Integrating waste management with indigenous algal bio resource for socio-economic development

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1. Introduction

The haphazard discharge of both industrial and municipal wastewater is polluting the water bodies in the cities and towns of India. The surface pollutants present in the untreated sewage water percolates and pose great threat to the groundwater reservoirs. The vast amount of wastewater reaches untreated to our rivers, ponds and also to the agriculture land. This is alarming as the untreated gray water contain many hazardous and toxic elements way beyond their permissible limits. Once this contaminated water reaches our agriculture fields, the agri-products lose their naturalness which causes a cascading effect on both the livestock and fisheries. Therefore, not just human beings but the entire food web is affected.

The richness of freshwater algal diversity across the eastern and north eastern regions of Himalayas has been explored by many biologists. However, the tremendous amount of potential for such a vivid natural bio resource is hitherto untapped. Algal bio resource can support our environment in numerous and unimaginable ways. These mighty organisms are commonly called 'Pond scum' and looked upon as nasty and slimy growth in the water bodies that sometimes create nuisance in the forms of harmful algal blooms. Nevertheless, there are now ample of innovative solutions to convert the 'pond scum' into the future 'green gold'.

As a matter of fact, the freshwater bodies such as ponds play an extensive role in the socio-ecology of the regions in West Bengal and north east states.Interestingly, rich microalgal flora diversity has been described in the ponds found in the vicinity of the housing complexes of various districts in the state of WB[1, 2]. There is ample of untapped algal biodiversity in different ecological habitats of this state such as in Sunderbans[3]. On other hand, the North Eastern region is also regarded as centre of origin for many species. Sustainable and scientific bioprospecting of the rich repertoire of algal biodiversity is needed to boost the local economy while ensuring the conservation of bioresource.

2. Motivation/Problem(s) statement

2.1 Untreated wastewater menace

The fate of untreated waste waters is its discharge into our water bodies including rivers, community ponds, lakes and agriculture land. This create problem of pollution in both surface and groundwater resources that affect the entire life supporting ecosystem. At national scale, the amount of sewage generated is not being effectively treated (Fig 1) due to operational and maintenance problems of the existing treatment plants. It is worrisome that nearly 62% of the waste water generated goes to the environment untreated.

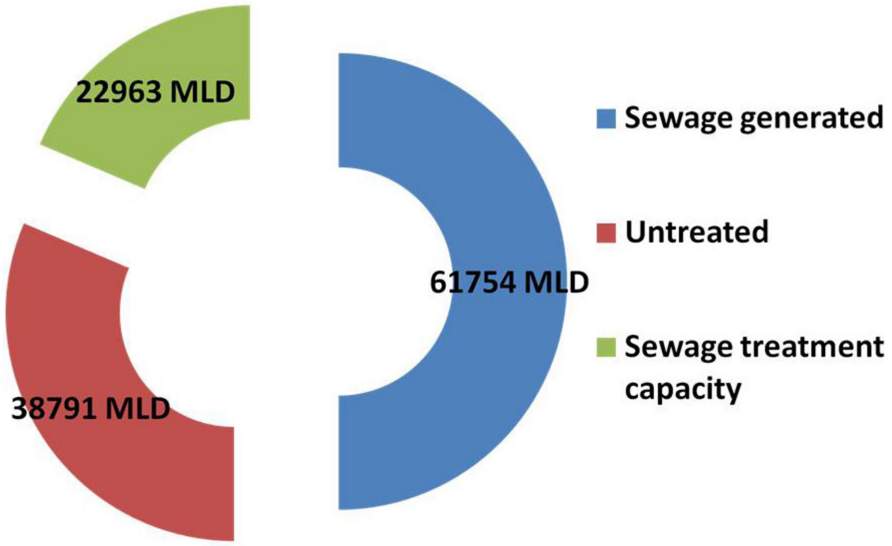

Fig 1. Sewage generation and treatment status in India.

Data source: ENVIS Centre on Hygiene, Sanitation, Sewage Treatment Systems and Technology,Ministry of Environment & Forests, Govt. of India)

It is worth noting that most of the north eastern states of India do not have any operational sewage treatment plants (Table 1). In the list of state wise percentage generation of sewage, West Bengal stands at the fourth place[4]. The north east region is one of the major biodiversity hotspot of India and many of its water bodies and wetlands are regarded as Ramsar sites. One of the world's largest and longest rivers which is also the major river of Central and South Asia has become a victim of untreated sewage waste as there is no treatment plant in Assam (Table 1). With profound grief, we are presenting the account of Bahini-Bharulu, a small tributary of Brahmaputra in Guwahati which has

Table 1 Urban sewage generation and treatment status in the north east states and West Bengal.

Sl. no.	State	Sewage Generated in millions litres/ day (MLD) in urban areas*	Total number of sewage treatment plants#	Number of operational Sewage Treatment Plants#	Treatment capacity of installed STPs (MLD)*
1	Arunachal Pradesh	50	NA	NA	–
2	Assam	703	1«	NA	0.21
3	Manipur	132	0	0	–
4	Meghalaya	95	1	0	1
5	Mizoram	90	1«	0	10
6	Nagaland	92	0	0	–
7	Sikkim	24	6	6	31.88
8	Tripura	154	1	1	0.05
9	West Bengal	4667	67	24	416.9

*updated 2018;
#updated 2020;
« update CPCB report 2016

Source: Government of India Ministry of Environment, Forest and Climate Change Lok Sabha unstarred question no.2541; Status Report, Central Pollution Control Board, Parivesh bhavan, Arjun Nagar, Delhi-110032; http://www.sulabhenvis.nic.in/database/stst_wastewater_2090.aspx

transformed into gangrene sewage canal due to lack of central sewage collection and treatment plant anywhere in Assam[5].

2.2 Water Security in India

Mushrooming and unplanned urbanisation raise the demand for fresh water for varied purposes including safe drinking water. On top of this, the major player determining the availability of potable water is climate change and global warming that would affect the spatio-temporal variations on the freshwater availability in many parts of the country. In this regard, the management of water pollution of both surface and ground water pose a greatest challenge. The clean water supply is necessary for both our health and the economic prosperity. The three deciding sectors of economic growth namely industrial, agriculture and domestic are totally dependent on the renewable supply of freshwater. On the contrary, the three sectors also are the major contributors of water pollution and lowering of groundwater. Hence, it is mandatory to replenish and sustain the vitality of our hydrosphere.

2.3 Untapped and threatened Algal Bioresource Of east and north east India

Algae are the primary producers of the aquatic food chain, the progenitor of multicellular land plants and even the source of fossil fuels. Apart from their aquatic habitats, algae can also be found growing on the forest tress, rocks and walls. In addition to the pristine environments, algae effortlessly grow in anthropegenically disturbed water bodies such as urban ponds that are fed with domestic waste water. Due to their diversified habitats, they play an integral role in maintaining the ecological balance. For example, algae safeguard the mangrove vegetation of the world including the Sundarbans in West Bengal[6]. Gloomily, the rare species of algae which have hitherto remained untapped have already become endangered due to climate change and changes in atmospheric temperature and increasing salinity[6].

3. Approach/methods

3.1 Database for the indigenous Algal biodiversity for Eastern and North eastern regions

It is needless to say that creation of a comprehensive database is inevitable because it is the first necessary step to explore the untapped potential of the available bio resource. The database formulation will give us an access to the collective knowledge on the vivid biodiversity and its status quo. Many species of algae act as indicator of the water quality and are therefore useful for bio monitoring of the freshwater bodies. The various anthropogenic activities such as agriculture run off, industrial and domestic wastes are leading to the disturbances in the ecological balance of these freshwater bodies, the main source of potable water. Hence, the database will provide a platform to identify various freshwater species of algae to allow their usage as bio indicators.

3.2 Utilization of the untapped algal bioresource to address the environmental crisis

North eastern region of India is considered as biodiversity hotspot comprising of diverse flora and fauna. This region forms one of the 12 mega biodiversity-rich zones of the world[7]. Several different kinds of freshwater bodies such as ponds, rivers and lakes are abundantly found in this region, which houses a wide-range of algal population. A wide occurrence of algae is encouraged by conducive climate of this region which involves a well distributed rainfall throughout the year with the least dry spells. However, an extensive research to exploit these algae is still underway and their true potential remains undeciphered. Out of the extensive spread of algae observed in north eastern and eastern region of India, few are referenced as following[7].

- Manipur – *Lemanea, Anabena, Nostoc, Calothrix marchia* and *Microchaeta uberrima*.
- Meghalaya – *Nostoc, Anabena, Calothrix, Westiellopsis, Gloeocapsa, Fischerella, Tolypothrix, Stigonema, Cylindrospermum, Loriella, Plectonema.*

- Assam – Several genera belonging to class *Bacillariophyceae, Chlorophyceae, Chrysophyceae, Cyanophyceae, Dinophyceae, Euglenophyceae, Xanthophyceae and Zygnematophyceae*
- Chandrapur near Guwahati in Assam – *Chlorella sp., Selenastrum sp., Scenedesmus dimorphus, Scenedesmus quadricauda and Desmodesmus sp.*
- Sikkim – Several genera belonging to class *Chlorophyceae* as well as *Spirogyra nitida, Netriumdigitus, Scenedesmus bijugatus, Staurastrum sp.*
- West Bengal – *Microthamnion, Chaetophora, Protoderma, Pearsoniella, Radiofilum, Cylindrocapsa, Microspora, Hormidium, Uronema, Ulothrix, Radiofilumconjuntivum, Schmidle and Microspora membranacea* [8].

Such enormous diversity of algae needs to be channelized for tackling few of the environmental issues such as waste water management. The north eastern region owns a very basic waste water management system. The algal potential for waste water treatment should be explored and implemented. Algae farmed on waste water not only removes the eutrophication causing nutrients such as nitrogen (N) and phosphorous (P) but also convert these elements to a wide range of bio-products obtained from its biomass.

4. Solutions/Recommendations

4.1 Sewage Wastewater treatment plant (STP) using algaebioresource- A win – win situation

A wide diversity of algae flourishing in the north eastern region can be employed for upgrading the conventional waste water treatment of the region. Microalgal coupled waste water treatment offers several benefits over the traditional process; such as low energy and operating cost, reduced formation of biological and chemical sludge, higher recovery of valuable metals from waste water, production of biomass for several applications, higher efficiency for removal of heavy metals, reduced release of greenhouse gases and reduced release of foul smell.

The microalgae-based waste water treatment involves the cultivation of microalgae on waste water (utilizing open ponds or closed systems) resulting into efficient removal of nutrients majorly, N and P from waste water and its assimilation by microalgae for their growth. Likewise, nutrients stripping phenomena also occurs, for instance, high pH induced by the growth of algae results into the ammonia volatilisation and phosphorus precipitation. Few of the research suggest a 90% of phosphorus removal due to this effect9. Microalgae-based system lowers the COD and BOD substantially. Additionally, tertiary treatment employing microalgae may uphold the heterotrophic growth in the secondary treatment by providing oxygen. Moreover, the increase in the pH during the photosynthesis has a disinfecting effect on the waste water. The cultivated algae are harvested to produce biomass, which is subsequently processed into bio-fuel, bio-fertilizers and several other valued bio-products. Thus, microalgal based waste water treatment is, not only more environmentally friendly as compared to conventional strategies but also provides beneficial bio-products which can sustain the process economically.

4.2 Harnessing the economic benefits of algal biomass derived from STP

The utilization of wastewater to produce algal biomass has been present since 1950s. The biomass produced is subsequently utilized for generation of bio-fuels. The lipids present in the biomass act as the precursor of bio-fuels. Once the lipids are extracted, the remaining biomass forms a high-quality fertilizers and animal feed. Similarly, the biomass under the anaerobic digester yields biogas – a renewable source of energy. Currently, an extensive emphasis is given on utilization of algae for obtaining several products due the following advantages of algae[10].

Higher development rate:

- The doubling rate of algae is few hours and can be cultivated effectively to deliver its biomass which is subsequently utilized further.

Utilizes CO_2:

- Algae being photosynthetic organism produce oxygen and absorb CO_2, hence mitigating climate crisis.

Ease of cultivation:

- Algae can be grown on any land which is not suitable for agriculture and in several water sources.

The Algal Industry is an intense job creating sector. The industry involves variety of strategies for cultivation of algae from open ponds to close photobioreactors, followed by several harvesting techniques, contributing to large employment. Likewise, several classified jobs such as engineering, research; marketing and financial services also advance.

4.3 Utilization of Microalgae–Bacteria Consortium for Treating Wastewater

The traditional wastewater treatment has several downsides, which are now eliminated using innovative techniques. Recently, the advantageous interaction of microalgae and bacteria has been explicitly utilized for the treatment of municipal and industrial wastewater. The microalgae – bacteria consortia serves a few advantages such as; (i) the cooperative interaction between these organisms enhances the nutrient uptake of the system. (ii) more resilient system against fluctuating environmental conditions. (iii) increased yield of algal biomass and the associated products (iv) enhanced CO_2 sequestration and (v) lower operating cost. Algal and bacteria synergistically impact each other's physiology and metabolism. There occurs a beneficial interaction between photo-autotrophic algae and heterotrophic bacteria regarding the exchange of oxygen and carbon dioxide. The heterotrophic bacteria consume the oxygen released by the photosynthetic activity of microalgae and utilize the oxygen for the degradation of organic compounds. This process eliminates the energy cost incurred for the mechanical aeration of the wastewater required for the nitrification process. Additionally, the release of carbon dioxide by the bacterial population is further consumed by the microalgae aiding the CO_2 sequestration while yielding intracellular lipids in the microalgae. Some species of bacteria can release hormones to promote algal growth. The process efficiently removes the nutrients from the wastewater thereby treating it with higher efficiency and resulting in higher algal biomass.

4.4 Community scale 'Algal farming' to promote socio-economic development

With its wealth of diverse algal flora, the North eastern region of India can play a major role in algal farming and can become a leader in this sector. With the algal data base of indigenous strains in place, it will be possible to set up community driven algal farms which will prove to be a promising opportunity for uplifting the livelihood of the local communities that inhabit these areas. This low-cost occupation involves manual labour and can sustain the entire family, including women, thereby not only helping the families' earning potential, but also supporting the community's holistic economic status. While over harvesting naturally present algal flora may lead to over exploitation, as with any other natural resources, community farming with the right choice of algae has no negative impacts on the natural environment. Such algal farms can be used to grow some potent strains of cyanobacteria and green algae as a source of biofertilizer [11a, b], biodiesel[12, 13,14] or some species which are high in protein content or other bio actives for animal feed/aquaculture.

The cyanobacterial fertilizer production begins with cultures which are seeded in shallow ponds and are ready to use a few weeks later. To make the whole process even more economic, there are many inexpensive methods that can be employed such as the trough method, pit method, field method or even shallow waters of rice paddy fields can be used which is a natural habitat for microalgal growth. A simple nursery method for vegetative multiplication of algaecan be developed for an easy, large-scale production of efficient N2-fixing cyanobacterial biofertilizer to be adopted by the farmers [15, 16]. The use of wastewaters or user soils can further lower the cost of cultivation [17, 18].

Once the algae grow to sufficient biomass it can directly be added to the agricultural fields as liquid culture or air dried into flakes and then sprinkled on the field where they develop into colonies coming in touch with soil and water. This algalization technology is not only beneficial for rice paddy but also for a variety of vegetables and other plant[19]. These algal farms will act as a C sink from the surrounding atmosphere and play a big role in enhancing soil fertility and produce other beneficial effects on the rice/paddy plant/soil system, such as excretion of organic acids that increase P-availability, provision of nitrogen by biological nitrogen fixation, increased soil organic matter, production and release of bioactive extracellular substances that may influence plant growth and development. These have been reported to be plant growth regulators (PGRs), vitamins, amino acids, polypeptides, antibacterial or antifungal substances that exert phytopathogen biocontrol and polymers, especially exopolysaccharides, that improve soil structure and exoenzyme activity.

Likewise protein rich, lipid rich, carbohydrate rich and algae rich in other bioactive compounds can be grown on artificial shallow ponds in this area which can be harvested for animal feed and fish feed and biofuel if needed.

4.5 Engaging small scale aquaculture enterprises to reap the benefits of algal as biofeed

Fish farming, or "aquaculture," has become a billion-dollar industry, and more than 30 percent of all fishes and sea animals consumed each year are now raised on these farms. Aqua culture based on algal biofeed therefore maybe a potential way for socioeconomic development of the north eastern region of India where fish is a favourite choice[20].

Beneficial ingredients from microalgae for aqua feed is attractive from a market point of view in terms of low-cost input, foot prints, carbon credits, waste water remediation. As of date a handful of ingredients from a few microalgae are recognized to be able to supply well balanced nutrients and immunostimulatory compounds. Analyses from varied sources have shown the biochemical composition of these few microalgae maybe promising candidates for aqua feeds based on their supply of well- balanced amino acids, essential omega -3, long chain polyunsaturated fatty acids, vitamins, minerals, carotenoids, and other bioactive compounds.

Another novel approach to address aquaculture is to consider rice- algae -animal co-culture as an important way to improving the socio-economic status of farmers by efficient use of available resources and obtaining aquatic animals as surplus money providers with rice crop. Co-culture of rice and aquatic animals, with added algal strains that combines animal production (e.g., fish, shellfish, crab, shrimps, and ducks) in paddy rice systems, has been suggested as a strategy to improve the utilization of land and water resources to provide both grains and meat to humans, while reducing the risks of environmental pollution associated with rice production[21]. In recent years, co-culture systems have gained increasing attention as they can potentially help to alleviate the pressure of food and environmental insecurity. Aquatic animals in rice- algal-animal co-culture systems can reduce CH_4 emission by oxidation facilitation due to addition of NH_4^+-N from algal nitrogen fixation. Aquatic animals can enhance the gaseous exchange in soil environment that will increase its redox potential. Eventually, the increase in redox potential can decrease methanogens activities that directly reduce CH_4 emission[22, 23, 24].

Also, fish culture can be done in small ponds with added algae to generate the local strain of fish with a huge market. Local fish growers can be educated to use this technique. Algae driven aquaculture include fish farming, shrimp and oyster crab farming and algae culture (production of selected strains of algae for commercial use). The fish produced because of aquaculture are high protein food source.

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