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Relationship of Algae to Water Pollution and Waste Water Treatment

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1. Introduction

Pollution of surface water has become one of the most important environmental problems. Two types of large and long-lasting pollution threats can be recognized at the global level: on the one hand, organic pollution leading to high organic content in aquatic ecosystems and, in the long term, to eutrophication. It is a well-known fact that polluted water can reduce water quality thus restricting use of water bodies for many purposes.

Organic pollution occurs when large quantities of organic compounds from many sources are released into the receiving running waters, lakes and also seas. Organic pollutants originate from domestic sewage (raw or treated), or urban run off, industrial effluents and farm water. Organic pollution could negatively affect the water quality in many ways. During the decomposition process of organic water dissolved oxygen in the water may be used up greater rate than it can be replenished thus, giving rise to oxygen depletion which causes severe consequences on the aquatic biota. Organic effluents also frequently contain large quantities of suspended solid which reduce the light available to photosynthetic organisms mainly algae. In addition organic wastes from people and animals may also rich in disease causing (pathogenic) organisms [1,2,3].

2. Algae and water pollution

Algae are the main the primary producers in all kinds of water bodies and they are involved in water pollution in a number of significant ways. Firstly, enrichments of the algal nutrients in water through organic effluents may selectively stimulate the growth of algal species producing massive surface growths or 'blooms' that in turn reduce the water quality and affect its use. However, certain algae flourished in water polluted with organic wastes play an important part in "self-purification of water bodies". Some pollution algae may

frequently are toxic to fish and also mankind and animals using polluted water. In fact, algae can play significant part of food chain of aquatic life, thus whatever alters the number and kinds of algae strongly affects all organisms in the chain including fish.

Algae are also known to be causes of tastes and odors in water [4]. In fact, a large number of algae are associated with tastes and odors that vary in type. Certain diatoms, blue-green algae and coloured flagellates (particularly Chrysophyta and Euglenophyta) are the best known algae to pose such problems in water supplies, but green algae may also be involved. Some algae produce an aromatic odor resembling to that of particular flowers or vegetables. In addition, a spicy, a fishy odor and a grassy odor can also be produced by odor algae [5,6].

3. Algae as bioindicators

Bioindicator organisms can be used to identify and qualify the effects of pollutants on the environment. Bioindicators can tell us about the cumulative effects of different pollutants in the ecosystem and about how long a problem may persist. Although indicator organisms can be any biological species that defines a trait or characteristics of the environment, algae are known to be good indicators of pollution of many types for the following reasons.

- algae have wide temporal and spatial distribution.
- many algal species are available all the year.
- response quickly to the changes in the environment due to pollution.
- Algae are diverse group of organisms found in large quantities.
- easier to detect and sample.
- The presence of some algae are well correlated with particular type of pollution particularly to organic pollution

Algae of many kinds are really good indicators of water quality and many lakes are characterized based on their dominant phytoplankton groups. Many desmids are known to be present in oligotrophic waters whilst a few species frequently occurs in eutrophic bodies of water [7]. Similarly, many blue-green algae occurs in nutrient-poor waters, while some grow well in organically polluted waters [8]. The ecosystem approach to water quality assessment also include diatom species and associations used as indicators of organic pollution. Five algal species were selected as indicators of the degree of pollution in rivers in England. *Stigeoclonium tenue* is present at the down stream margin of the heavily polluted part of a river, *Nitzschia palea* and *Gomphonema parvulum* always appear to be dominant in the mild pollution zone whilst *Cocconeis* and *Chamaesiphon* are reported to occur in unpolluted parts of the stream or in repurified zone [9]. *Navicula accomoda* is stressed to be a good indicator of sewage/organic pollution as the species comfortably occur in the most heavily polluted zones in which other species can not occur. The same hold true for species and varieties of *Gomphonema* [10] which is commonly found in highly organically polluted water. *Amphora ovalis* and *Gyrosigma attenuatum* are also introduced as good examples of diatoms to be affected by high organic content of water [11].

A list of more than 850 algal taxa was published based on the reports of considerable number of authors. According to this list, many algal genera have species that grow well in water containing a high concentration of organic wastes. Green algae *Chlamydomonas*,

Euglena, diatoms, *Navicula*, *Synedra* and blue-green algae *Oscillatoria* and *Phormidium* are emphasized to tolerate organic pollution [12]. At species level, *Euglena viridis* (Euglenophyta), *Nitzschia palea* (Bacillariophyta), *Oscillatoria limosa*, *O. tenuis*, *O. princeps* and *Phormidium uncinatum* (Cyanophyta) are reported to be present than any other species in

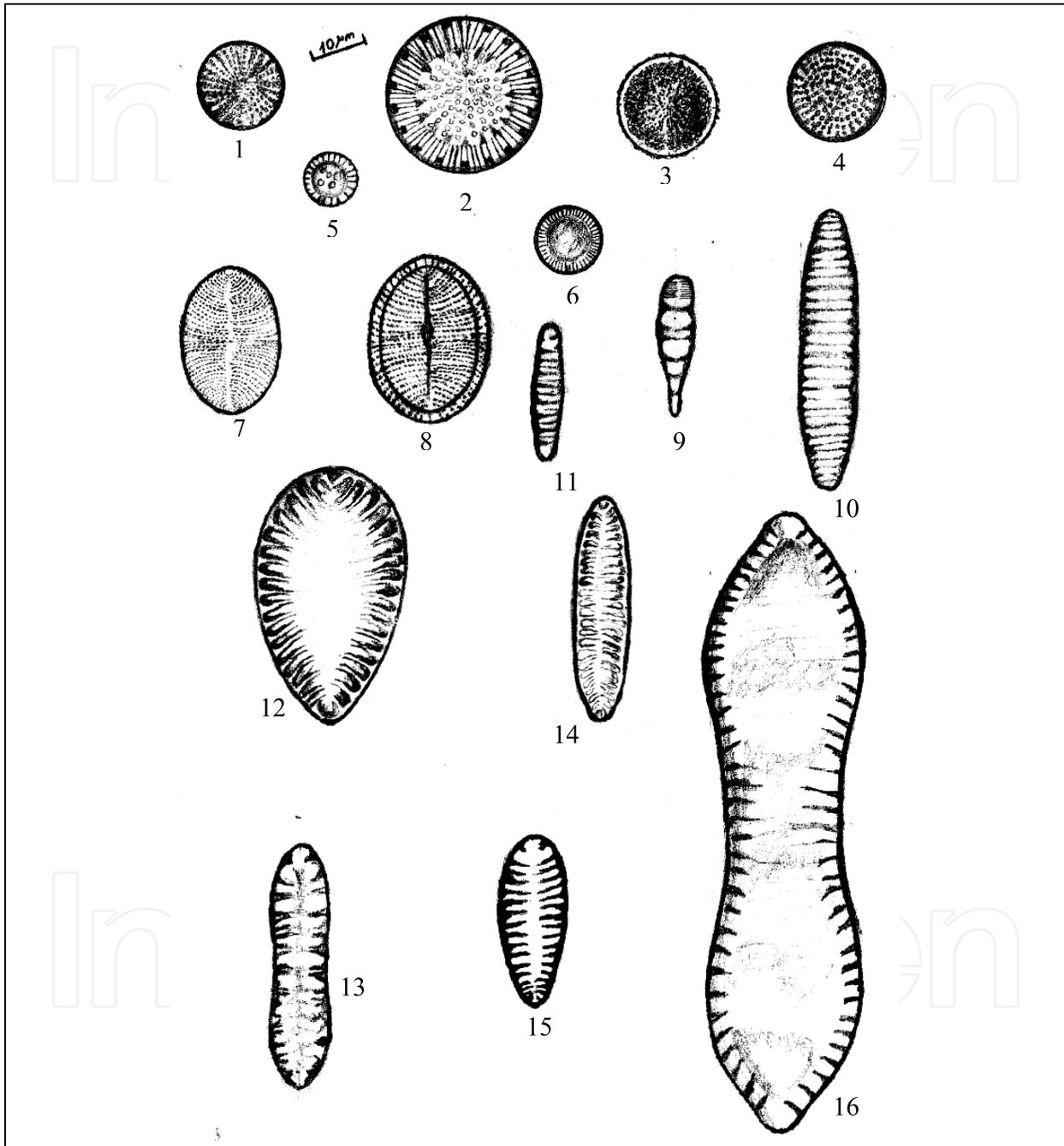


Plate 1. 1. *Stephanodiscus hantzschii* Grunow 2. *Cyclotella comta* (Ehrenberg) Kützing 3. *Thalassiosira weissflogii* (Grunow) G. Fryxel & Hasle 4. *Aulacoseira distans* (Ehrenberg) Simonsen 5. *Cyclotella ocellata* Pantocsek 6. *C. kützingiana* Thwaites 7. *Cocconeis pediculus* Ehrenberg 8. *C. placentula* Ehrenberg 9. *Meridion circulare* (Greville) C. Agardh 10. *Diatoma vulgare* var. *lineare* Grunow 11. *D. tenuis* C. Agardh 12. *Surirella ovalis* Brébisson 13. *S. ovata* var. *apiculata* W. Smith 14. *S. linearis* W. Smith 15. *S. minuta* Brébisson 16. *Cymatopleura solea* (Brébisson) W. Smith [14].

organically polluted waters [13]. Some diatom taxa in a stream polluted with the waste water of a slaughter house are given in Plate 1-4 [14].

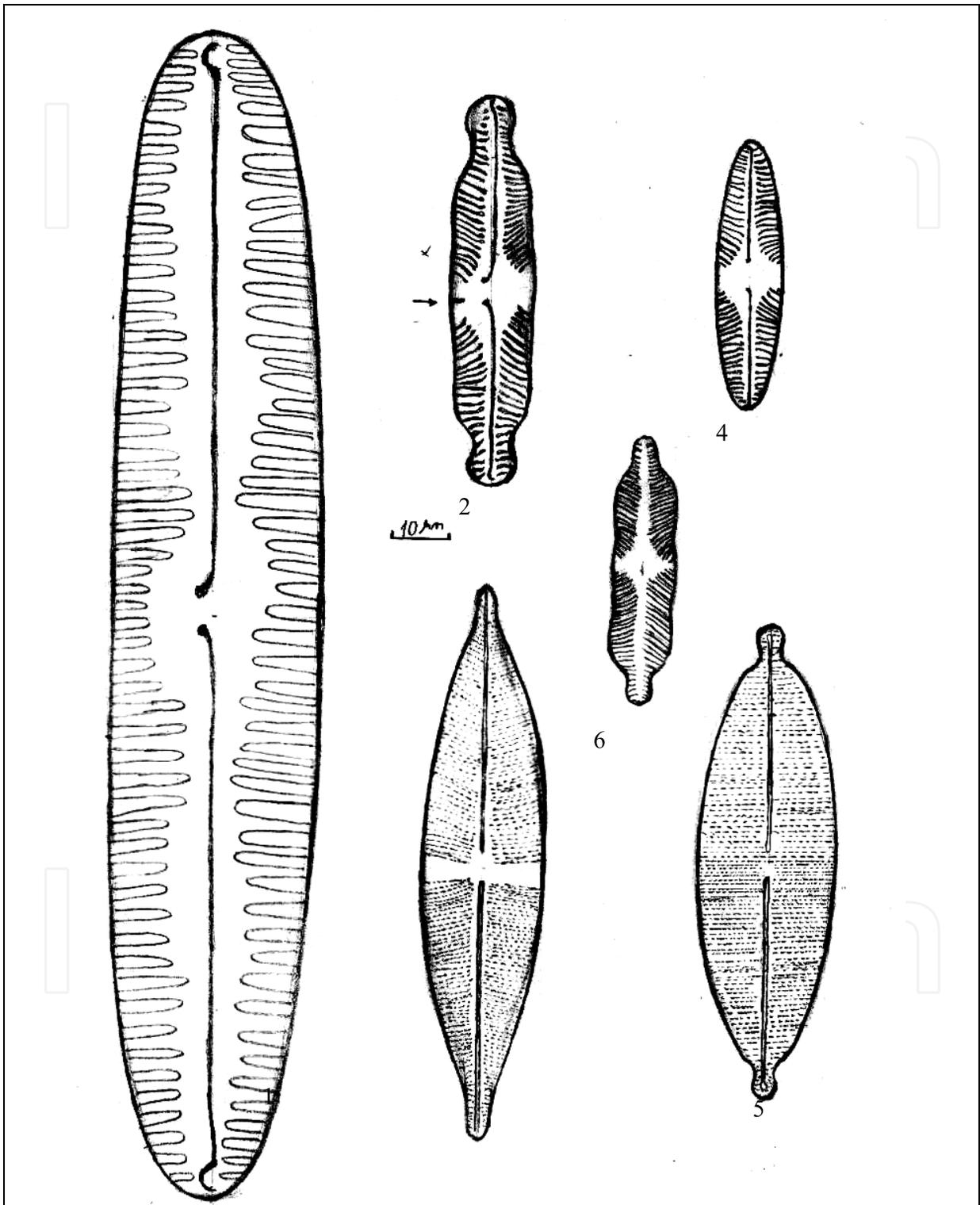


Plate 2. 1. *Pinnularia viridis* (Nitzsch) Ehrenberg 2. *P. biceps* W. Gregory 3. *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg 4. *Pinnularia brebissonii* (Kützing) Rabenhorst 5. *Craticula ambigua* (Ehrenberg) D. G. Mann 6. *Pinnularia mesolepta* (Ehrenberg) W. Smith [14].

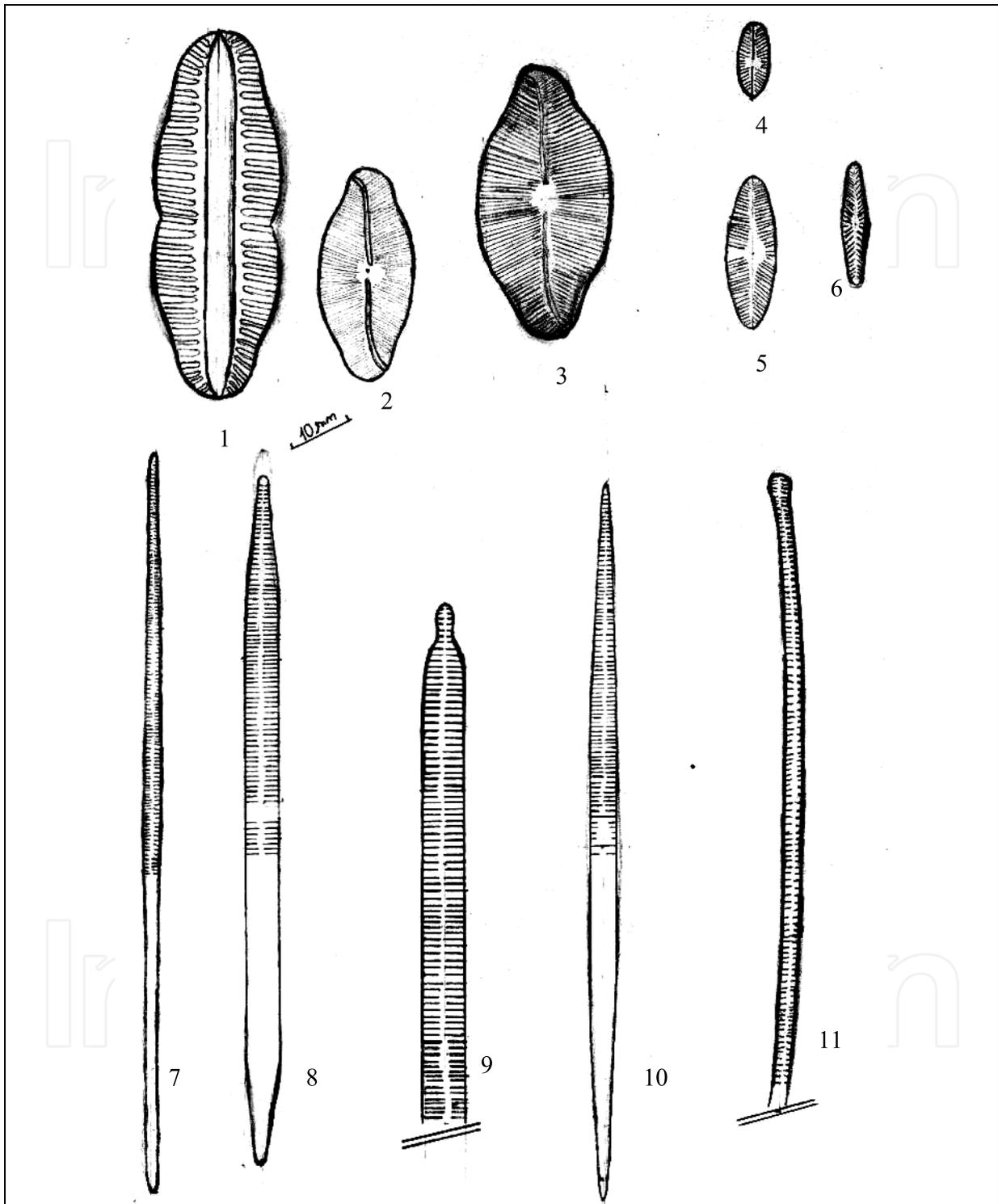


Plate 3. 1. *Rhopalodia gibba* (Ehrenberg) Otto Müller 2-3. *Eucoconeis flexella* (Kützing) Meister 4. *Achnanthis minutissimum* (Kützing) Czarnecki 5. *Eucoconeis quadratarea* (Østrup) Lange-Bertalot 6. *Achnanthes marginulata* Grunow 7. *Ulnaria delicatissima* var. *angustissima* (Grunow) M. Aboal & P. C. Silva 8. *U. acus* (Kützing) M. Aboal 9. *U. amphirhyncus* (Ehrenberg) Compère & Bukhtiyarova 10. *U. danica* (Kützing) Compère & Bukhtiyarova 11. *U. biceps* (Kützing) P. Compère [14].

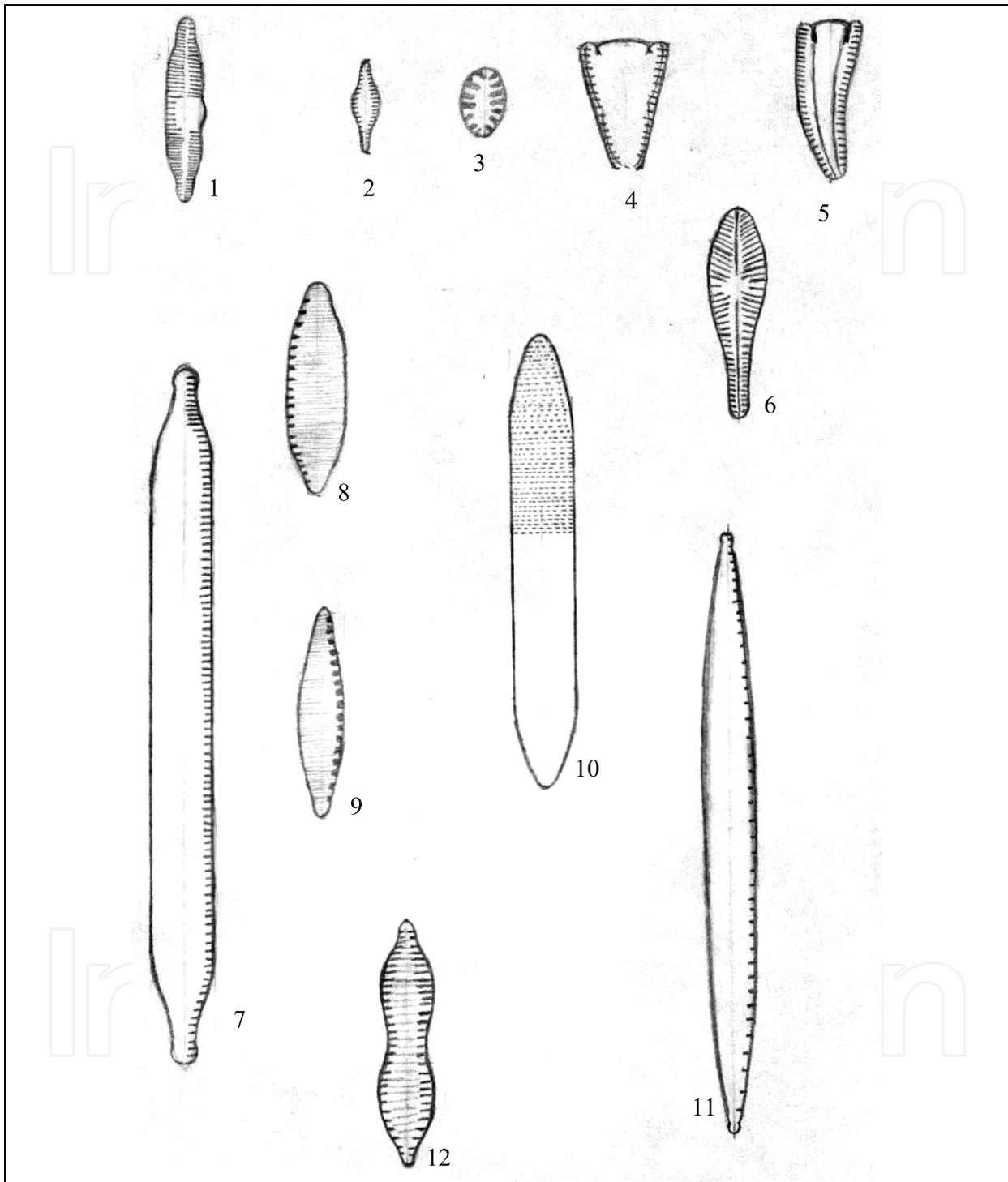


Plate 4. 1.*Fragilaria capucina* var. *vaucheriae* (Kützing) Lange-Bertalot 2.*Pseudostaurosira brevistrita* (Grunow) D.M.Williams & Round 3.*Staurosirella pinnata* (Ehrenberg) D.M.Williams & Round 4.*Gomphonema truncatum* Ehrenberg 5.*Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot 6.*Gomphonema olivaceum* (Hornemann) Brébisson 7.*Nitzschia sublinearis* Hustedt 8.*N. umbonata* (Ehrenberg) Lange-Bertalot 9. *N. hantzschiana* Rabenhorst 10. *Tryblionella angustata* W. Smith 11. *Nitzschia linearis* (C. Agardh) W. Smith 12. *N. constricta* (Kützing) Ralfs. [14].

Algae are also good indicators of clean water since many species occur insistently and predominately in the clean water zone of the streams. However it is more satisfactory to emphasize the presence or absence of several species of clean water algae rather than of any one species to define the clean water zone. Approximately 46 taxa has been announced as representatives of the clean water algae including many diatoms, several flagellates and certain green and blue-green algae [12]. However it is emphasized that minute flagellates are better indicators of clean water than many larger algae. A few of the clean water algae are planktonic whilst many are benthic, attached to substrata at the bottom or sides of the running waters.

There are many studies by various authors emphasizing the relationships of algae to clean water. A community composed of the diatom *Cocconeis* and the blue-green alga *Chamaesiphon* is claimed to be present in the portion of the stream which has returned to normal following purification of a polluted condition [9]. Kolkwitz listed 61 diatoms, 42 green algae, 41 pigmented flagellates, 23 blue-green algae, and 5 red algae as organisms of oligosaprobic and /or unpolluted zones and Lackey found 77 species of planktonic algae in the clean water portion of a small stream, 40 of which were absent in the polluted area [15,16]. The flagellates *Chromulina rosanoffi*, *Mallomonas caudata*, the green algae *Ulothrix zonata* and *Microspora amoena* are also reported as oligosaprobic zone organisms [17]. Two groups of algae, Cryptophyta and Chrysophyta, are reported to be indicators of clean and/or unpolluted water as the members of these algal groups tend to occur in abundance, oppositely reacting adversely to pollution [18]. The absence of blue-green algae was also accepted an indication of clean water [19].

4. Use of algae in saprobien system

The classic scheme for the interpretation of streams ecological conditions based on the biota was first introduced by Kolkwitz and Marsson [20]. They defined five zones based on the degree of pollution and proposed the use of aquatic organisms as indicators of different pollution and/or recovery zones of rivers which were polluted with organic matter such as sewage. However more recently Werner proposed nine different zones in the saprobic system in a stream organically polluted [21]. Survey of the saprobic zones and the corresponding communities are given Table 1. Pollution zones proposed in that saprobient system were basically termed "**Coprozoic**", "**Polysaprobic**", "**Mesosaprobic**", "**Oligosaprobic**" and "**Katharobic**". Each zone was different in chemical and physical characteristics and containing characteristic species. He listed indicator species of these zones except the last one which is infact clean water.

Polysaprobic zone was characterized by almost complete absence of algae except for blue-green alga *Arthrospira (Spirulina) jenneri* and green alga *Euglena viridis*. Bacteria and Protozoa were the most common groups in this zone. The preponderance of blue-green algae (Cyanophyta) was characteristic of alfa-mesosaprobic zone while diatoms (Bacillariophyta) and green algae (Chlorophyta) were dominant organisms in beta-mesosaprobic zone. Peridinales (Dinophyta) and Charales (Charophyta) occurred in any quantity only in the

oligosaprobic zone. In the same zone, the bacterial count was low but there was a great variety of plants and animals (including fish) in considerable numbers.

5. Use of algae in wastewater treatment

Recently, algae have become significant organisms for biological purification of wastewater since they are able to accumulate plant nutrients, heavy metals, pesticides, organic and inorganic toxic substances and radioactive matters in their cells/bodies [22-25]. Biological wastewater treatment systems with micro algae have particularly gained importance in last 50 years and it is now widely accepted that algal wastewater treatment systems are as effective as conventional treatment systems. These specific features have made algal wastewaters treatment systems an significant low-cost alternatives to complex expensive treatment systems particularly for purification of municipal wastewaters.

In addition, algae harvested from treatment ponds are widely used as nitrogen and phosphorus supplement for agricultural purpose and can be subjected to fermentation in order to obtain energy from methane. Algae are also able to accumulate highly toxic substances such as selenium, zinc and arsenic in their cells and/or bodies thus eliminating such substances from aquatic environments. Radiation is also an important type of pollution as some water contain naturally radioactive materials, and others become radioactive through contamination. Many algae can take up and accumulate many radioactive minerals in their cells even from greater concentrations in the water [12]. MacKenthun emphasized that *Spirogyra* can accumulate radio-phosphorus by a factor 850.000 times that of water [26]. Considering all these abilities of algae to purify the polluted waters of many types, it is worth to emphasize that algal technology in wastewater treatment systems are expected to get even more common in future years.

Wastewater treatment which is applied to improve or upgrade the quality of a wastewater involves physical, chemical and biological processes in primary, secondary or tertiary stages. Primary treatment removes materials that will either float or readily settle out by gravity. It includes the physical processes of screening, comminution, grit removal, and sedimentation. While the secondary treatment is usually accomplished by biological processes and removes the soluble organic matter and suspended solids left from primary treatment. Tertiary or advanced treatment is process for purification in which nitrates and phosphates, as well as fine particles are removed [27]. However initial cost as well as operating cost of wastewater treatment plant including primary, secondary or advanced stages is highly expensive [28].

It is well known that algae have an important role in self purification of organic pollution in natural waters [29]. Moreover, many studies revealed that algae remove nutrients especially nitrogen and phosphorus, heavy metals, pesticides, organic and inorganic toxins, pathogens from surrounding water by accumulating and/or using them in their cells [30,31,32,33,34,35,36,37,38]. Also, studies showed that algae may be used successfully for wastewater treatment as a result of their bioaccumulation abilities [39].

Zone I.	Coprozoic zone the bacterium community the <i>Bodo</i> community both communities
Zone II.	α-Polysaprobic zone <i>Euglena</i> community Rhodo-Thio bacterium community Pure Chlorobacterium community
Zone III.	β-Polysaprobic zone Beggiatoa community Thiothrix nivea community <i>Euglena</i> community
Zone IV.	γ-Polysaprobic zone Oscillatoria chlorina community Sphaerotilus natans community
Zone V.	δ-Mesosaprobic zone Ulothrix zonata community Oscillatoria benthonicum community (O.brevis, O.limnosa, O.splendida with O.subtilissima, O. princeps and O.tenuis present as associate species) Stigeoclonium tenue community
Zone VI.	β-Mesosaprobic zone Cladophora fracta community Phormidium community
Zone VII.	γ-Mesosaprobic zone Rhodophyceae community (Batrachospermum moniliforme or Lemanea fluviatilis) Chlorophyceae community (<i>Cladophora glomerata</i> or <i>Ulothrix zonata</i> (clean-water type))
Zone VIII.	Oligosaprobic zone Chlorophyceae community (<i>Draparnaldia glomerata</i>) Pure Meridion circulare community Rhodophyceae community (<i>Lemanea annulata</i> , <i>Batrahcospermum vagum</i> or <i>Hildenbrandia rivularis</i>) Vaucheria sessiis community Phormidium inundatum community
Zone IX.	Katharobic zone Chlorophyceae community (<i>Chlorotylum cataractum</i> and <i>Draparnaldia plumosa</i>) Rhodophyceae community (<i>Hildenbrandia rivularis</i>) Lime-incrusting algal communities (<i>Chamaesiphon polonius</i> and various <i>Calothrix</i> species)
a, b, c, d, e	= as alternatives
1, 2, 3	= as differences in degree

Table 1. Aquatic communities representing various zones of pollution. Survey of the saprobic zones and the corresponding communities [21].

6. Advantages of use of algae in wastewater treatment

There are a symbiotic relation among bacteria and algae in aquatic ecosystems. Algae support to aerobic bacterial oxidation of organic matter producing oxygen via photosynthesis whilst released carbon dioxide and nutrients in aerobic oxidation use for growth of algal biomass. Considering ammonium, carbon dioxide and orthophosphate as main nutrient sources, Oswald determined that oxygen release ratio is 1.5 g O₂/1 g algal biomass [40]. Grobbelaar et al. reported to oxygen release ratio of 1.9 g O₂/1 g algal biomass [41]. Arceivala, accounting latitude, climate and atmospheric conditions, calculated that 4-6% of mean daily solar radiation reaching on treatment pond in 40°N latitude use for new biomass production and production rate of algal biomass may reach 80 kg O₂/1 ha-day [42].

Most of nitrogen in algal cell bound to proteins which compose to 45-60% of dry weight and phosphorus is essential for synthesis of nucleic acids, phospholipids and phosphate esters. Algae using nitrogen and phosphorus in growth may remove to nutrients load of wastewater from a few hours to a few days [43].

In comparison to common treatment systems, oxidation ponds supporting growth of some species may be effective of nutrient removal (Fig. 1). Increasing dissolved oxygen concentration and pH cause for phosphorus sedimentation, ammonia and hydrogen sulphur removal. High pH in algal ponds also leads to pathogen disinfection [44]. Removal efficiency of heavy metals by algae shows changes among species. In fact, studies showed that chrome by *Oscillatoria*, cadmium, copper and zinc by *Chlorella vulgaris*, lead by *Chlamydomonas* and molybdenum by *Scenedesmus chlorelloides* may remove successfully [45,46,47,48,49]. Although algae have adaptation ability to sub-lethal concentrations, accumulation of heavy metals in cells may be potentially toxic effects to the other circles of food web [50].

7. Algal-bacterial ponds

Algal-bacterial pond is water body which is designed to keep and improve of wastewater in a certain time. Although wastewater is treated in pond via physical, chemical and biological processes and/or mechanical processes like aeration, there are also ponds completely based on processes of natural conditions. Ponds, where stabilization of dissolved compounds and suspended solids is in completely aerobic conditions, are named "oxidation ponds". When stabilisation in anaerobic or facultative conditions, ponds are named "waste stabilisation ponds". Stabilisation pond systems are assessed in different types: facultative, anaerobic, aeration and maturation ponds. Common pond type which utilizes from algae is facultative stabilisation ponds. Facultative ponds are designed for purposes such as decrease of waste retention time, achieve of effective treatment or algal culture (Fig. 2). Algal photosynthesis and bacterial decomposition is principal mechanism of algal-bacterial ponds. The processes including oxidation, settling, sedimentation, adsorption, disinfection in the ponds are results of symbiotic relation between algae and bacteria populations [51].

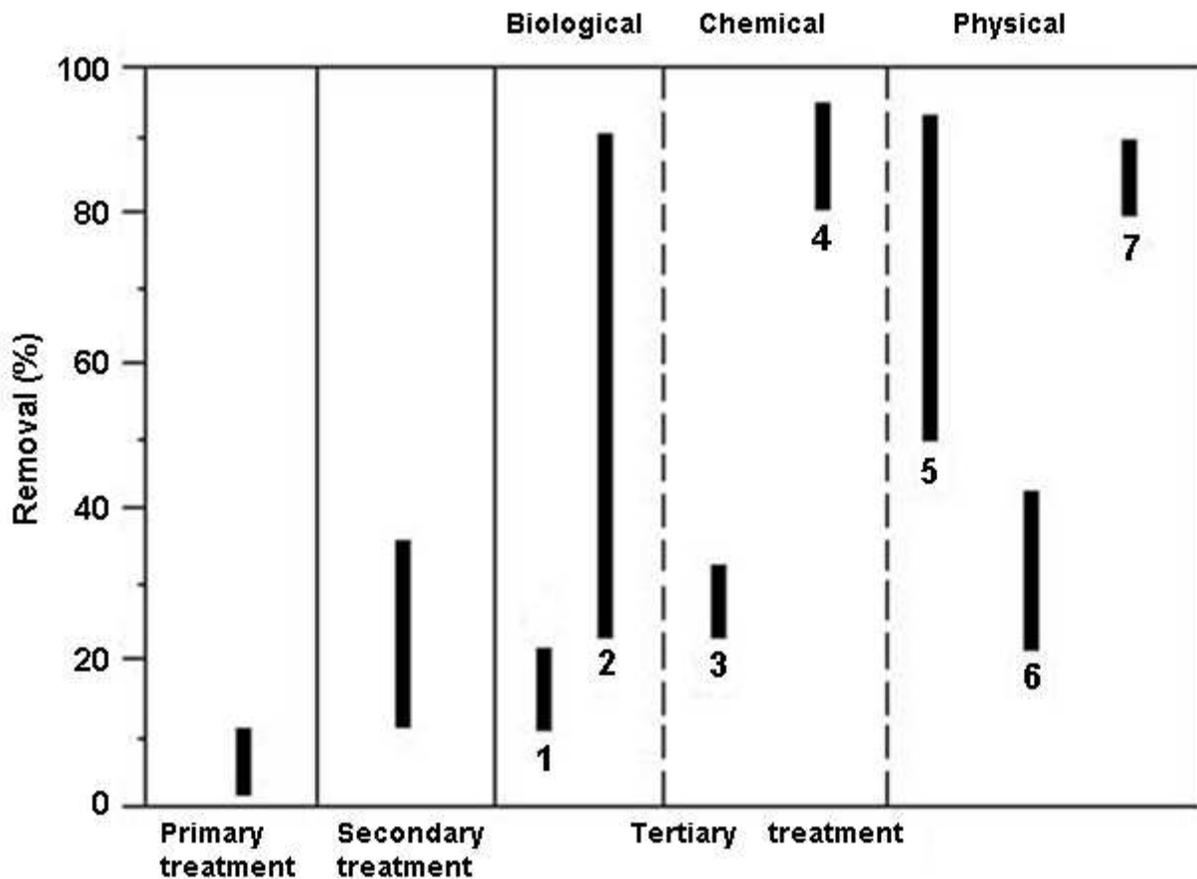


Figure 1. Removal efficiency of organic nitrogen in treatment methods [44]. 1-nitrification, 2-oxidation pond, 3-chemical coagulation, 4-chlorination, 5-ammonia removal, 6-filtration, 7-reverse osmosis

Facultative ponds (usually 2.5m in depth) are systems where effluent quality improves between 5 and 30 days depending on factors such as climate, temperature, wind and surface area [52]. There are three main zones in such ponds; two upper zones with oxygen whilst anaerobic conditions prevail in bottom. Algal photosynthesis and atmospheric diffusion are main oxygen source. Wastes are stabilized by aerobic bacteria in upper zone and by facultative bacteria in intermediate depths while degraded by anaerobic bacteria in bottom zone [53]. Zooplankton controls to excessive bacterial growth and algal blooms through grazing as well as contributing to carbon dioxide production for algal photosynthesis. Food web in a facultative pond is given in Figure 2.

Acceptable effluent quality is the most important advantage of facultative ponds though low operation and maintenance costs. However there are some disadvantages such as high land costs, odour problem in high waste loading, loss of nitrogen to atmosphere, limiting the nutrient reuse by phosphate sedimentation also limiting of irrigation potential by salinity increase during high evaporation period [54]. Although temperature largely affects retention time of wastewater, facultative ponds are widely used in different climate regimes. For example there are more than 3000 facultative ponds in Germany and France and 7000 in United States [53].

8. High rate algal ponds

Municipal wastewater treatments with high rate algal ponds were first proposed by Oswald and Golouke and thereafter were used in many parts of the world [55,56]. High rate algal pond is usually shallow (20-50 cm) and is equipped with mechanical aeration and mixing by means of paddle wheels. High oxygen level resulting from photosynthesis and aeration allows to low retention times in these ponds. Removal rates of high rate algal ponds are almost similar to conventional treatment methods but may also be more efficient with lower retention time. In fact biochemical oxygen demand (BOD) up to 90% and more than 80% of nitrogen and phosphorus are treated in high rate algal ponds in a few days. However required time for treatment of biochemical oxygen demand up to 90% using by conventional activated sludge and bio filtration techniques, which are highly expensive secondary treatment methods, is between five and eight hours during which lower ratio of nitrogen and phosphorus may be removed. Further, construction and energy costs are highly lower and land requirement is half the required for facultative ponds [57]. It is a well-known fact that only a small amount of nitrogen and phosphorus are removed in active sludge and bio filtration techniques, In addition active sludge and bio filtration techniques require expensive chemicals and complex systems.

Cost of harvest in high rate algal ponds may be most important problem. Thus sedimentation of algae with flocculating is aimed when the wheels are stopped for harvest. In addition growth of resistant algal species to sinking such as *Chlorella*, *Euglena*, *Chlamydomonas* and *Oscillatoria* is undesired algae in the ponds. *Scenedesmus* or *Micractenium*, non-preferred species due to their cell morphology for grazing, are dominant in well mixed ponds [40]. Harvested algae may use for industrial and agricultural use as well as effluent in aquaculture (Fig. 3).

9. Advanced integrated wastewater ponds

Advanced integrated wastewater pond systems are an adaptation of waste stabilisation ponds systems based on a series of four advanced ponds: A facultative pond; a high rate algal pond; an algal settling pond and finally a maturation pond for solar disinfection and pathogen abatement. The first pond in series is a facultative pond with depth of 4 to 5 m containing a digester pit, which functions much like an anaerobic pond while surface zone remains aerobic. Effluent of the facultative pond flows to the high rate algal pond for remove to dissolved organic matter and nutrients, then to settling pond with residence time of one or two days for sedimentation of algae and suspended solids. The last unit is maturation ponds where treated water is exposed to the sun and wind leading to natural oxygenation and solar disinfection, and thus an inactivation of pathogens [58].

Wastewater Treatment and Reclamation Plant in St. Helena, California, by US Department of Energy built of formed earth rather than of reinforced concrete in the early 1960s (Fig. 4).

The total pond area needed is much larger than that needed for a conventional plant, but ponds should still cost only one-third to one-half as much to build. Another important advantage of the plant is the small amount of sludge they produced. For example, during nearly 3 decades of operation, St. Helena's wastewater treatment plant has never had to remove residue and measured less than 1 meter of residue had accumulated at the bottom of the deep digester pit [59].

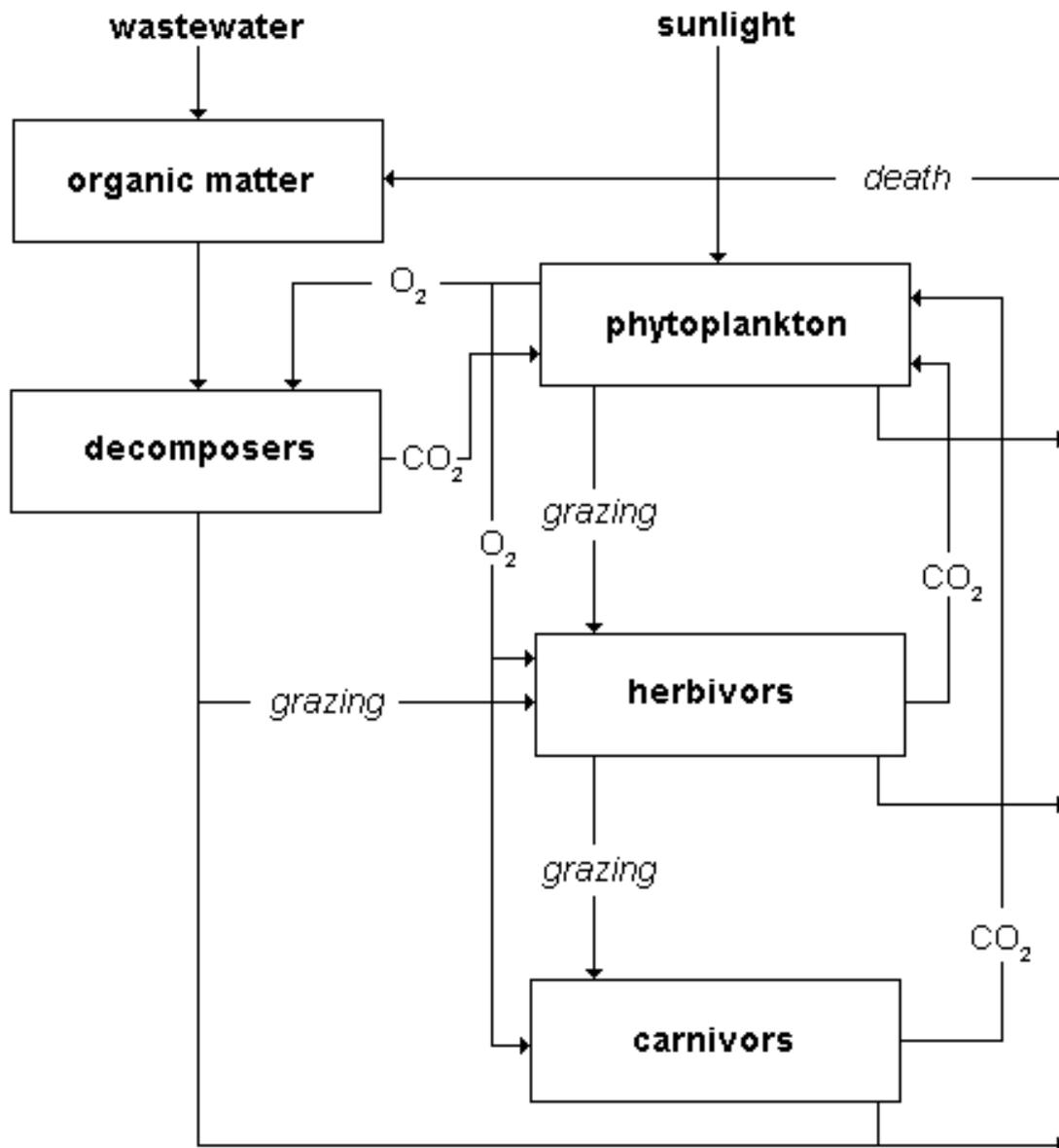


Figure 2. Food web in facultative wastewater treatment pond [51]

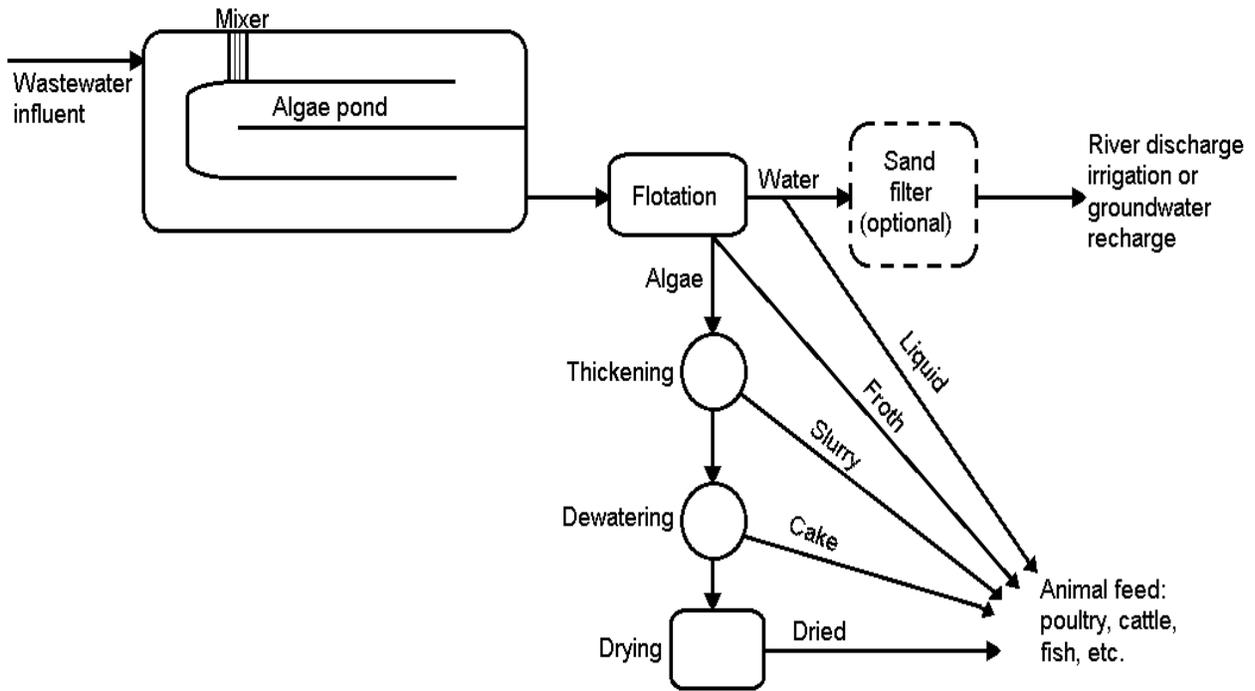


Figure 3. Flow Scheme of the Accelerated Photosynthetic Process for Waste-Water Treatment and Algal Protein Production [56]

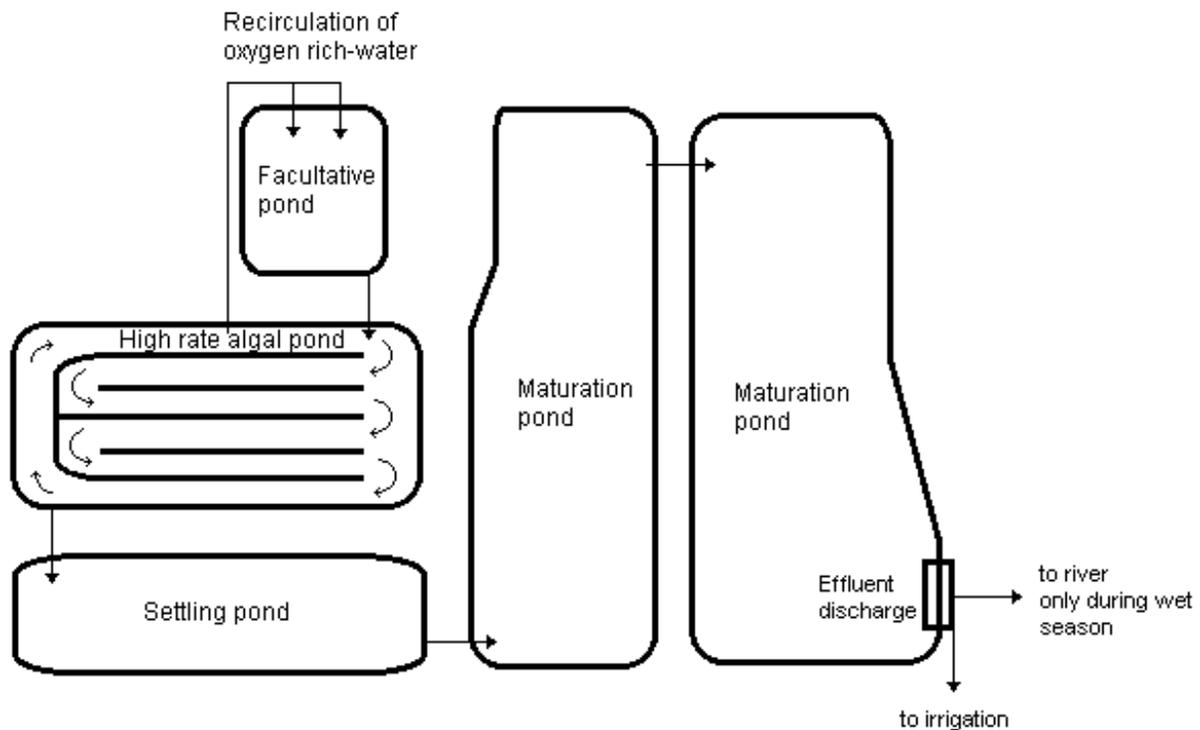


Figure 4. Diagram of St. Helena advanced integrated pond system [59]

Comparison of algae involved wastewater treatment systems is given at table 2. Many useful criteria have been used in the table for more constructive and trustable comparison of wastewater treatment systems connected to algae.

Criteria	Bacteria-Algae Pond	High rate Algae Pond	Integrated Pond
Depth	2.5 m	0.2-0.5 m (20-50 cm)	4-5 m
Salinity	increase	-	-
Retention time	low	lower (because O ₂ level is high)	high
Land required	high	low	low
Odor problem	occur	not occur	not occur
Loss of N to atmosphere	occur	not occur	not occur
Operation/maintenance cost	low	lower (5 folds lower)	high
PO ₄ sedimentation	occur	not occur	not occur
Time required for treatment	5-30 days	a few days	5-6 days
Energy requirement	low	low	high
Efficiency quality	low	high	high
BOD removal	fair	good	good
Suspended solid removal	fair	good	good
Harvesting cost		high	low

Table 2. Comparison of wastetreatment ponds in terms of various criteria

10. Conclusion

The water flows from lands into aquatic environments contribute enormous amounts of organic matters and plants nutrients to the aquatic systems which give rise to eutrophication and pollution. With increased urbanization the need for sewage treatment plants (STP) became more important. Wastewater treatment which is applied to improve or upgrade the quality of a wastewater involves physical, chemical and biological processes in primary, secondary or tertiary stages. More sewage plants are designed to remove solids (primary process), followed by a secondary process which involves either activated sludge or trickling filters to reduce the Biological Oxygen Demand (BOD). Removal of the nutrients left after secondary treatment is possible by a variety of processes, one of which involves growth and harvesting of algae from the effluents: others involve ion exchange electro chemical, electrodialysis, reverse osmosis, distillation, chemical precipitation as tertiary processes. However initial cost as well as operating cost of wastewater treatment plant including primary, secondary or advanced stages is highly expensive.

Recently, algae have become significant organisms for biological purification of wastewater since they are able to accumulate plant nutrients, heavy metals, pesticides, organic and inorganic toxic substances and radioactive matters in their cells/bodies with their bioaccumulation abilities. Particularly, biological wastewater treatment systems with micro algae have gained great importance in last 50 years and it is now widely accepted that algal wastewater treatment systems are as effective as conventional treatment systems. Removal rates of particularly high rate algal ponds are almost similar to conventional treatment methods but it is more efficient with lower retention time. With these specific features algal wastewater treatment systems can be accepted as an significant low-cost alternatives to complex expensive treatment systems particularly for purification of municipal wastewaters.

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