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Mitigating the impacts of drought via wastewater conversion to energy, nutrients, raw materials, food and potable water.

Simrat Kaur, Fatema Diwan, and Brad Reddersen[1]

[1]*Climate Survival Solutions India, Pvt Ltd, Siliguri, West Bengal, India, and Climate Survival Solutions, Inc.*

Abstract

Water management has become extremely challenging due to worst impacts of the climate change on the hydrological cycle due to unpredictable precipitation patterns. The harsh reality in some parts of the world today is that the daily showers and flushing of the toilets with the potable water has become unaffordable. Many cities in the world are facing the 'Day zero' when millions of settlers are without adequate water both for households and industries.

This scarcity is driven by ill-management of water resources by multiple parties, vulnerability to climate change, and the fast pace of economic and population growth. The single-biggest user of water worldwide is agriculture, followed by energy production, industry, and in last place household use. The climate crisis has multiple impacts, including from increasing heat and rising sea levels tied to global melting of the cryosphere. The draining of the aquifers and related saltwater intrusion from the oceans are already depleting freshwater resources at an increasing rate. While freshwater can be sourced via desalination, that path is expensive and energy intensive, effectively countering much of the good it might offer.

It is for this reason efficient treatment and reuse of wastewater is the current best hope to mitigate this global crisis. Agriculture-based economies which are exporting "virtual waters" must increase the share of wastewater to meet their internal needs. This is even more imperative for the world's most populated countries, India and China, as they work to stay the water scarcity crisis within their own lands. Besides that these countries will benefit from just water resource alone, building into the process an energy recovery capability helps achieve sustainability in the water reclamation process.

This paper presents how wastewater can be channelized into green energy resource such as biogas, microbial fuel cells, and biodiesel; and how it is transformed into various bio products, nutrients, food and potable water in order to combat severe impacts of droughts. Furthermore, even while it has become the norm to measure carbon footprints to minimize global heating aspects of production and consumption, we propose instituting the new concept of calculating the "water footprint" for each of our future actions. This footprint includes consideration of what are referred to as green, blue and grey water, as they related to intake from precipitation, the surface or groundwater, and polluted water at the point-source as well as runoff. Understanding of the water footprint is not only relevant for government bodies, policy makers and industry, but also for us as individuals within our communities. Doing so could help transform our total available supply of water for all uses. It could also shift our thinking of water as something we consume to something which is genuinely renewable.

Keywords

Biorefinery; Climate Change; Circular economy; Drought; Green energy; Mitigation; Wastewater, Water footprint

1. Introduction

The 'Blue Planet' has plenty yet vastly unavailable amounts of water on its surface. As considerably large fraction (96.5%) which is present in the oceans is unsuited for consumption by the freshwater beings. The 70% of the remaining 2.53% freshwater resources is blocked in the snow packed glaciers, polar snow covers and permafrost (Shiklomanov, 1990). Therefore, only a meagre portion of about 1% freshwater is available for consumption by the freshwater organisms. Apprehensively, by the end of 2100, the active glaciers which store hydrologically valuable solid water or permafrost are expected to vanish because of the rate at which they are declining due to global warming (Wagner, et al., 2021). With unprecedented socio-economic advances and rapidly growing human and livestock populations along with drastic loss of freshwater biodiversity and disappearing global wetlands; we are thickening our water footprints (Albert, et al., 2021). The rate of water withdrawal is more than the rate of replenishment of freshwater in the aquifers and ground waters. More than 50% of world's largest rivers have witnessed the reduction in stream flow (Albert, et al., 2021). According to an estimate, the rate of water withdrawn is likely to increase by 50% in developing countries and by 18% in the developed countries by 2050, creating more water deficit that will push two-third of the world's population towards water crisis (Pal, 2017). The defined factors responsible for global water crisis are over exploitation of aquifers, domestic and industrial pollutant discharges into the rivers, intensified groundwater extraction, degradation of upstream ecosystems, old infrastructure causing leaks and losses, sewage seepage to the groundwater, saltwater intrusion due to sea level rise, in-efficient water use policies such as no user charges, rapid urbanization, climate change and drought (Ghosh & Ghosh, 2021).

The drought resulting from the water deficit is an outcome of various climatic and anthropogenic processes. The severity and longevity of drought due to atmospheric and climatic events is driven by the changes in surface sea temperatures (SST) which has global impact. The oceans play an enormous role in the regulation of Earth's climate by absorbing and redistributing the solar heat energy via oceanic currents. Pacific Ocean which is world's largest contain more than 50% of the free water, play an influential role in bringing mega decadal droughts. The regional dry spells in many parts of the world are highly driven by the dynamics of atmospheric and surface ocean phenomena. For example, the strong El-Niño events were found to be associated with the dry years in the North East Brazil (de Medeiros & Oliveira, 2021). A very recent global hydroclimate reconstruction study based on the climate model derived from the assimilation of archival and paleoclimate proxy data established the co-occurrences of the El Niño/Southern Oscillation or ENSO events and the coupled megadroughts in North American Southwest and South American Southwest (Steiger, Smerdon, Seager, Williams, & Varuolo-Clarke, 2021). The strong El-Niño event in United States in 1998 was followed by the rapid emergence of drought which subsequently caused wildfires in Florida and million dollars of agricultural losses in many southern states (Wilhite & Svoboda, 2000).

Apart from Pacific Ocean, the SST anomalies on the two sides of the Indian Ocean create a climatic phenomenon called Indian Ocean Dipole (IOD) which has historically influenced the Australia's worst drought events. The deprivation of normal rainfalls and the many multiyear historical droughts in southeast Australia including the 'Big Dry' or the Millennium drought that lasted from 1996 to 2012, has been attributed to the lack of the negative phase of IOD (Ummenhofer, et al., 2009).

The damages caused to the communities and environment by the droughts are massive and irreversible. The extreme deficiency of the water during the drought has significantly pushed the world towards adopting treated wastewater as the source of freshwater. The wastewater serves as a potential candidate to be converted into a source of energy. Significant progress in energy-producing systems such as biofuel, microbial fuel cells, biogas production has suitably used the wastewater as a substrate to obtain renewable energy. The wastewater can be significantly converted into energy through the process of "anaerobic digestion" (generation of biogas) and "transesterification" (generation of biodiesel). The energy recovery from the wastewater forms a crucial component in achieving sustainability in the developmental plans for alleviating climatic stresses such as drought and formulating a better future. The wastewater treatment provides the most vital portion – the sewage sludge, which is largely utilized as the feedstock for anaerobic digester to produce "biogas", which after further processing acts as a decent source of heat and electricity. Furthermore, the sewage sludge provides an excellent source for the growth of oleaginous organisms producing lipids which by transesterification technology is converted into biodiesel. The biodiesel hence obtained can be employed as green fuel in automobiles. The process of conversion of wastewater into a valuable source of energy also includes the microbial fuel cell (MFC) which utilizes the electrogenic nature of certain bacteria to simultaneously treat the wastewater and produce electricity.

The wastewater treatment plants have become an inseparable part of our society now, as they not only treat the wastewater, which is highly recommended prior to its dumping in the aquatic bodies but also provide energy. The additional energy generated shall be further utilized to compensate for the reduction in energy production due to the disruption of hydropower stations with the advent of droughts. The wastewater conversion system provides a decent answer to overpopulation, extreme scarcity of fresh water, and climate crisis. The paybacks of wastewater conversion to energy are tremendous including energy production for supporting the expanding cities and their energy needs; cheap, renewable, and affordable methodology for the production of energy; harnessing of methane which is considered 30 times more potent than carbon dioxide as a greenhouse gas; reduction pollution due to dwindling need of incineration of the waste and economic benefits from the sale of gas and solid digestate. Several innovations and thoughtful practices in terms of the economic feasibility of water conversions shall aid the mitigation of droughts and supports the waste -to- resource technology. Several innovations and thoughtful practices in terms of economic feasibility of water conversions shall aid the mitigation of droughts and supports the waste -to- resource technology.

2. Biography of drought

Drought is complicated and multidimensional phenomenon which considers various physical phenomena such as rainfall pattern, humidity, and rate of evaporation. It is a creeping phenomenon as the effects of drought persists for longer period even after the culmination of actual drought event (Wilhite & Svoboda, 2000). Droughts are defined as the abnormally long period of acute shortage of water with below normal levels of precipitation. They are one of the grave outcomes of global climate change. The most imperative impact of droughts is the invalidity of water and the high-water stress index. Apart from causing direct impact, drought imposes many secondary impacts such as famines, epidemics, wildfires, etc. It possesses the potentiality of causing huge economic loss which robs the region of its basic amenities for survival. The exploration and innovations in the field of science and technology have still not safeguarded humans from the devastating impacts of droughts. Understanding drought and its causes open the doors to design the mitigation strategies and plan out the way forward to combat the drought which is to stay with us for a considerable long period. Drought has impacted around 30% of the world's population, i.e. 2.5 billion people reside in dry areas and are facing the ill impacts of droughts on regular basis. The droughts can be appropriately differentiated into natural droughts (majorly caused due to environmental factors) and anthropogenic droughts (caused due to human-induced environmental modification). The anthropogenic droughts are of major concerns as they could be easily be avoided by following several thoughtful practices and evading the exploitation of nature by humans. The population explosion in both developing and developed nations with increase in living standard aggravates the anthropogenic droughts due to high demand and limited water supply. For instance, the population increase in California over the past century has induced the development of major infrastructure and water transfer projects. Extensive research and exploration are necessary to formulate a detailed system for assessing the impact of anthropogenic droughts on the natural ecosystem and wildlife. This becomes very essential for the sustainable development of the environment and socio-economic gains. A conjugated team of scientists, researchers, and policymakers should be involved for this purpose.

3. Impacts of drought on various sectors

The drought has equally and substantially impacted many sectors. The ripple effect created by the dry condition can impact the entire nation as agriculture and industrial economies are interconnected. The ill effects of drought on few of the sectors are discussed.

3.1 Socio-Economical

Droughts lead to shortages of the domestic supply of water and thus, directly impact the socio-economic framework of the society. The major water-dependent economic sectors such as irrigation, hydroelectricity production, and agro-industries face severe losses due to water shortage. Likewise, the capital invested for the implementation of a mitigation plan and to alleviate the impacts of droughts contributes to the economic cost of drought. There occurs the competition among the different sectors as the water becomes scarce. The tax revenue tends to decrease due to the decline in income, employment, and export (Chand & Biradar, 2017). Similarly, the rise in crime due to provisional unemployment, migration, and increased poverty imparts huge pressure on the law and order services of the nation.

Agriculture is the major sector impacted by the droughts due to water scarcity and alteration in the soil parameter. This is an input-intensive sector (in terms of hybrid seeds, modern irrigation, and farming techniques) that increases the initial investment of the farmers, which is generally credit-based. The farmers facing the loss of crop yield are incapable of repaying their loans and get trapped in the vicious poverty circle. Acute water shortage and limited intake of food have severe effects on the human health causing malnutrition, anxiety, depression, respiratory disorders, infectious food borne diseases caused by Escherichia coli and Salmonella. The limited availability of food resource, and reduction in the daily intake of essential minerals (such as calcium) and vitamins (vitamin B1 and vitamin A) further deteriorate human health. The livestock rearing sector is equally impacted by the droughts. The droughts substantially reduce the grazing land for the livestock. The farmers are compelled to feed their livestock on the roadside growth of weeds and field bunds. The partial loss in crops (i.e., the stunted crop yield) is also fed to the livestock. These practices adversely impact the health of the livestock leading to extremely low production. Likewise, the acute shortage of water makes it unavailable for the livestock. In many cases, contaminated water is utilized for the drinking purposes of livestock, which makes them prone to many diseases. The innovations in developing alternative livestock feed from waste water are discussed in later sections of this article. The drought distress also induces the sale of the livestock at marginal prices. There occurs migration on large scale from the rural areas to the urban settlements in search of jobs. Many farmers and laborers seek low-skilled jobs in the cities and are economically exploited. The younger generation of the society, i.e. the schooling children are robbed of their basic right of schooling as the schools and other educational institutes cannot cope with the water crisis. The reduction in the size of water bodies and water stagnation act as the breeding grounds for a certain type of mosquitoes and increasing the incidence of vector-borne diseases. The extreme shortage of water has adversely impacted and reduced the recreational activities in the water bodies. The socio-economic setup is intricately balanced with the environmental parameters that are quite vulnerable to the changes in the availability of environmental goods and services.

3.2 Environmental

Drought affects several components of ecosystems and the environment. There occurs a drastic reduction in the water levels of the wetland areas (such as lakes, rivers, and ponds) along with a reduction in the groundwater levels. Even the aquifers are not replenished, which dries them up. The droughts effectively reduce the soil moisture contents. Additionally, biodiversity entirely depends upon the environment for the supply of water. The intensity and the scale of drought may cause permanent and temporal impacts on biodiversity. The unavailability of water and food (during the droughts) alters the supply of food to different life forms, subsequently altering the food web (Kala, 2017). Likewise, the distribution of the species is also adversely impacted. The species having a narrow distribution range and low population size will decline further due to droughts. There occurs a loss of aquatic communities due to reduced and altered water flow, accumulation of pollutants, higher water temperatures, and reduced concentration of oxygen. The elevated temperatures melt the glaciers and reduce the size of glaciers. This in turn lowers the availability of water in the river basin over a period. The unexercised withdrawal of groundwater causes it depletion and other ecological disturbance such as land subsidence. The quality of the air reduces due to the abrupt and extensive increase in the level of dust and chloride levels during the drought. These impacts disseminate even in the areas having moderate dry conditions. The elevated levels of temperature and acute water shortage are disastrous for all the natural ecosystems that disrupt the natural balance of the environment.

4. Drought mitigation measures

The only way to combat the severe water crisis and drought is to conserve the available fresh water. There are numerous ways to conserve water at social levels.

4.1 Recycling of water

The water can be conserved at the individual level by recycling the indoor and outdoor waters. The recycling is done by installing a grey water recycling system. The wastage of water can be minimized in bathrooms, kitchens, and laundry. The efficiently serviced leaks in the plumbing system prevent considerable amounts of the water loss. Few stringent conservational goals (for example, utilization of only 40 gallons of water per person per day for indoor water uses in the US) should be implemented. The drip irrigation system should be used for irrigating the landscaping. Additionally, rainwater should be harvested for landscaping. The wastage of water can also be minimized by employing an adjustable nozzle or sprayer to regulate the water flow during the washing of vehicles.

4.2 Ways to enhance soil-crop efficiency and reduce water demand in agriculture

Agriculture is the major economic sector that use maximum amount of freshwater resource and which is equally responsible for polluting vast amounts of water. Water conservation in agriculture can be achieved by implementing well known traditional practices and by adopting innovative measures. Conventionally, the well-structured soils with high infiltration rate can substantially conserve water in agricultural farming. The improvement in soil's physical and hydraulic properties by the application of polyacrylamides minimizes soil erosion (Kebede, Tsunekawa, Haregeweyn, Mamedov, & Tsubo, 2020). The newer techniques such as laser leveling off the field boost uniform infiltration and decrease the runoff. The selection and cultivation of native drought-tolerant plants requiring less water is also a critical factor in the water conservation at regional levels. The traditional method of cover crops plantation to trap the surface water reduces evaporation and runoff. The tailwater (i.e. water that drains to the lower sections of fields) must be recycled back in the fields. The most efficient way to conserve water in agriculture is capturing rainwater and storm water for irrigation and other purposes. Apart from implementing these best farming practices; the novel agrivoltaic systems wherein the photovoltaic panels are mounted within the agricultural fields to perform dual functions of electricity generation and food production, have the potential to reduce water demand along with the improved water productivity of crops such as tomatoes (AL-agele, Proctor, Murthy, & Higgins, 2021).

4.3 Industrial water use efficiency

The manufacturing industries, such as food, chemical, paper, petrochemical refinery are required to recycle and reuse the water efficiently. Government and other organizations can provide financial incentives to the industries to establish water-saving practices. The industries should undertake water use or water footprint assessments to represent their pressure on surface and groundwater resources taking into account the units of water used and polluted. Currently, the best approach to lower the impact of industries on water resources is to create circular economy of water (Sauv´e, Lamontagne, Dupras, & Stahel, 2021) based on the treatment and reuse of grey or polluted water in parallel sectors of the economy. The grey water footprints of the raw industrial effluents decrease with each level of treatment and eventually become negligible when the tertiary treated waste water is reused as means of irrigation (Lahlou, Mackey, & Al-Ansari, 2021).

4.4 Role of public education and awareness

Public awareness and education play a vital role in the conservation of water in different sectors. Public awareness and education can be achieved by conducting awareness campaigns on the conservational techniques and the existing regulation for the management of the coastal areas and ocean environment which supports the economic gains of the country (Kumari & Singh, 2016). The opportunities for interaction between the communities, policymakers, regulating agencies, NGOs, researchers, etc. must be developed and improved. The tools used for policies and decision-making should be improved, that would further enhance the abilities of the professionals, government, and non-government organizations to conduct regional and community level action programs.

5. Green wastewater conversion technologies

The global water scarcity crisis and ever-expanding grey water footprint across the planet has triggered the developments and redevelopments of waste water treatment technologies that integrate biological systems to additionally harness various forms of green energy and bioproducts.

5.1 Microbial fuel cell (MFC) technology to harness green electricity

MFC represents one breakthrough development in the wastewater treatment process that directly generates bio-electricity. Diverse forms of wastewater provide substrate to the MFC which operates on the catalytic conversion of organic waste to electrical energy using complex microbial communities (Agrawal, Bhardwaj, Kumar, Chaturvedi, & Verma, 2019). The MFC comprises of an anode (in an anaerobic environment) and cathode (in the aerobic environment), separated by a cationic selective membrane and linked together with an external conductor through a load. The input of organic fuel from the wastewater into the anodic chamber (comprising of microbes) results in the oxidation of the substrate by microbes to generate ATP that fuels the cellular machinery forming electrons, protons, and carbon dioxide as the by-products. The electrons produced pass from the anode to the cathode through an external load connection, generating an electric current. At the same time, the protons migrate to the cathode chamber from the anode chamber freely through the protonic selective membrane separating the two chambers. Several variants of MFCs can be possibly used such as the double-chambered biofilm MFC. A typical double-chambered biofilm MFC with reactions occurring at anode and cathode is shown in Figure 1.

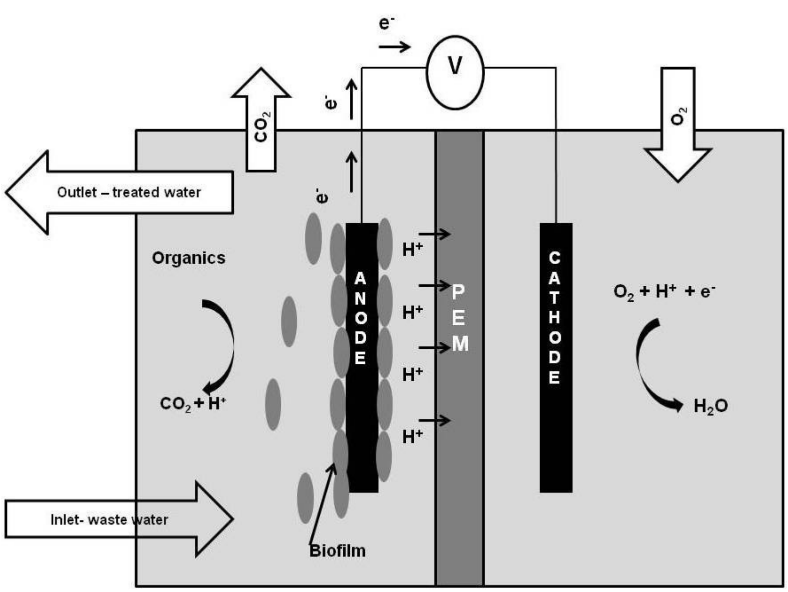

Figure 1. A typical double-chambered biofilm MFC

The reactions occurring at anode and cathode are using a typical example of acetate as a substrate is as mentioned in figure 2.

$$\textbf{Anode reaction: } CH_3COO^- + H_2O \xrightarrow[\text{Anaerobic environment}]{\text{Microbes}} 2CO_2 + 7H^+ + 8e^-$$

$$\textbf{Cathode reaction: } 2O_2 + 8e^- + 8H^+ \longrightarrow 4H_2O$$

$$\textbf{Overall reaction: } CH_3COOH + 2O_2 \rightarrow 2CO_2 + 2H_2O + \text{Electricity}$$

Figure 2. Reactions occurring at anode and cathode (using acetate as a substrate)

As observed in the reaction, along with electricity, carbon dioxide and water from the substantial by-products of the reaction.

MFC anode:

The anode present in the anodic chamber forms a confined area for microbes, which forms the biofilm on the surface of the anode. The fuel cell's activity relies on the number of bacteria occurring on the anode, and thereby, on the surface of the anode. For optimum performance, an appropriate selection of electrode material is a mandate which facilitates bacterial adhesion, electron transfer, and electrochemical efficiency. Several carbon-based electrodes are utilized including carbon paper, carbon fiber such as carbon-nanotube-based composites to obtain the maximum power yield. Furthermore, the utilization of bamboo charcoal has displayed satisfactory outcomes, illustrating all the required characteristics of an ideal anode. A few supplementary advantages of bamboo charcoal involve; rapid growth, lower manufacturing cost, minimum carbon footprint, reuse, and easy disposal. (Sato, Paucar, Chiu, Z. I. M. Mahmud, & Dudgeon, 2021)

MFC cathode:

Cathodes are involved in the reduction of oxygen to water and materials selected for the construction of cathode must facilitate the reaction. Platinized carbon cathodes can be generally utilized in MFC. The high cost of Pt is usually replaced by nonprecious electrodes like Mn_2O_3, and Fe_2O_3.

The oxygen (electron acceptor) present in the cathode chamber combines with hydrogen ions and electrons to form water, hence completing the reaction. This reaction can be significantly facilitated by a catalyst such as platinum

A few examples of microbes utilized in MFC are *Pseudomonas aeruginosa, Escherichia coli Shewanella sp., Nocardiopsis sp., Streptomyces enissocaesilis , Geobacter metallireducens , Enterococcus gallinarum, Leptothrix sp., Brevibacillus agri, Vibrio sp, Pseudoalteromonas sp. Shewanella oneidensis , Clostridium cellulolyticum ,Geobacter sulfurreducens ,Cupriavidus basilensis , Pseudoalteromonas sp., Marinobacter sp., Oseobacter sp., Bacillus sp., Thiobacillus ferrooxidans , Klebsiella variicola , Methanocorpusculum ,Mycobacterium, Enterobacter, Stenotrophomonas, Enterobacter cloacae, Staphylococcus sp., Virgibacillus sp., Aeromonas hydrophila*. (Agrawal, et al. 2019)

The applicability of the MFC is still a matter of extensive research and development as long-term future goals. However, currently, few of the applications of MFC include wastewater treatment, seawater desalination, hydrogen production, source of power, and as remote sensors. The MFC treated wastewater can likely be used for irrigation purposes to compensate for the scarcity of water during the drought. The potential use of MFC is a reclamation of wastewater for irrigation and electricity production. The MFCs have illustrated a high degree of potentiality in terms of treating not only the wastewater from the household but also from several different industries. For instance, double-chambered typical MFC illustrates the percentage of COD removal from chemical wastewater and food leachate of 63% to 85% respectively (Kumar, Singh, & Abd Wahid, 2017). Likewise, the wastewater rich in organic materials such as carbohydrates, proteins, lipids, and fatty acids acts as an optimum substrate for the metabolism producing electrons and protons and further improving the efficiency of the production of electricity. Furthermore, the removal of COD is assisted by the mesophilic temperatures as well as the fed-batch mode. Several studies have shown not only bacteria but even algae can produce with the same efficiency in the MFCs. (Ghazi & Saleh, 2020) . MFC is beneficial in drought-prone regions where electricity costs are skyrocketing, and therefore, the technique could be more economically feasible than conventional wastewater treatment.

The utilization of MFCs as biosensors serves as a pollution detector in water, which can be united with the wastewater treatment process. The MFC-based biosensor displays several advantages over the conventional biosensors in terms of cost, maintenance, shelf-life, stability, and reliability. (Kumar, Singh, & Abd Wahid, 2017) .

Several upsides of MFC include; Generation of energy from organic waste, direct conversion of substrate to electricity, low production rates, reduced emission of GHGs, self-generation of microbes, resistance to environmental stress, and low carbon footprint. These are the crucial advantages to mitigate the climate crisis.

However, additional understanding and knowledge for scaling up the MFC system are needed to overcome the challenges occurring due to unstable bacterial biofilm formation, low power density in the case of low organic input, high cost of selective proton membrane with low efficiency of proton transfer, and lack of durability and strength of electrodes (Shiong Khoo, Yi Chia, Tang, & Loke Show, 2020) The MFC parameters are needed to be adjusted with the different types of wastewater for its adequate treatment.

5.2 Wastewater as renewable resource of biofuels

With the ever-increasing consumption of fossil fuels and constant reduction of their quantities from the earth, a shift to cleaner and greener energy becomes quite essential. One of such alternatives to fossil fuels is the generation of biofuels (biodiesel) from the wastewater to fulfill the demands of fossil fuels. The first-generation biodiesel uses virgin edible vegetable oil such as soybean, rapeseed, sunflower, palm, and coconut oil as feedstock. The second-generation biodiesel utilizes jatropha, castor, neem, tobacco, and rubber seed oil, which decrease the dependence on edible oils. However, the third generation of biodiesel eliminates the drawbacks of both, the first and second generation of biodiesel majorly in terms of arable land and cost. It involves the production of biodiesel by utilizing the microbial lipids extracted from bacteria, yeasts, microalgae, and fungi.

In the wastewater treatment process, sewage sludge forms an imperative component. The types of sludge produced during the wastewater treatment include the primary sludge (a blend of organic and inorganic matter with a gas bubble trapped within the suspension) and the secondary sludge also termed activated sludge (comprising of the microbial cells and suspended solids generated during the aerobic biological wastewater treatment) (Cea, et al., 2015). The heterotrophic microbial population of activated sludge consumes the organic compounds of the wastewater (hence, treating it) to grow and convert them into high-energy storage carbon compounds such as triacylglycerol (TAG). The TAG is generally synthesized by oleaginous species belonging to the order Actinomycetales (e.g. *Mycobacterium, Streptomyces, Nocardia, and Rhodococcus)* and green microalgae to yield biodiesel. Microalgae are cultivated in a specialized algal pond to yield biodiesel. These ponds aid the treatment of wastewater and cultivate microalgae. These organisms can accumulate the lipid to around 20% of their biomass. The accumulated lipids can be then be extracted by various extraction methods. The extracted lipids (from microalgae and microbes) are then trans-esterified in the presence of short-chain alcohol and in presence of an acidic or basic catalyst to produce biodiesel. The reaction involving transesterification is depicted in figure 3.

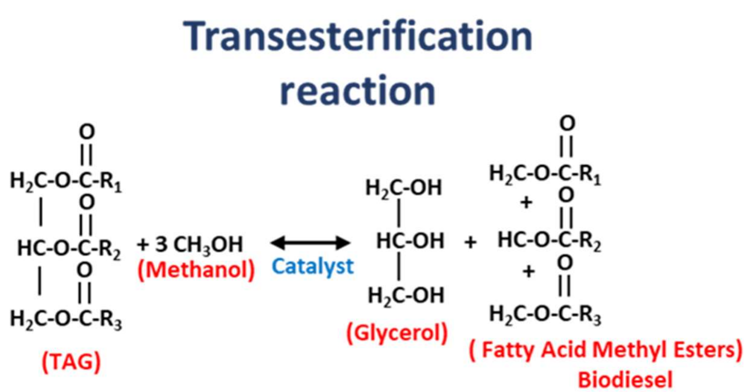

Figure 3. Esterification reaction yielding biodiesel

Various methods for lipid extractions involve, ultrasound, microwave, supercritical fluid extraction, agro-solvent, accelerated solvent extraction, enzyme-assisted extraction, instant controlled pressure drop, pulse electric field, etc. (Meullemiestre, Breil, Abert-Vian, & Chemat, 2015). The obtained biodiesel is further subjected to purification to obtain the end-product.

A few of the advantages of utilization of microbes for the production of biodiesel include; utilization of the sewage sludge, elimination of arable land for the cultivation of feedstock, the rapid doubling time of microbes, low energy requirements, efficient bioremediation of the wastewater, and reduction in the waste generated. However, the stringent growth requirements, sophisticated extraction techniques, and easy contamination of the system lead to further exploration and development in this sector.

5.3 Wastewater sewage sludge to biogas

Biogas is generated by the anaerobic digestion of organic matter such as sewage sludge, animals, and municipal waste (Demirbas, Taylan, & Kaya, 2016). Treating the wastewater to obtain energy and other valuable products aids the economic gains during the tough times of droughts. The valuable products include the "residue" of the digestion termed as "digestate", which can be further utilized as soil conditioners to improve the fertility of the soil. Biogas forms a vital source of energy in heat and electricity generation along with being the worthiest renewable source of energy globally. The biogas comprises of methane (55-60%), carbon dioxide (35-40%), hydrogen (2-7%) hydrogen sulphide (2%), ammonia (0-0.05 %) and nitrogen (0-2%).

Conversion of organic matter (sewage sludge) into biogas through a series of reactions (Figure 4) accomplished by several groups of bacteria in an anaerobic condition (anaerobic digestion). A device offering a conducive environment for organic feedstock conversion into a gas (biogas) through a procedure known as anaerobic digestion is referred to as "Anaerobic Digester". The anaerobic digester functions on the step-wise reactions occurring during the degradation of organic waste by the specified group of microorganisms – the anaerobic digestion (Abbasi, Tauseef, & Abbasi, 2012).

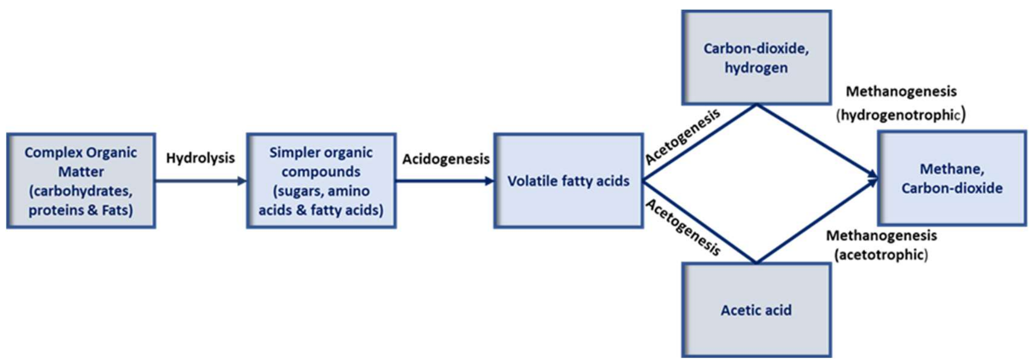

Figure 4. The series of reactions occurring during anaerobic digestion.

The process initiates with the pretreatment of sewage sludge from primary and secondary water treatment. Prior to entering the anaerobic digesters, the sludge undergoes sieving followed by thickening to adjust the dry solids up to 7% to evade the very high consumption of energy for heating due to excessive water content. Once inside the digester, the feedstock (treated sewage sludge) is acted upon by a wide array of microorganisms to degrade the organic matter, with a retention time of 20-60 days and with mesophilic temperature ranges. The biogas obtained at the end of the process largely comprises methane and other gases**.** The methane is purified through a scrubbing process that removes other gases. The purified methane can be combusted in the combined heat and power (CHP) plant to produce electricity and heat simultaneously. The production of biogas from the wastewater fills in the gap created between the demand and supply of electricity due to droughts. The biogas-powered cogeneration units contribute up to 60% of electricity demand while generating surplus heat. (Masłoń, 2019)

Biogas provide an economical clean, green, and renewable source of energy (Figure 5) which is widely used in many parts of the world. Some of the microorganisms involved in each stage are: acidogenesis micro-organisms such as *Bacteriods, Clostridium, Butyrivibrie, Eubacterium, Lactobacillus, Bifidobacterium;* acetogenesis - *Desulfovibrio, Syntrophobacter, Wolinii, Syntrophomonas* and methanogenesis- *Methanobacterium, Methanosprillum, Methanosarcinae.*

Figure 5. Advantages of Biogas.

The production of biogas through anaerobic digestion aids the production of digestate that discovers its place as enriched fertilizers that efficiently reduces the usage of chemical fertilizers. This technique allows significant utilization of wastewater to produce electricity, which otherwise gets dumped in the aquatic bodies leading to aquatic pollution. Likewise, the revenue generated from the sale of electricity and digestate serves as an added advantage during droughts. However, the system requires the stringent maintenance of optimum growth parameters such as the absence of oxygen and the purification of methane.

5.4 Reorienting wastewater towards food production

With the increasing drought conditions globally, the gap between the supply and the water demand has increased drastically. It is causing a threat to human existence. Therefore, researchers and scientists all over the globe are working to come up with innovative techniques for reenergizing the used and wastewater. One of the ways to overcome the water crisis, especially in the agricultural sector is to reuse the wastewater for agricultural purposes and to produce food. This food will help to curb hunger during droughts. In the developed countries, the wastewater (generally the municipal) is treated to an adequate level for its application in irrigated land for the growth of fodder, fiber, and seed crops, and lesser extent, for the irrigation of orchards, vineyards, and other crops. However, in developing countries, such as India, China, and Mexico, though the stringent regulations are not followed, the wastewater is used for agriculture (Hussain, Raschid, Hanjra, Marikar, & Wim van der Hoek, 2002). The wastewater must be treated to meet the international guidelines for the permissible levels of microbes and chemicals present in the treated water. WHO guidelines on the safe use of water for agriculture and aquaculture states the following for the microbiological contamination. Restricted irrigation (irrigation not intended for the crop used for direct human consumption): not more than one viable human intestinal nematode egg/litre of wastewater (Hussain, Raschid, Hanjra, Marikar, & Wim van der Hoek, 2002). Unrestricted irrigation (irrigation intended for the crops used for direct human consumption): includes the limit of restricted irrigation and not more than one thousand faecal coliform bacteria/100 ml of effluent.

The widely adopted treatment processes involved three stages namely the primary sedimentation process, secondary aerobic biological treatment, and tertiary disinfection treatment. However, these treatments are cost-intensive, high maintenance, and with high technological requirements, which renders them ineffective in most developing countries. These countries are now adopting more cost-efficient land-based systems for wastewater treatment. These systems involve waste stabilization ponds. Wastewater stabilization ponds (WSPs) are large man-made ponds where the wastewater is treated naturally under the influence of sunlight, carbon dioxide, wind, microorganisms, and algae (Dorothee, 2014). The ponds occur either individually or are combined in the series for improving the treatment process. The three different types of ponds utilized are anaerobic ponds, facultative ponds, and aerobic ponds, each with different designs and characteristics. The ponds are a cost-efficient system with low operation and maintenance costs but high biological oxygen demand (BOD) and pathogen removal efficiency. The wastewater treated by such ponds can be utilized for agriculture; however, the water is not utilized for direct surface water recharge. The two most significant concerns regarding the utilization of ponds for wastewater treatment include the large demand for land and the high evaporation rate. One more approach includes the utilization of wetland and aquatic plants, such as water velvet and duckweed for treating the sewage water before being used in agriculture.

The utilization of wastewater for irrigation must be implemented only after assessing its impact on human health, crops, soil, and groundwater resources, social and economic sectors. The treatment of wastewater for utilizing it for irrigation purposes forms a significant alternative for food production during the dire situation of droughts with an acute shortage of water.

Utilization of wastewater for agriculture increases food security, supports the nutrient recovery of the wastewater to improve the crop yields, reduces the issue of eutrophication, aids the all-year-round irrigation producing two or more crops per year, assist the growth of a variety of crops especially in during the droughts, reduce the water and fertilizers related costs, accelerates the recharging of aquifers through infiltration and reduces water competition among the drought struck population. (Jiménez & Navarro, 2013)

6. Rejuvenation of wastewater into a potable water

The increasing water scarcity and drought conditions throughout the globe have resulted in the unavailability of clean drinking water to a large segment of the population. Many places are currently involved in the reclamation of this sewerage wastewater to be utilized for drinking purposes by the technique known as potable water reuse. The indirect potable reuse (IPR) process reclaims the freshwater that is sent to the sewage treatment plant and is wasted. The existing IPR includes, a) Unplanned IPR (involves the release of the treated water into the natural environment – aquatic bodies, where it can be utilized by the cities downstream as a potential drinking water source), b) Planned IPR (involves the release of the water treated in the treatment plant at a very high degree into the developed groundwater system or aquatic body used as the source of drinking water). IPR has been the approach to reclaimed wastewater for several decades. However, another concept of direct potable reuse (DPR) has been adopted in the US, Australia, and South Africa. This approach involves further treatment of wastewater treated in the sewage treatment plant and is directly released into the drinking water distribution system, closer to where water is needed. There occurs no discharge of treated water into the natural environment like in IPR. A few of the advantages of DPR include the availability of drinking water close to the point of consumption and eliminates the cost associated with pumping the water from long distances which is an energy-efficient process.

The basic wastewater treatment and the reuse involve the primary treatment, where the sewage enters the sedimentation tanks and 80% of the solids are removed, and the effluent may be released into the ocean. However, instead of releasing the water into the environment and intending to reuse it, the water is further treated in the secondary treatment stage (Cho, 2011). This stage involves the biological degradation of wastewater by the bacteria. Consequently, the water is subjected to tertiary treatment. This stage filters the water to remove any of the remaining solids and disinfects the water with chlorine. For IPR, the tertiary treated water undergoes the advanced water technologies (microfiltration, reverse osmosis, and disinfection by U.V. or hydrogen peroxide), remains in the groundwater or surface reservoirs (for about 6 months for further purification of the water by natural processes), and undergoes the standard water purification process for drinking water, before being used.

A few of the challenges associated with reclamation of wastewater in near future include; effectively coupling advanced wastewater treatment facilities with seawater desalination facilities, which would substantially increase the amount of water available in the drought conditions; incorporation of efficient methods to assess the health risk and environmental impacts and implementation of stringent reuse regulations, which would be applied in varied situations to promote the reuse of water. (Angelakis, Asano, Bahri, Jimenez, & Tchobanoglous, 2018)

The reuse of the wastewater for drinking purposes will become the only alternative for drinking water across the globe very soon. If the population is not currently involved in reclaiming the wastewater for drinking purposes, they will be doing it soon. The wastewater passes through stringent treatment processes and technologies before making it available for drinking purposes. The reclaimed water tastes like regular drinking water. However, there are a few concerns regarding the use of reclaimed water for drinking purposes. A large group of the population globally fails to understand the importance of wastewater reuse for drinking purposes and hesitate to adopt the approach based on the "yuck factor". The idea of drinking the water from the toilet disgusts them. The advocacy of wastewater for drinking purposes also has political issues. The governing party promoting the reuse of wastewater faces criticism and disappointments. Likewise, the health impact of reusing wastewater has been researched for several years. Few of the health-related issues due to chlorine byproducts are now eliminated by using current methods which produce fewer chlorine byproducts. People are also concerned about the economics of wastewater reuse. The involvement of technology at each stage of treatment makes the process cost-intensive. There is a compelling need for innovative green technologies that effectively treat and convert wastewater to infinite resources. Conducting campaigns and projects illustrating the safety of wastewater reuse can significantly reduce people's concerns and trust issues over utilizing wastewater for drinking.

We are going to drink the wastewater in some way to combat the water crisis. However, new, and innovative techniques will still find their way among the other techniques that are already being used for recycling purposes. The 2017 WHO and US EPA census states the reusing of wastewater for drinking purposes is conducted by Australia, California, Texas, Singapore, Namibia, South Africa, Kuwait, Belgium, and the United Kingdom. In Brazil and India, several projects of water recycling are under consideration. Several stringent regulations apply to the safe use of

7. Innovations in water sector

Mining novel freshwater sources, apt infrastructure, innovative designs for reducing water dependence, efficient use technologies, water reuse, recycling (Wehn & Montalvo, 2018) and up cycling are some of the technological challenges for conceiving water management. Innovations in the water sector are needed at water resource management level which relies on scientific knowledge and information and communication technology (ICT) and in building infrastructure and services that ensure infinite supply from the finite water resources. Wehn & Montalvo have discussed various innovative path dependencies to ensure better distribution and management of water supply related to the dynamics of water innovation (Wehn & Montalvo, 2018). Some examples are sensors, monitoring networks, novel construction materials including pipes, compressors, transfer systems, mixers, pumps, controllers, chemical reagents, coagulants which are required in the water treatment processes.

The effluents from waste water treatment plants are generally discharged into the nearby freshwater bodies where it blends with the stream flow. Ideally the municipalities treat this water that may contain health hazardous agents and supply as potable water. When the upstream waste water treatment process is efficient, it provide high quality potable water to household, industrial and agricultural sector (Tortajada & Nambiar, 2019). Further, this water is supplied either through indirect potable system wherein the treated water is stored in surface or groundwater environmental buffers from where it is re abstracted, retreated and supplied; or it is introduced to municipalities without any environmental buffer but post extensive treatment and monitoring for water quality standards (Tortajada & Nambiar, 2019).

Some of the cutting-edge technologies adopted by Singapore for recycled drinking water which is termed as NEWater include efficient membrane filters with reactors that can harness energy from bacteria, incorporating nanotechnology for faster and cost-effective treatment and downstream processing using reverse osmosis technique and ultra violet radiation (Tortajada & Nambiar, 2019). The Changi Water Reclamation plant of Singapore is one of the world's largest and most advanced reclamation facility which was commissioned in 2008 which produces treated effluents which further get ultra-cleaned into high-grade NEWater and it meet 30% of total water demand of the country. Other water reclamation technique involve the use of chemicals such as chlorine and cleaning agents like charcoal and sand and further elimination of biological hazardous agents is achieved via ozonation, membrane filters, UV and reverse osmosis.

7.1 Wastewater as a resource to mitigate water scarcity

The Sustainable Development Goal 6 in the 2030 sustainable development agenda of the United Nations is an obligation for the countries to reduce their grey water footprint and to ensure safe clean water and sanitation (U.N., 2020). The leading wastewater producing nations are Asian countries, Europe and North America that produce around 159, 68 and 67 trillion L/year respectively (Goswami, Mehariya, Verma, Lavecchia, & Zuorro, 2021). The wastewater is loaded with nutrients which are both in the form of inorganic such as nitrates ($NO^-{}_3$), ammonium ($NH^+{}_4$), urea, phosphates ($H_2PO^-{}_4$, $HPO^{2-}{}_4$), heavy metals, micronutrients and organic compounds namely sugars, fatty acids, amino acids, steroids etc. The raw wastewater discharge containing these toxic and harmful components primarily cause water pollution that jeopardize humans, animals, and environmental health. Secondarily, the excessive nutrients in the wastewater lead to the eutrophication in freshwater lakes, rivers, ponds, and marine waters. The remediation of effluent discharge is critical to protect the inherent natural purification potential of coastal waters where the eutrophication cause chronic stress to the benthic microbial communities and drastic shift in the trophic assemblages (Meyer-Reil & Koster, 2000). Dual mitigation strategy that target both nitrogen and phosphorous loadings is key to tackle the issues of coastal water pollution that globally impact the fisheries, tourism and economy (Ngatia, Grace III, Moriasi, & Taylor, 2019). The harmful algae blooms associated with coastal eutrophication critically impact the aquaculture industry worldwide (Trottet, George, Drillet, & Lauro, 2021). Therefore, the need of hour is to redirect the nutrient loadings towards an integrated high efficiency nutrient reclamation biorefinery processes.

High energy consumption, economic and environmental costs, climate resilience, building capacity to meet the demand of growing population are some of the challenges associated with the conventional waste water treatment plants. Processes involved in the conventional waste water treatment include anaerobic digestion, sedimentation, coagulation, adsorption, UV-radiation, membrane filtration, nitrification and denitrification (Goswami, Mehariya, Verma, Lavecchia, & Zuorro, 2021) which require aeration, produce ample amounts of sludge and does not co-produce value added products to support economics and sustainability.

The reduction in costs and burden on environment can be achieved through alternative approach of developing biorefinery which can convert waste water to economically valuable resources. Various types of micro and macro organisms such as bacteria, fungi, algae and plants are exploited in the biological water treatment and reclamation processes along with co-production of renewable bioenergy and bioproducts via conversion of the organic and inorganic nutrients into biomass. The waste water biorefinery is an example of circular economy in which raw material and final products are obtained from within the same process cycle.

When exploited sustainably, biomass is renewable resource and effectively processing each of its constituents individually to produce different kinds of products is defined as biorefinery. When the biomass is derived via water treatment and reclamation process plant, it is called waste water biorefinery. Important considerations during the setting up of waste water biorefinery include the composition and complexities of the waste waters and the market assessment for the co-products recovered from the refinery (Kusch-Brandt & Alsheyab, 2021). For example, the baker’s yeast wastewater or the vinasse has very high chemical oxygen demand (COD) of 29,000 mg/l with acidic pH of 4-5 is a cost-effective substrate for fermentation growth of the protein rich filamentous fungi which is subsequently grown with suitable bacteria for further breakdown of organic nutrients via anaerobic digestion. Thus, in a twostep waste water biorefinery process, the chemical oxygen demand is lowered with co-production of protein rich biomass and methane rich biogas (Hashemi, Keikhosro, & Taherzadeh, 2021).

7.2 The need to address the issue of water scarcity across various sectors.

Municipality wastewater which has low COD values such as 250-290 mg/l are used in the alternative technology of agriculture irrigation for non-food crops called Phyto-filtration. Depending upon the geographical regions, various such crops can be selected that have low nutrient requirement, grow faster and produce valuable co-products. For instance, willow plantations in Quebec, Canada when irrigated with primary effluent municipal wastewater with COD of 290.3 mg/l and pH 7.1 for hypofiltration treatment process resulted in better yields of willow trees with biomass rich in glucose, lignin, and diverse phytochemicals (Sas, et al., 2021). The exploitation of photosynthetic organisms such as microalga are widely chosen for phosphate removal and co-production of multiple bioproducts as discussed in the next section.

8. Wastewater-algal biorefinery: path towards the circular bio-economy

In comparison to other micro and macro organisms, the microalgae presents unique characteristics such as a) their abilities to drive nutrition photo-, hetero- and mixotrophically b) pollutant scavenging c) CO_2 assimilation and sequestration d) synergistic growth with bacteria e) production of numerous bioproducts. Due to these advantages, microalgae can be simultaneously exploited for treating wastewater from industries, agriculture, and municipalities along with the co-production of industrial products. On the other hand, the commercial production or microalgae farming have several constraints such as high production cost, nutrient requirement which has high environment footprint, water scarcity and need for phosphorous which is a non-renewable resource (Delrue, Álvarez-Díaz, Fon-Sing, Fleury, & Sassi, 2016). Therefore, wastewater becomes a necessity for sustainable and economical farming of microalgae. Thus, the 'marriage' of microalgae and wastewater treatment is inevitable.

8.1 Bioremediation using microalgae

Microalgae have a high tolerance to nutrients and salt stresses (Catone, Ripa, Geremia, & Ulgiati, 2021). Microalgae uptake inorganic nutrients from industrial, agricultural and domestic wastewaters in the form of nitrates, ammonium, phosphates, potassium, etc. for their growth and conversion to biomass. In addition, microalgae are also known to incorporate and disintegrate several forms of micropollutants such as Pharmaceutical and Personal Care Products (PPCP), Endocrine Disrupting Compounds (EDC) and heavy metals (Delrue, Álvarez-Díaz, Fon-Sing, Fleury, & Sassi, 2016) as they possess catabolic genes for degrading pollutants (Subashchandrabose, Ramakrishnan, Megharaj, Venkateswarlu, & Naidu, 2013). Some conventional treatment plants are inefficient to tackle the problem of micropollutants; therefore, microalgae present an alternative method of treatment of these harmful and toxic chemicals. Being ubiquitous in nature, microalgae including blue green algae, or the cyanobacteria can thrive in variety of diverse habitats and niches which present a plethora of bioresource wealth that can be exploited for diverse forms of wastewater sources. The bacteria and fungi led breakdown of organic pollutants is disadvantageous due to associated increase in the atmospheric carbon pool (Subashchandrabose, Ramakrishnan, Megharaj, Venkateswarlu, & Naidu, 2013).

The ability of microalgae to grow hetero and mixotrophically make them suitable candidates for treating wastewaters with phenolic compounds as algae grown under this mode of nutrition can reduce the toxicity of these pollutants. For examples, the microalga *Ocromonas danica* possess metabolic pathway that can catabolize phenol to pyruvate and CO_2; microalgae namely *Ankistrodesmus braunii* and *Scenedesmus quadriquada* can degrade various forms of phenolic compounds by 70%, the green microalgae *Chlorella vulgaris* photodegraded an endocrine disruptor phenolic compound called Bisphenol. Algae can also convert toxic pollutants to non-toxic forms (Subashchandrabose, Ramakrishnan, Megharaj, Venkateswarlu, & Naidu, 2013).

8.2 Waste water treatment and sustainable co-production of value added bioproducts

Microalgae utilize inorganic nitrogen and phosphorous from the wastewaters for its growth and cell division along with the production of molecular oxygen when they are cultivated in phototrophic mode. The filamentous nitrogen fixing cyanobacterium called *Aulosira fertilissima* can accumulate up to 85% (dry cell weight) of poly-β-hydroxybutyrate (PHB), an elastomeric, water insoluble, biocompatible, safe bioplastic with high degree of polymerization. (Samantaray, Nayak, & Mallick, 2011) have shown a high nutrient removal capacity of *A. fertilissima* with significant increase in dissolved oxygen (DO) content in a recirculatory aquaculture system while yielding valuable PHB. Cyanobacteria especially the heterocysts forms are well documented for their capability to act as potent biofertilizers. The production of high value compounds is more economical and sustainable in comparison to biofuels. Microalgae naturally produce lipids, proteins and carbohydrate-based compounds that can be extracted through biorefinery approach (Ansari FA, 2017). An extensive range of bioproducts can be derived from the waste water cultivation of microalgae.

The global demand for livestock products is increasing globally which is the driving factor for shift in livestock sector from small scale mixed farming towards large industrial production units. The environmental footprints associated with this shifting of meat production are huge in terms of greenhouse gas emissions, increasing agriculture land and grey water generation. The latter two also lead to freshwater scarcity. Poultry, cattle, and sheep are the global dominant livestock types as major source of protein (Ritchie & Roxer, 2017). With growth in their production, the demand for animal feed rich in protein with high feed conversion ratio to improve the quality of meat is increased. Some countries such as Europe rely on import of high vegetable protein meal such as soybean meal and others like China would no longer be self-reliance to meet their growing demands (Patsios, Dedousi, Sossidou, & Zdragas, 2020). The import of vegetable meals for the expanding livestock sectors carry environmental burden in terms of both carbon and virtual water footprint. Other crop-based protein meal such as rapeseed meal have even higher environmental impact; therefore, non-food crop alternatives that can be cultivated everywhere on non-agricultural land achieve the sustainability targets. Some of these novel sources of animal feed protein are derived from algae, seaweeds, single cell protein such as yeast, bacteria and fungi (Patsios, Dedousi, Sossidou, & Zdragas, 2020). The production of these novel animal feed attain sustainability when they are looped into the bio-based circular economy using agro-industrial or livestock generated wastewaters (Figure 6). In coastal regions, the marine macroalgae and seaweed have immense potential to provide high quality animal feed with lesser environmental impacts. Another advantage of using seaweed animal feed is their ability to absorb minerals from sea water which is higher than that found in the land plants and are used as mineral supplements for farm animals (Morais, et al., 2020) (Øverland, Mydland, & Skrede, 2019).

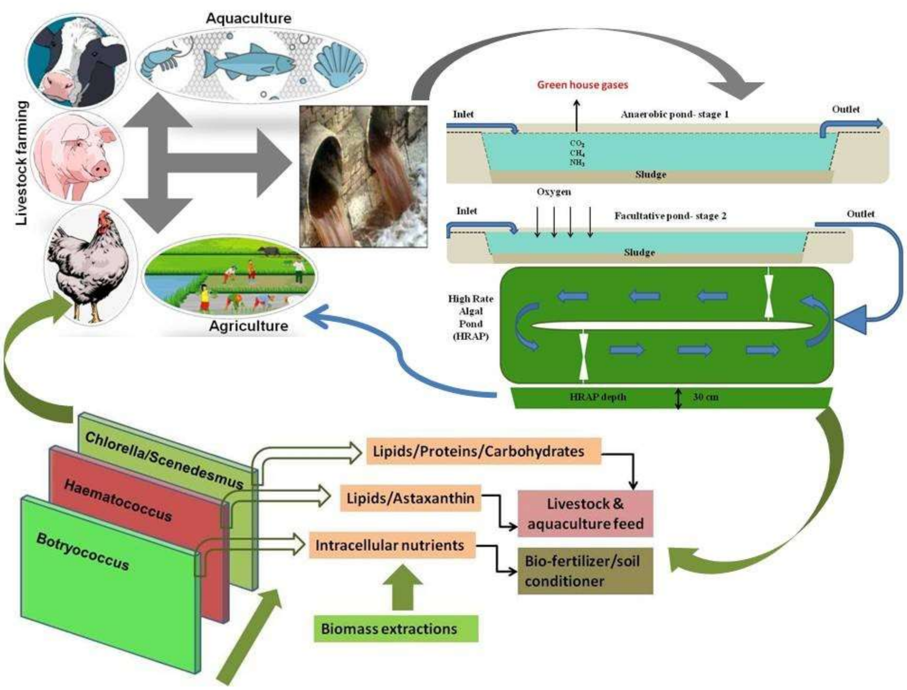

Figure 6. An example of algae-based circular economy. Wastewaters from agriculture and livestock farming treated at primary stages using microorganisms followed by nutrient conversion into biomass with high nutritive value utilized back into agro-livestock farming.

9. Role of Water footprint assessment in decision and policy making

The basic idea of water foot printing is to improve water use efficiency through sparking the water consciousness at hierarchal levels (individual, society, community and national) and across various economic sectors (industrial, agricultural, communication). Water is a renewable resource with conditions that the atmospheric water stock is regenerated about every 10 days; the average regeneration time of a river is 16 days and the renewal periods of the glaciers, groundwater, ocean, and large lakes are 100s to 1000s years (Meran, Siehlow, & Hirschhausen, 2021). The phenomenon of precipitation has high spatial and temporal variability. In terrestrial ecosystems, the water which is utilized through ‘photosynthesis’ for conversion into the biomass and lost via ‘transpiration’ process is termed as “green water”. On other hand, the precipitated water which is not evaporated but becomes the part of surface water bodies (rivers and lakes) and ground water aquifers is termed as “blue water” (Meran, Siehlow, & Hirschhausen, 2021). Hence based on water uses, utilization and conversion to wastewater, the footprints can be categorically sub divided into 1) Green water footprint which is the water used and utilized by the rain-fed agricultural crops, forests wood/timber, forest crops, and horticulture plants. This is basically the water obtained from rainfall. 2) Blue water footprint which is the water majorly consumed for drinking and used in various domestic activities, utilized by agriculture through various means of irrigation, utilized to harness electricity and used for industrial purposes. This is our main water resource present in the rivers, aquifers, and groundwater. 3) Grey water footprint which is the water polluted by individuals, society, farmers, industries, and companies. The polluted water is then being discharged into the freshwater sources such as rivers through sewage, agriculture runoff, and in groundwater sources through seepage.

The sustainability of the green water footprint measures the allocation of freshwater. The production of agriculture-based products such as food, feed, fiber, wood, biofuel consume significantly large fraction of green water and consequently this sector of the economy has a large green water footprint. This footprint fundamentally involves the allocation and does not consider the local impacts. The sustainability of green water footprint is closely linked with sustainable land use. The land use and green water for human activities are not considered as sustainable until a minimum area of unaltered land is being secured in the eco-regions of the production forests (Chapagain, 2017). The available green water forms the sustainable resource when there is a balance between the production of forest products or crops and an uninterrupted natural flow cycle. Environmental sustainability in terms of water quality can be obtained by comparing the grey water footprint with total assimilation capacity to understand the level of water pollution. The higher grey water footprint than the assimilation capacity indicates the higher pollution of water as compared to the accepted standards. Water footprint assessments are a key water management approach that considers the sustainable utilization of water resources. Although, it was created mainly to assess the agricultural and food production, it is now a mandate for various industries and manufacturing process to assess their water footprints to formulate the conservation strategies.

10. Conclusions

Drought is a product of disequilibrium in natural phenomenon and climate change. Timely monitoring through combination of various drought and climatic indices that measure water deficit in surface, groundwater, and soil and at mountain tops under the current and future climate change scenarios is the foremost and crucial step to tackle the prevalent global crisis. The need of the hour is to devise and implement mitigation plans to preserve the freshwater resources on the surface of the earth not to safeguard our economies but primarily to restore the ecosystem balance. The fundamental needs of water management through innovation are conservation of freshwater resources, minimizing wastage and recycling of the used or polluted water. Several water conservation techniques are formulated to minimize water loss, as well as to preserve the available water resources. All the water conservation techniques aim to balance the demand and supply of water in an effective manner. The techniques vary with the sectors of water use such as irrigation, industrial and domestic uses. In current scenario, waste water treatment using hybrid nature-based systems involving bio and phytoremediation, waste stabilization cum high rate algal ponds and microbial fuel cells is the most feasible strategy to support the circular economy and to overcome the impacts of drought on agriculture, livestock, and green energy production.

References

Abbasi, T., Tauseef, S., & Abbasi, S. (2012). Biogas and Bioenergy : An introduction. In *Biogas energy.* Springer.

Agrawal, K., Bhardwaj, N., Kumar, B., Chaturvedi, V., & Verma, P. (2019). Microbial Fuel Cell: A Boon in Bioremediation of waste. In M. P. Shah, & S. Rodriquez-Couto (Eds.), *Microbial waste water treatment.*

AL-agele, H., Proctor, K., Murthy, G., & Higgins, C. (2021). A Case Study of Tomato (Solanum lycopersicon var. Legend) Production and Water Productivity in Agrivoltaic Systems. *Sustainability, 13*(5), 2850. doi:doi.org/10.3390/su13052850

Albert, J., Destouni, G., Duke-Sylvester, S., Magurran, A., Oberdorff, T., Reis, R., . . . Ripple, W. (2021). Scientists' warning to humanity on the freshwater biodiversity crisis. *Ambio, 50*, 85-94. doi:https://doi.org/10.1007/s13280-020-01318-8

Angelakis, A. N., Asano, T., Bahri, A., Jimenez, B. E., & Tchobanoglous, G. (2018). Water Reuse: From Ancient to Modern Times and the Future. *Frontiers in Enviornmental Science*. doi: https://doi.org/10.3389/fenvs.2018.00026

Ansari FA, S. A. (2017). Exploration of microalgae biorefinery by optimizing sequential extraction of major metabolites from Scenedesmus obliquus. *Industrial & Engineering Chemistry Research, 56*(12), 3407-3412. doi:10.1021/ac.iecr6b04814

Catone, C., Ripa, M., Geremia, E., & Ulgiati, S. (2021). Bio-products from algae-based biorefinery on wastewater: A review. *Journal of Environmnetal Management, 293*, 112792. doi:10.1016/j.jenman.2021.112792

Cea, M., Sangaletti-Gerhard, N., Acuña, P., Fuentes, I., Jorquera, M., Godoy, K., . . . Naviaa, R. (2015, December 8). Screening transesterifiable lipid accumulating bacteria from sewage sludge for biodiesel production. *Biotechnology reports*.

Chand, K., & Biradar, N. (2017). *Socio-Economic Impacts of Drought in India.* ICAR - Indian Grassland and Fodder Research Institute. Scientific publishers.

Chapagain, A. (2017). *Water footprint: state of the art: what, why, and how?* Elsevier Inc.

Cho, R. (2011). *From Wastewater to Drinking Water.* State of Planet, Columbia Climate School: Climate Earth and Society.

de Medeiros, F., & Oliveira, C. (2021). Dynamical aspects of the recent strong El Nino events and its climate impacts in Northeast Brazil. *Pure Appl Geophys., 178*, 2315-2332. doi:10.1007/s00024-021-02758-3

Delrue, F., Álvarez-Díaz, P., Fon-Sing, S., Fleury, G., & Sassi, J. (2016). The environmental biorefinery: using microalgae to remediate wastewater, a win-win paradigm. *Energies, 9*, 132. doi:doi:10.3390/en9030132

Demirbas, A., Taylan, O., & Kaya, D. (2016, October 4). Biogas production from municipal sewage sludge (MSS). *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 38*(20).

Dorothee, S. (2014). *Factsheet waste stabilization pond.* Adapted from: Compendium of Sanitation Systems and Technologies. 2nd Revised Edition.

Ghazi, D., & Saleh, A. A. (2020). Electricity Production by Microbial Fuel Cell.

Ghosh, S., & Ghosh, S. (2021). Water crisis in urban and sub-urban areas: a global prespective. *Saudi J Bus Manag Stud, 6*(8), 327-344.

Goswami, R., Mehariya, S., Verma, P., Lavecchia, R., & Zuorro, A. (2021). Microalgae-based biorefineries for sustainable resourcerecovery from wastewater. *Journal of water process engineering, 40*, 101747. doi:10.1016/j.jwpe.2020.101747

Hashemi, S., Keikhosro, K., & Taherzadeh, M. (2021). Integrated process for protein, pigments, and biogas production from baker's yeast wastewater using filamentous fungi. *Bioresource Technology, 337*, 125356. doi:10.1016/j.biortech.2021.125356

Hussain, I., Raschid, L., Hanjra, M. A., Marikar, F., & Wim van der Hoek. (2002). *Wastewater Use in Agriculture: Review of Impacts and Methodological Issues in Valuing Impacts.* Inernational Waste Water Institute.

Jiménez, B., & Navarro, I. (2013). Wastewater Use in Agriculture: Public Health Considerations. *Encyclopedia of Environmental Management*. doi:10.1081/E-EEM-120046689

Kala, C. (2017). Environmental and Socioeconomic Impacts of Drought. *Applied Ecology and Environmental Sciences,, 5*(2), 43-48. doi:10.12691/aees-5-2-3

Kebede, B., Tsunekawa, A., Haregeweyn, N., Mamedov, A. I., & Tsubo, M. (2020). Effectiveness Of Polyacridime In Reducding Runoff And Soil Loss Under Consecutive Rainfall Storm. *Sustanibility, 12*(4). doi: https://doi.org/10.3390/su12041597

Kumar, R., Singh, L., & Abd Wahid, Z. (2017). Microbial Fuel Cells: Types and Applications. doi:10.1007/978-3-319-49595-8_16

Kumari, M., & Singh, J. (2016). Water Conservation: Strategies And Solutions. *International JOurnal of Advanced Research and Review, 1*(4), 75-79.

Kusch-Brandt, S., & Alsheyab, M. (2021). Wastewater refinery: producing multiple valuable outputs from wastewater. *J, 4*, 51-61. doi:10.3390/j4010004

Lahlou, F., Mackey, H., & Al-Ansari, T. (2021). Wastewater reuse for livestock feed irrigation as a sustainablepractice: A socio-environmental-economic review. *Journal of Cleaner Production, 294*, 126331. doi:doi.org/10.1016/j.jclepro.2021.126331

Masłoń, A. (2019). An Analysis of Sewage Sludge and Biogas Production at the Zamość WWTP. doi:10.1007/978-3-030-27011-7_37.

Meran, G., Siehlow, M., & Hirschhausen, C. (2021). *The economics of water. Rules and institutions.* (ISBN978-3-030-48485-9 ed.). Springer, Cham ebook. doi:10.1007/978-3030-48485-9

Meullemiestre, A., Breil, C., Abert-Vian, M., & Chemat, F. (2015). *Innovative Techniques and Alternative Solvents for extraction of microbial oil* (1 ed.). Springer International Publishing. doi:10.1007/978-3-319-22717-7

Meyer-Reil, L., & Koster, M. (2000). Eutrophication of marine waters: effects on benthic microbial communities. *Marine pollution bulletin, 41*(1-6), 255-263. doi:10.1016/S0025-326X(00)00114-4

Morais, T., Inácio, A., Coutinho, T., Ministro, M., Cotas, J., Pereira, L., & Bahcevandziev, K. (2020). Seaweed Potential in the Animal Feed: A Review. *J. Mar. Sci. Eng., 8*(559). doi:10.3390/jmse8080559

Ngatia, L., Grace III, J., Moriasi, D., & Taylor, R. (2019). Nitrogen and phosphorous eutrophication in marine ecosystems. In H. Fouzia (Ed.), *Monitoring of Marine Pollution.* IntechOpen. doi:10.5772/intechopen.81869

Øverland, M., Mydland, L., & Skrede, A. (2019). Marine macroalgae as sources of protein and bioactive compounds in feed for monogastric animals. *Journal of the Science of Food and Agriculture, 99*, 13-24. doi:10.1002/jsfa.9143

Pal, P. (2017). Introduction. In P. Pal, *Industrial water treatment process technology.* Butterworth Heinemann.

Patsios, S., Dedousi, A., Sossidou, E., & Zdragas, A. (2020). Sustainable animal feed protein through the cultivation of YARROWIA lipolytica on agro-industrial wastes andby-products. *Sustainability, 12*, 1398. doi:10.3390/su12041398

Ritchie, H., & Roxer, M. (2017). Meat and dairy production. OurWorldInData.org. Retrieved from https://ourworldindata.org/meat-production

Samantaray, S., Nayak, K., & Mallick, N. (2011). Wastewater utilization for poly-B-hydroxybutyrate production by the cyanobacterium Aulosira fertilissima in a ricirculatory aquaculture system. *Applied and Environmental Microbiology, 77*(24), 8735-8743. doi:10.1128/AEM.05275-11

Sas, E., Hennequin, L., Fremont, A., Jerbi, A., Legault, N., Lamontagne, J., . . . Pitre, F. (2021). Biorefinery potential of sustainable muncipal wastewater treatment using fast-growing willow. *Science of the Total Environment, 792*, 148146. doi:10.1016/j.scitotenv.2021.148146

Sato, C., Paucar, N., Chiu, S., Z. I. M. Mahmud, M., & Dudgeon, J. (2021). Single-Chamber Microbial Fuel Cell with Multiple Plates of Bamboo Charcoal Anode Performance Evaluation. *Processes, 9*. doi:https://doi.org/10.3390/pr9122194

Sauv´e, S., Lamontagne, S., Dupras, J., & Stahel, W. (2021). Circular economy of water: Tackling quantity, quality and footprint of water. *Environmental Development, 39*, 100651. doi:doi.org/10.1016/j.envdev.2021.100651

Shiklomanov, I. (1990). World fresh water resources. In G. PH, *Water in crisis: A guide to the world's fresh water resources* (pp. 13-24). New York: Oxford University Press.

Shiong Khoo, K., Yi Chia, W., Tang, D., & Loke Show, P. (2020). Nanomaterials Utilization in Biomass for Biofuel and Bioenergy Production. *Energies, 13*. doi:https://doi.org/10.3390/en13040892

Steiger, N., Smerdon, J., Seager, R., Williams, P., & Varuolo-Clarke, A. (2021). ENSO-driven coupled megadroughts in North and South America over the last millennium. *Nat Geosci*. doi:10.1038/s41561-021-00819-9

Subashchandrabose, S., Ramakrishnan, B., Megharaj, M., Venkateswarlu, K., & Naidu, R. (2013). Mixotrophic cyanobacteria and microalgae as distinctive biological agents for organic pollutant degradation. *Environment International, 51*, 59-72. doi:dx.doi.org/10.1016/j.envint.2012.10.007

Tortajada, C., & Nambiar, S. (2019). Communications on technological innovations: potable water reuse. *Water, 11*(251). doi:10.3390/w11020251

Trottet, A., George, C., Drillet, G., & Lauro, F. (2021). Aquaculture in coastal urbanized areas: a comparative review of the challenges posed by harmful algal blooms. *Critical review in environmental science and technology*. doi:10.1080/10643389.2021.1897372

U.N. (2020). *The sustainable development goals report.* United Nations.

Ummenhofer, C., England, M., McIntosh, P., Mayers, G., Pook, M., Risbey, J., . . . Taschetto, A. (2009). What causes southeast Australia's worst droughts? *Geophys. Res.Lett*, L04706. doi:10.1029/2008GL036801

Wagner, T., Kainz, S., Helfricht, K., Fischer, A., Avian, M., Krainer, K., & Winkler, G. (2021). Assessment of liquid and solid water storage in rock glaciers versus glacier ice in the Austrian Alps. *Science of The Total Environment, 800*, 149593. doi:https://doi.org/10.1016/j.scitotenv.2021.149593.

Wehn, U., & Montalvo, C. (2018). Exploring the dynamics of water innovation: foundations for water innovation studies. *Journal of cleaner production, 171*, S1-S19. doi:10.1016/j.jclepro.2017.10.118

Wilhite, D., & Svoboda, M. (2000). Drought Early Warning Systems in the Context of Drought Preparedness and Mitigation. In D. Wilhite, M. Sivakimar, & A. Deborah (Eds.), *Early warning systems for drought prepardness and drought management.* Lisbon, Portugal: Geneva, Switzerland: World Meterological Organization.