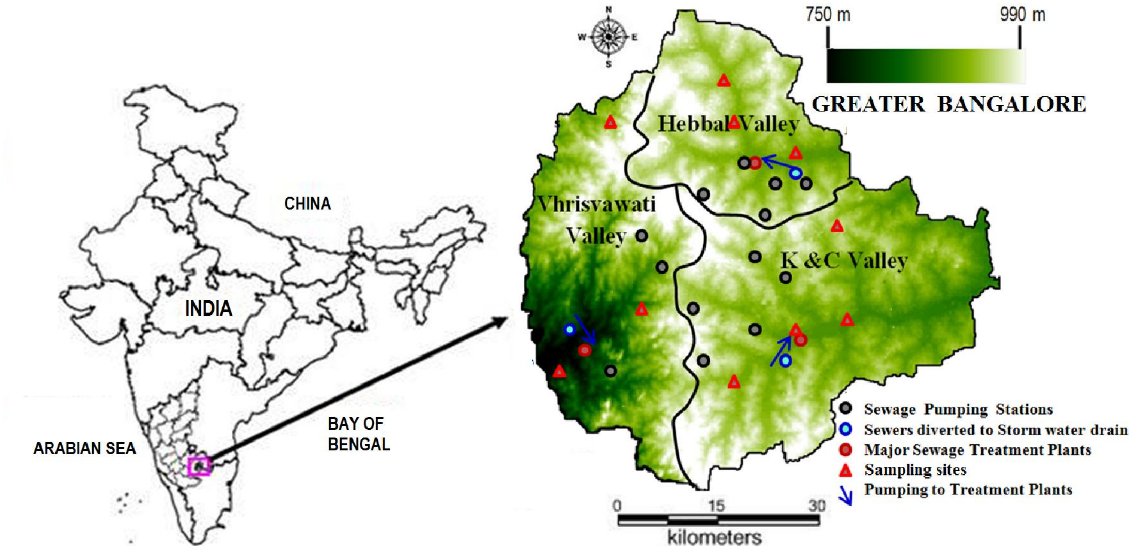

Figure 1. Study Area: DEM showing the sampling locations valleys and the treatment units in Greater Bangalore


Figure 2. Algal Scums in storm waters, lakes and in treament plants in Bangalore

The P removal efficiencies in algae-based treatment systems are very efficient compared to chemical treatment (Hoffmann 1998) Though there was a net retention of soluble P in the effluents of the lake units that can be attributed to the re-suspension of the P from the lake bottoms due to anoxia (Mahapatra et al, 2011a). The laboratory based studies on algal P uptake showed 80% of orthophosphate removal and ~72% of TP removal (Reported elsewhere and yet to be published). As P is in excess, a higher retention of wastewaters would allow total algal capture of P through luxury P uptake. Figure 4 elucidates the accumulation of polyphosphates in the algal solids. The SEM image shows significant P accumulation (~3% by wt.) as shown by the P peak through the electron dispersion XRD data of dried algal cells.

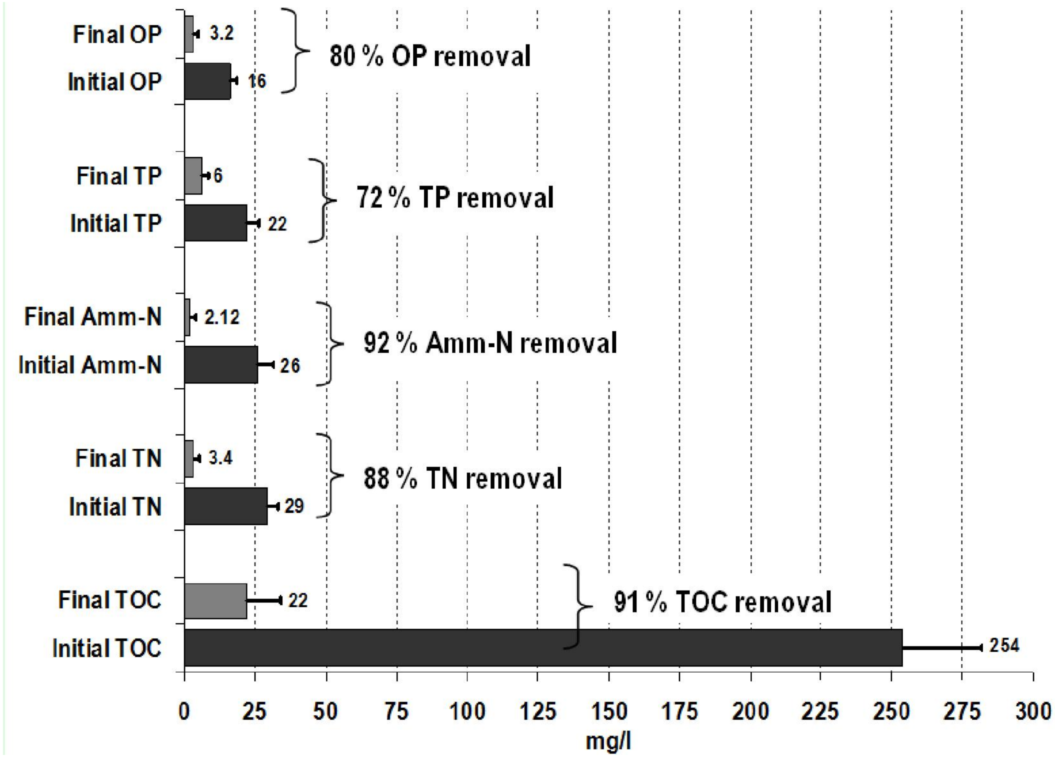

Figure 3. Laboratory studies on nutrient removal by wastewater algae

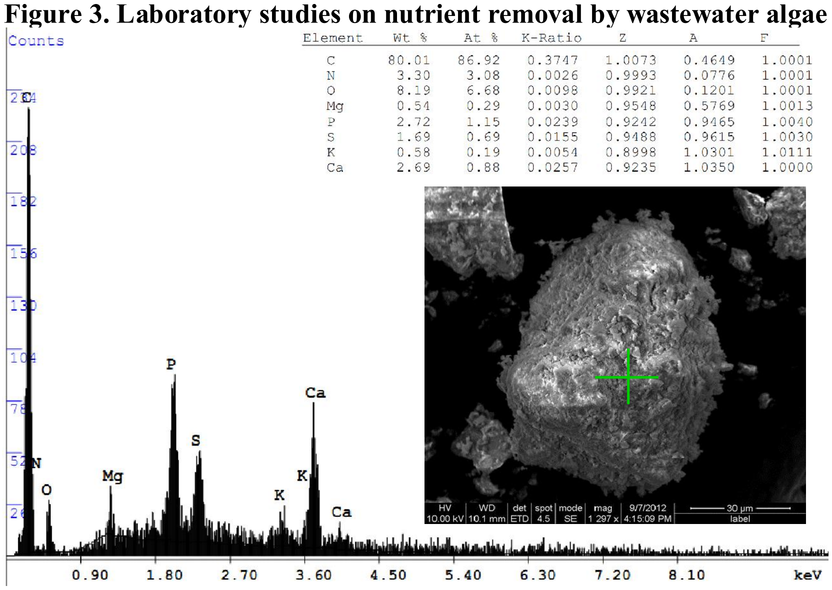

Figure 4. SEM image: Polyphosphate accumulation in algal solids

Significantly high rates of oxygen generation from photosynthetic algae (6-28 ppm) in the present study can offset the requirement of mechanical aeration systems which has a high initial and operational costs (Mallick, 2002). Oxygen in the dissolved forms in treatment units enhances the rate of heterotrophic bacteria (faster decomposition) to remove organics and other ionic substances and treat the wastewater (Munoz and Guieysse, 2006). Furthermore the algal treatment systems enhances the sustainability of the treatment systems by avoiding the generation of bi-products and additional pollutants like sludge thereby closing the loop for efficient nutrient recycling. The biomass in these ponds are rich in nutrients that can directly applied to land as low-cost fertilisers, as animal feed (Munoz and Guieysse, 2006) or can be made to use in many different ways that satisfies our biofuel needs. Thus algae have the abilities to completely tap the nutrients in the wastewaters with optimal feed rate and proper growth conditions at the same time abate GHG emissions. The algal based pond technologies are advantageous over conventional ones as they are simple, cost effective less energy intensive, thus best suiting the developing countries as India.

The urban wastewaters are enriched with very high concentrations of nutrients as C, N and P compared to the other growth media. The major fraction of N is in the form of ammoniacal–N sustains many algal species mostly dominated by Chlorophyceaen members comprising *Chlorella* sp., *Monoraphidium* sp. and *Chlorococcum* sp etc. Contrary to this there are many studies that highlight the lethal effects of higher Amm-N on algae due to ammonia toxicity (Ip et al., 1982; Konig et al., 1987; Wrigly and Toerien, 1990). The algal communities in urban lakes at Bangalore were responsible for about 45% N removal and 60% C removal (Mahapatra et al., 2011a). Similar findings were also found in earlier nutrient uptake studies in chlorophytic algae as *Chlorella* sp. and *Scenedesmus* (Ruiz-Marin et al., 2010) growing in wastewater lagoons and advanced algal ponds (9, 40). *Chlorella* sp. and *Scenedesmus* sp. has been studied widely as these species grows well in sewage effluents (Yujie and Zhang, 2011). These species show a very high (>80%) nutrient removal efficiency and in many instances results in almost complete removal of ammonia, nitrate and total P from secondary treated wastewater (Ruiz-Marin et al., 2010). *Euglena* sp. has been recently characterised in wastewater treatment ponds in India (Bangalore and Mysore, Karnataka). With a higher biomass productivities in raw sewage they grow heterotrophically in dark and have a mixotrophic mode of nutrition with a variable C and N (NH_4-N) uptake at growth rates of 155 mg/l (unpublished data) compared to 73 mg/l under phototrophic conditions for growing *Chlorella minutissima* in 10days (Bhatnagar et al., 2010). These experiments prove euglenophycean members as better nutrient assimilators in raw wastewater systems. The algal sp. that have been characterised to inhabit wastewaters in different physico-chemical conditions have been packaged as a module that can be integrated to STP effluents for total nutrient removal (to be published elsewhere).

The transitions in the biochemical compositions were identified using ATR-FTIR spectroscopy and the band assignments following Dean et al, (2010) to observe the cells at wave numbers between 1800 and 800 cm^{-1}. With a resolution of 2 cm^{-1} wave number and with 64 scans. The periodically harvested and dried algal biomass showed peaks at ~1,740 cm^{-1} due to C=O stretching in Lipids (esters of fatty acids); ~1,650 cm^{-1} C=O stretching in Proteins (Amide I); ~1,540 cm^{-1} N-H Amides of proteins (Amide II); ~1,398 cm^{-1} CH_3 and CH_2 of Proteins (Amide III); ~1,240 cm^{-1} P=O Phospholipids, DNA and RNA; 1,200-1,160 cm^{-1} C-O-C in Carbohydrates and Polysaccharides and ~830 cm^{-1} C=N (ring) in nucleotides and chlorophyll pigments. The *Chlorococcum* sp. grown in wastewater showed higher lipid content at the end of the batch cycles due to nutrient deprivation as can be observed in the shifts of the biochemical pools at the initial and the later stages of the cycle.

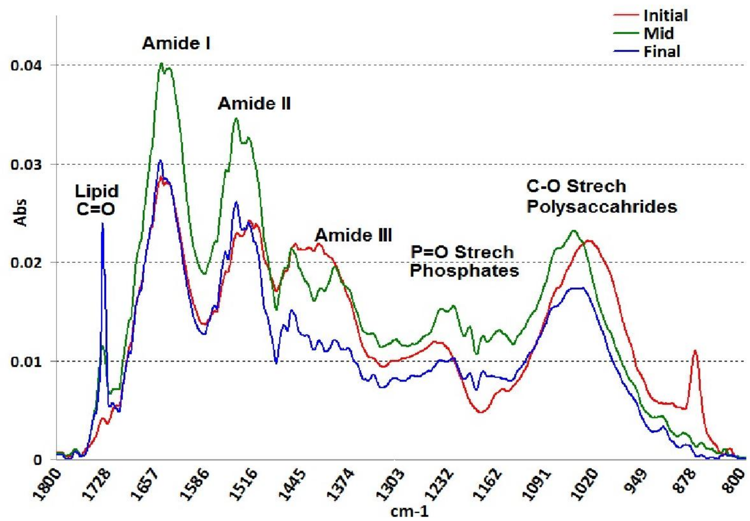

Figure 5. FTIR bands for the compositional analysis of algae during its cultivation

Note: The red, green and blue curves indicates the spectra of the algal cells during the initial, middle and final stages of the cultivation

The algae (chlorophycea) isolated from the wastewaters from Varthur lake were made to grow in outdoor cultures in open tub reactors (bench scale, batch reactors 10 litres volume) The daily growth of the algal species were monitored and lipid measurements showed a hype in lipid content in the stationary phases of the culture experiment and was confirmed with ATR-FTIR studies that showed a very prominent band at ~1740 cm^{-1} (lipid) in the Vibrational spectra (Figure 5). Ultrasonication was employed for cell disruption and the lipid extraction was carried following the methods of Bligh and Dier (1959). The total lipid content during the experiment varied from 24.5-28.4% of dry algal biomass. The mass productivity was observed to be 133 mg/l/d from the open tubs with an area productivity of ~10 $g/m^2/d$.

The capability of algal communities to thrive under acute wastewater conditions, as has signified the potential of these nutrient rich resources as suitable sustainable natural growth medium for biofuel feedstock. These algal communities can stock significant amount of lipids in the cell. The nature and type of lipids (saturates, unsaturates, polyunsaturates and glycol/phosphor lipids or TAGS) and the quantity of lipids produced (max-80% of the cell dry weight) depends on the nature of species and the algal growth conditions (Ramachandra et al, 2009; Griffiths and Harrison, 2009). The unlimited nutrient supply in wastewaters would result is high algal cell densities and higher lipid productivities.

The present studies undertaken to screen the algae with highest lipid content showed *Chlorococcum* sp. which had the highest lipid content (~28 %) followed by *Euglena* sp. (~24%), *Phormidium* sp. (~18%) and *Microcystis* sp. (~8%) (Reported elsewhere, yet to be published). Algae mostly grown on municipal wastewater and the biomass of the cells ranged from 20–35 mg/l/d and the wastewater produced each year desired to be used for the entire year would yield the algal biomass of 16-28 tonnes/ha/yr to produce an estimated lipid yield of 3260-3830 L/ha/yr (Chinnasamy et al., 2010). The batch culture growth studies in municipal wastewaters of *Chlamydomonas reinhardtii* revealed higher growth rates (100% centrate wastewater) with a lipid content of ~17% on a dry wt. basis (Kong et al., 2010). The same cultures being transferred to bio-coil showed a consistent growth in wastewaters with increased lipid content of 26% on a dry wt. basis and biomass productivity of 2 g/l/d and an estimated lipid yield of 0.505 g/l/d coupled with adequate nutrient removal (Kong et al., 2010). The lipid content from mixed algae cultures, isolated from sewage treatment ponds, grown in anaerobically digested dairy manure wastewater in outdoor batch cultures showed a leap in lipid accumulation In a week (14% to 29%) with an estimated lipid productivity of 2.8 $g/m^2/d$ (Woertz et al., 2009).

The gas chromatography and mass spectrometry (GC-MS) analysis of the fatty acid methyl esters (FAME) showed a higher content of important fatty acids having desirable biofuel properties (Knothe, 2006) with major contribution by the unsaturated fatty acid (UFA) oleic acid (C18:1; 42%) followed by palmitic acid (C16:0; 27%) followed by stearic acid (C18:0; 11%) and linoleic acid (C18:2; 6%) comprising of 86% of the total fatty acid constituents (Figure 6). During the end of the batch cycles, these algal species were auto-flocculated at the top of the cultures making the harvesting easier and faster for algal biomass and oil quantification.

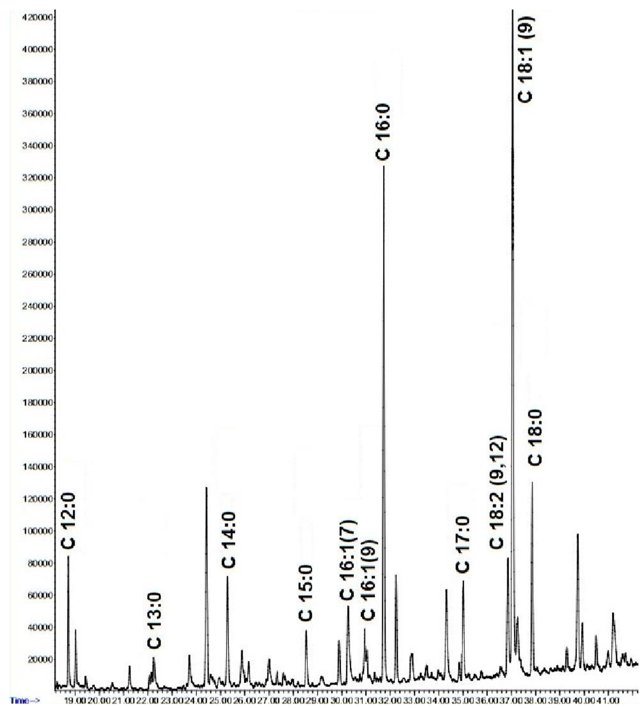

Figure 6. Chromatogram of the FAME present in *Chlorococcum* species.
*The peaks indicating the abundance (concentration) of the fatty acids

The use of enormous wastewater generated daily could offset these nutrient and CO_2 demands. The urban lakes in Bangalore are rich in nutrients fed from domestic sewage and have a very high and healthy aerobic bacterial microflora that generates ample CO_2 through respiration that can be subsequently utilised by the micro-algae (Mahapatra et al, 2011a) Similar findings are also observed in earlier studies (Munoz and Guieysse, 2006). The wastewater systems provide a year round availability of nutrients for a synergistic growth of algal-bacterial symbiotic systems degrading wastewater. The manmade lagoon system removes the burden of land area requirement at present to grow algae for biofuel requirements though in future such algal systems can be integrated to mechanised WWTP's. Bangalore generates >1200 MLD of wastewater and the studies in one of the catchment (K and C Valley) that draws ~500 MLD reveal satisfactory treatment of wastewater through natural algal growth. With an average efficiency of ~55% nutrient removal such systems can be optimised and made sustainable by careful feed rate management and optimal detention time. The average algal cell densities found in these systems are of the order of 10^5-10^6 cells/ml. That gives biomass productivities of ~10g/m^2/d. The nutrient loads were 90-120 mg/l TOC; 75-90 mg/l TN and 20-40 mg/l of TP in the waters of the catchment.

The average annual influx of nutrients amounts to 20,000 t TOC/yr of, 14,600 tTN/ yr of and 5,475 tTP/yr. With such enormous nutrient loads a number of algal species thrived in such conditions. The annual biomass generation for Bellandur lake (365 hac) yields roughly 13,000 t algal biomass/annum. Out of these if 40% is harvested for lipid extraction, then it still yields ~5000 t algal biomass/yr. Now considering the an average lipid content of 20%, 1000 t of lipid can be extracted from this water body annually. Similarly 640 t algal lipid/yr can be extracted from Varthur lake, the next lake in the cascading lake series. Likewise for the entire wastewater generated in Bangalore city the net lipid potential corresponds to >7,200 t/yr. The left out algal-biomass after lipid extraction through cell disruption and solvent treatment can be of the order of ~18000 tonnes/yr that can be anaerobically digested that would yield 7 Mm^3 of methane. This adds to additional energy security from the spent biomass. The slurry left after the anaerobic digestion can be used as an excellent nutrient media for further algal cultivation or can be used as rich fertilisers which would take us a step further to stabilise our agrarian economy. In this complete loop there is no net generation of waste at the same time there is a lot of positive net energy gain that indicates sustainability. Further investigations on such type of naturally managed system and its process understanding will eventually lead to optimal wastewater treatment with efficient biofuel production.

From the earlier observations and findings it's evident that the algal biomass can be transformed to biofuels via a wide range of technologies. But, lipid extraction from algal biomass as an oil source for biodiesel is the most promising option, particularly when there is option for cogeneration of methane from the remaining residual algal biomass (Brune et al., 2009). Albeit the lower average lipid content of algae in wastewaters, the enormous and consistent nutrient supply can results in higher biomass productivities resulting in increased lipid yields. A process flow diagram of the sustainable wastewater treatment with biofuel and nutrient recovery is proposed in Figure 7.

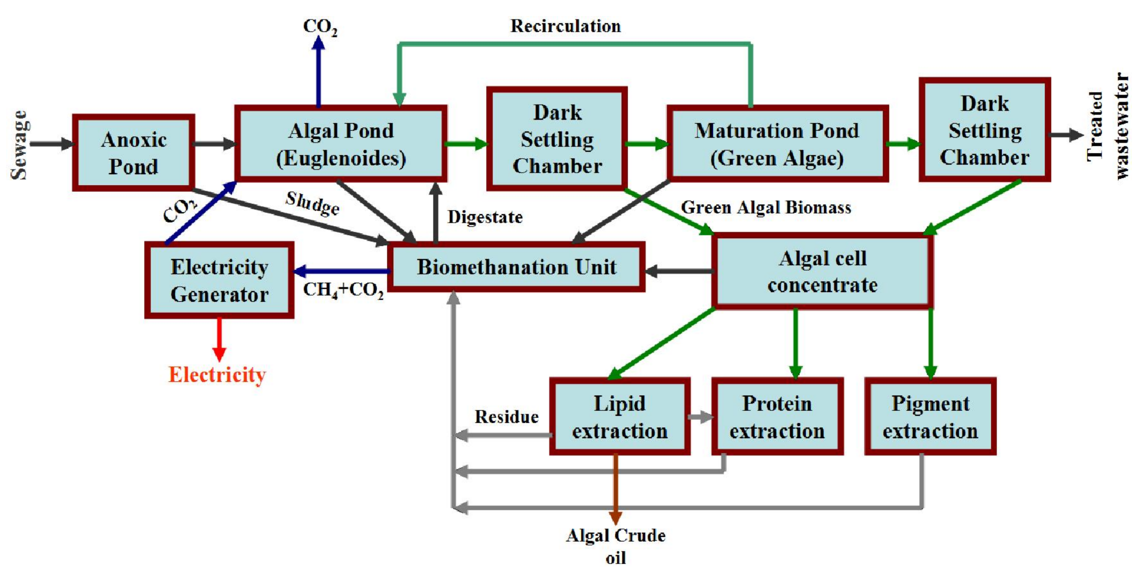

Figure 7. Process flow diagram showing a complete algal bio-refinery approach

4. CONCLUSION

Coupling algal wastewater treatment with biofuel production is a very attractive option for deriving bio-energy at low cost, reducing GHG emissions, nutrients (fertilisers for algal growth) and treatment of wastewater. The algal scums in surface waters is due to higher N and P in surface waters at C limiting conditions in the three valleys in Bangalore region. The mismanagement of nutrients has resulted in higher GHG emissions in the city accounting to 172 tonnes of N_2O/yr and 3,10,795 tonnes of CH_4/yr. The city wastewaters with a C:N:P ratio of 5:2:1 showed higher opportunities for algal treatment and subsequent algal harvest for biofuel production from wastewater algae. The algal blooms were found in regions with higher amm-N (~20-40 mg/l). The algal sp. being efficient devices for C capture were observed to transformed part of C into lipids in the wastewaters. The lipid accumulation in the cells was monitored through vibrational spectra obtained from ATR-FTIR analysis. The higher total lipid content was observed in *Chlorococcum* sp. (28%) that grows in obnoxious wastewaters in wastewater ponds and lagoons. Palmitate (C 16:0) was found out to be the most dominant among the analysed FAME. This analysis elucidated higher percentages of important fatty acids in the selected algal species that are necessary from biofuel combustion perspectives. With higher lipid content, a very high growth rate and having desirable fatty acids content wastewater grown algae found in ponds and lagoons are excellent substrates for biofuel/lipid production and can be used as a cost effective option for sustainable biofuel production. Renewable energy can be drawn consistently from the wastewater grown algae as higher biomass productivities gives a real potential as a feasible way of biofuel generation. This renewable algal biofuel can supplement to the present fuel needs for transports and can reduce imports fostering sustainability for the nation.

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