Wastewater Treatment Using Microalgae: A promising environmental biotechnology

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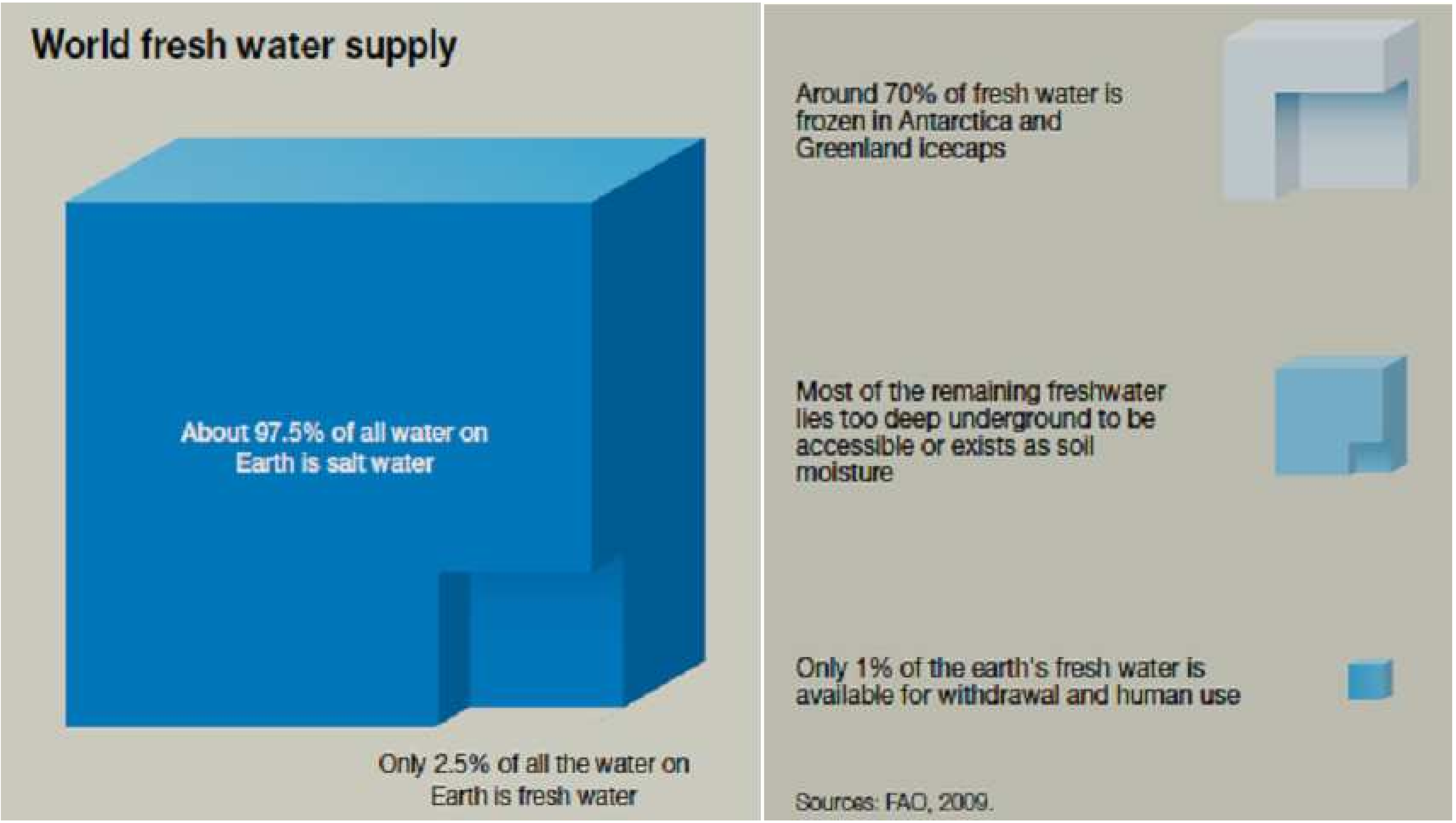
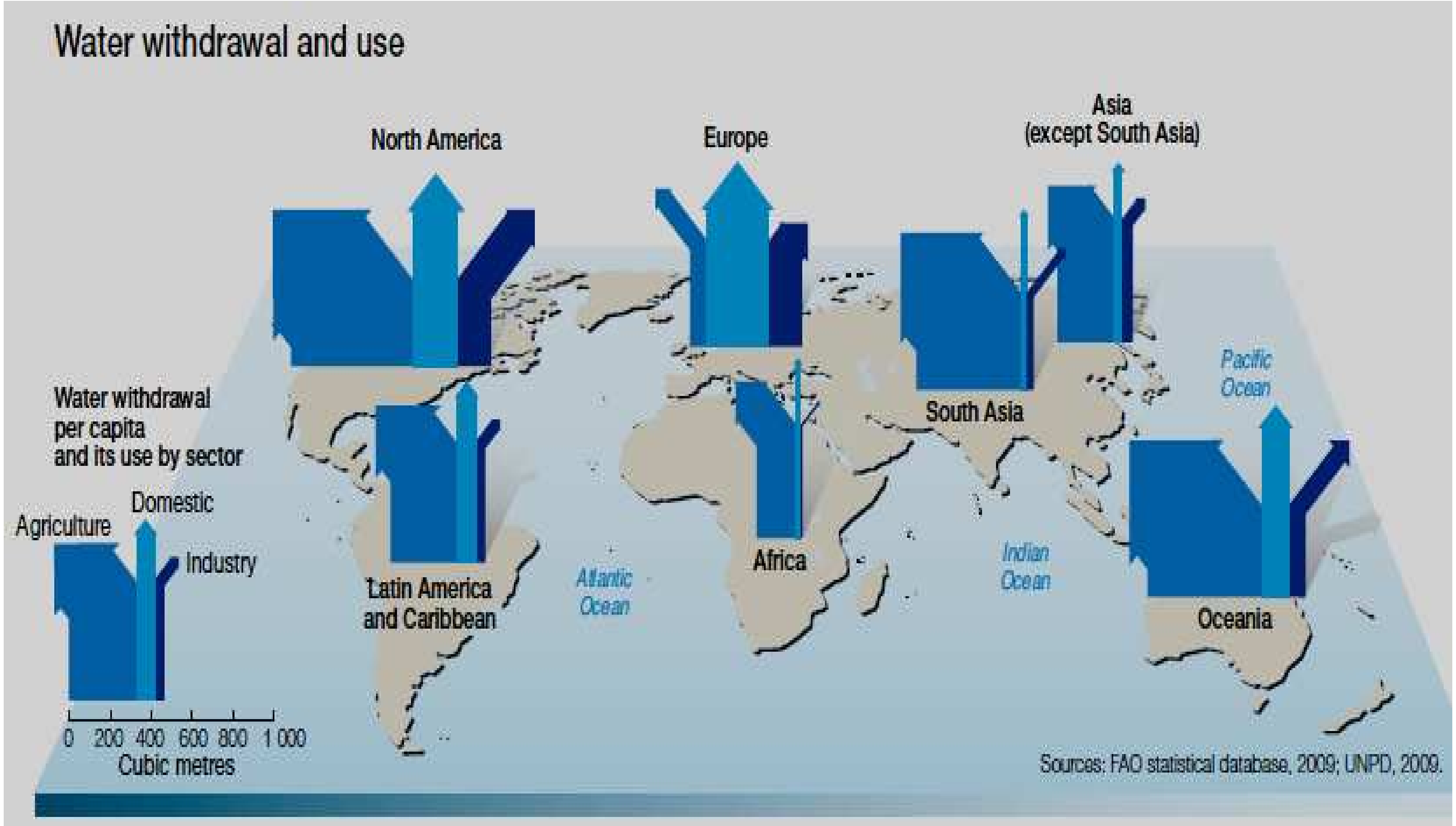
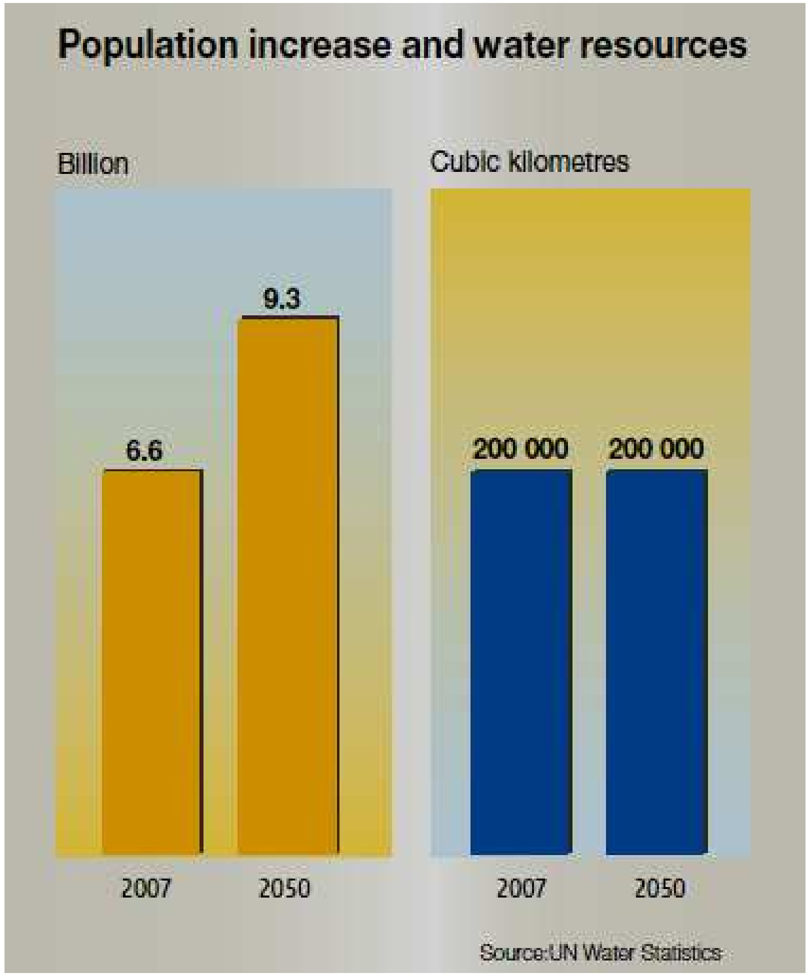
Imminent global freshwater crisis



Imminent global freshwater crisis



Imminent global freshwater crisis



The world's water resources will not change, but the human population and its demands on supply are growing rapidly. Meeting these demands will require wise investment in how we use and reuse our water (UN Water Statistics).

Wastewater or treasure? Wasting versus reusing of wastewater

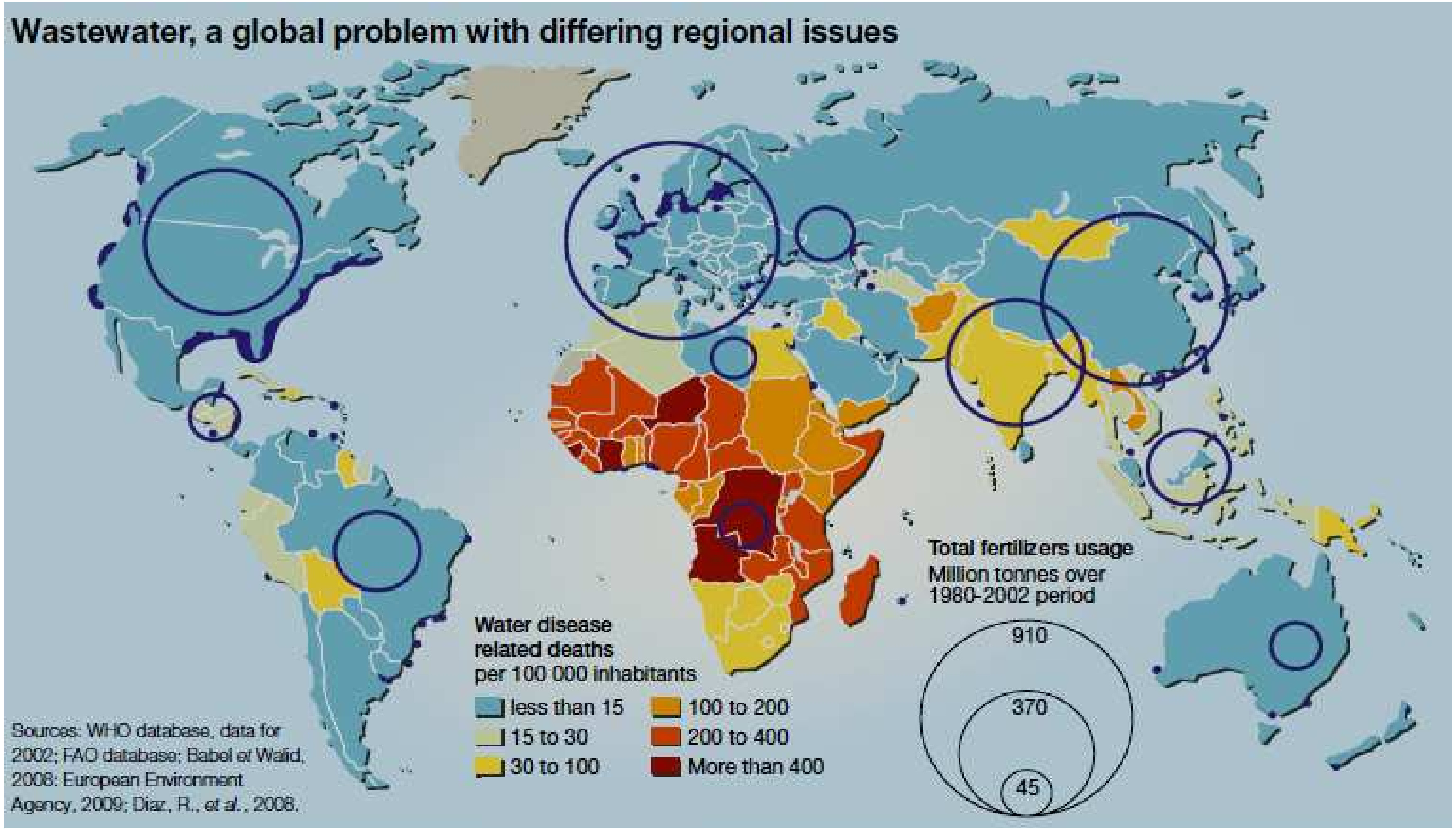
The most commonly cited estimate of annual global wastewater production is 1,500 cubic kilometers, which is a significant volume of water. There is a global trend in increasing dependence on the reuse of wastewater as sustainable non-conventional water resource for solving the rising global freshwater shortage especially in arid African countries.

Wastewater or treasure? Wasting versus reusing of wastewater

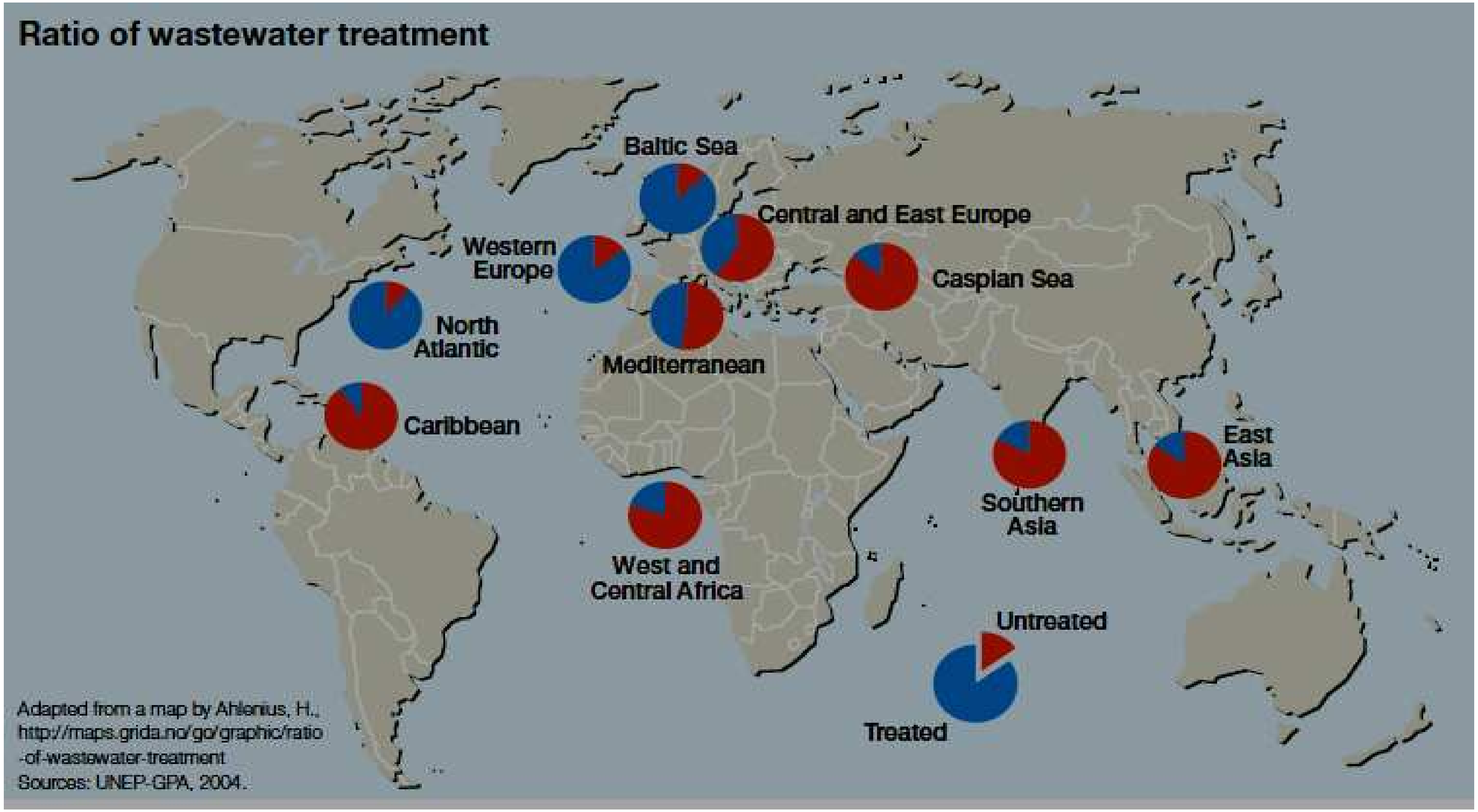
What do we mean by wastewater?

Wastewater can mean different things to different people with a large number of definitions in use. However, in a broad perspective, wastewater can be defined as a combination of one or more of: domestic effluent consisting of blackwater (excreta, urine and faecal sludge) and greywater (kitchen and bathing wastewater); water from commercial establishments and institutions, including hospitals; industrial effluent, stormwater and other urban run-off; agricultural, horticultural and aquaculture effluent, either dissolved or as suspended matter (adapted from Raschid-Sally and Jayakody, 2008).

Wastewater or treasure? Wasting versus reusing of wastewater



Wastewater or treasure? Wasting versus reusing of wastewater



Wastewater or treasure? Wasting versus reusing of wastewater

The world is facing a global water quality crisis. Continuing population growth and urbanisation, rapid industralisation, and expanding and intensifying food production are all

putting pressure on water resources and increasing the unregulated or illegal discharge of contaminated water within and beyond national borders. This presents a global threat to human health and wellbeing, with both immediate and long term consequences for efforts to reduce poverty whilst sustaining the integrity of some of our most productive ecosystems.

There are many causes driving this crisis, but it is clear that freshwater and coastal eco-systems across the globe, upon which humanity has depended for millennia, are increasingly threatened.

It is equally clear that future demands for water cannot be met unless wastewater management is revolutionized.

Microalgae for wastewater treatment

Algae are recognised to play a central role in the natural self-purification of contaminated waters.

The basics to purposely use microalgae for wastewater treatment has been laid by Caldwell et al. (1946) and Oswald et al. (1951, 1953, 1956, 1957.

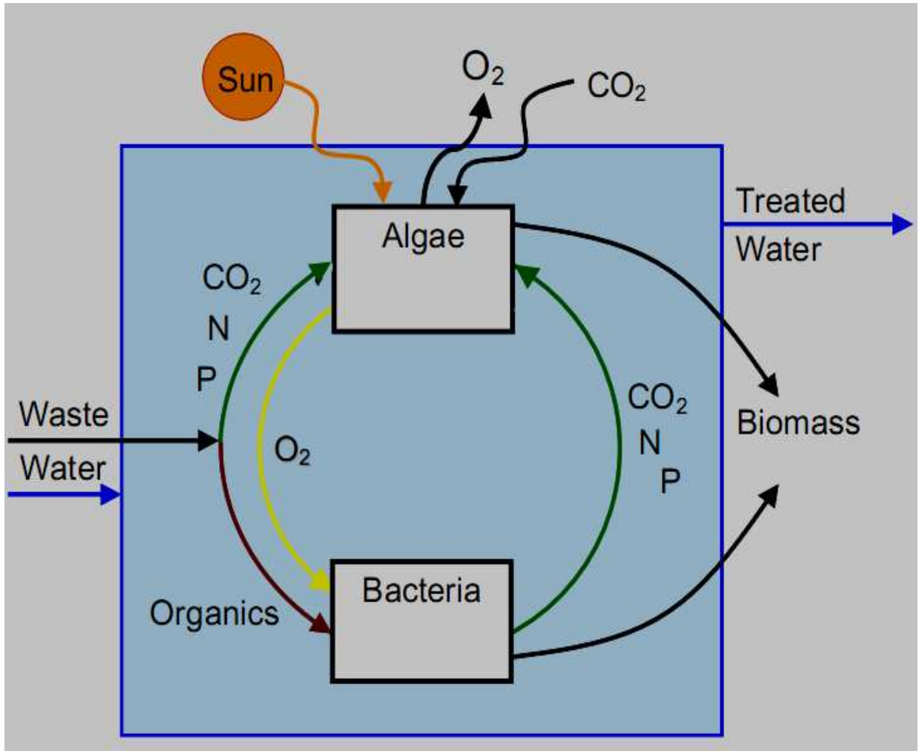
Following their pioneering work, microalgae wastewater treatment and nutrient removal has shown great promise and algae based wastewater treatment processes have been gaining tremendous attentions since 1960s

William J. Oswald, pioneer in the use of algae to treat wastewater, an innovator in algae biotechnology and natural wastewater treatment. He has died at 86 on Dec. 8, 2005.

Microalgae for wastewater treatment

Basic concepts of algae-bacteria symbiosis in wastewater treatment

Oswald et al. (1953) coined the term **photosynthetic oxygenation** to describe the treatment of wastewater by **algal cells and heterotrophic bacteria**. In this process the organic waste is decomposed by the bacteria to inorganic nutrients, and these are incorporated into algal biomass, which may then be separated from the effluent. **Thus the waste is treated and nutrients recycled into algal biomass.**



Algae-bacteria symbiosis in wastewater treatment (Lundquist et al. 2007)

Microalgae for wastewater treatment

Wastewater as fertile nutrient medium for microalgae

Domestic and agricultural wastewater are mostly non-toxic for certain eutrophic and saprobic microalgae (e.g. species of *Chlorella, Scenedesmus, Micractinium* …etc) c rich in plant nutrients mostly P and N)

These wastewaters are rich in essential macronutrients nutrients (e.g. N, P, P, S) and essential micronutrients (e.g. Fe, Cu, Mn) in addition to inorganic and organic carbon sources.

These are the nutrients, microalgae need to photosynthesis to grow and to build up the biomass

Accordingly, non-toxic wastewater could be potential natural fertile medium for heavy algal growth

Microalgae for wastewater treatment

Brief history of applied uses of microalgae for wastewater treatment

Aziz and Ng et al. (1992) treated wastewater with algae and found that it was able to remove 80-88% of BOD, 70-82% of COD, 60-70% of nitrogen and 50-60% of phosphorus, with a retention period of 15 days.

Martinez et al. (2000) reported that *Scenedesmus obliquus* was able to achieve 98% elimination of phosphorus and a complete removal (100%) of ammonium nitrogen in a stirred culture at 25 C° over 94 and 183 h retention time, respectively.

Gomez Villa et al. (2005) reported that the outdoor cultivation of *Scenedesmus obliquus* in artificial wastewater achieved reduction in nitrogen by 53% and 21% of initial values in winter and summer, respectively. Phosphorus showed a total reduction of 45% in winter and 73% in summer.

Hodaifa et al. (2008) recorded 67.4% reduction in BOD5 with *Scenedesmus obliquus* cultured in diluted (25%) industrial wastewater from olive-oil extraction.

Microalgae for wastewater treatment

Brief history of applied uses of microalgae for wastewater treatment

Shen et al. (2008) investigated the treatment of livestock wastewater and production of biomass and lipids of *Botryococcus braunii*. *B. braunii* was able to remove 88% of total nitrogen and 98% of total phosphorus over the course of two weeks while producing 19.8% (DW) crude oil content.

Hu et al. (2009) reported that the freshwater microalga *Scenedesmus* sp. LX1 was able to grow well in secondary treated domestic wastewater with biomass production (0.11 g l^{-1} dry weight) with lipid content of 31–33%.

Chinnasamy et al. (2010) investigated the effect of carpet wastewater on growth of a natural consortium of microalgae for feasible production of biofuels through anaerobic digestion or thermochemical liquefaction of algal biomass

Microalgae for wastewater treatment

Why are algae being considered the best candidates for wastewater treatment?

1. Saving money and energy :

mechanical aeration

one kg of BOD removed in an activated sludge process

⇓ requires

one kWh of electricity for aeration

⇓ produces

one kg of fossil CO_2 from power generation

oxygen through photosynthesis.

one kg of BOD removed by photosynthetic oxygenation

⇓ requires

no energy inputs

⇓ produces

algal biomass to generate methane that can produce one kWh of electric power

Microalgae for wastewater treatment

Why are algae being considered the best candidates for wastewater treatment?

2. The use of municipal wastewater to grow algae might obviate the need for freshwater.

3. Providing reusable water free from pollutants, pathogenic bacteria through bactericide action and bad odor.

4. Recycling nutrients into algae biomass as a fertilizer with almost sludge handling problem.

5. Offset treatment cost by lowering cost of operation.

6. Oxygen rich effluent is released into water bodies after wastewater treatment using algae.

7. Valuable and promising alternatives to conventional treatment systems based on activated sludge or trickling filters.

Microalgae for wastewater treatment

Phycoremediation (algae-based) processes in wastewater treatment

1. Nutrients uptake

- Nitrogen and phosphorous are essential macronutrients for the growth of microalgae
- Kim et al. (1998) reported 95.3% and 96% removal of nitrogen and phosphorus, respectively, by *Chlorella vulgaris* in 25% secondarily treated swine wastewater after four days of incubation.
- Microalgae showed their ability to increase growth by uptaking various forms of inorganic nitrogen mostly ammonium-N and nitrate-N with **stripping off the toxic ammonia gas through the elevated pH** (Jin et al., 2008).
- Travieso et al. (2008) treated distillery wastewater from an anaerobic fixed-bed reactor in a microalgae pond and obtained 90.2%, 84.1%, and 85.5% removal of organic nitrogen, ammonia, and total phosphorus, respectively.

Microalgae for wastewater treatment

Phycoremediation (algae-based) processes in wastewater treatment

2. Removal of heavy metals

Microalgae require different metals for biological functions

- It has been reported that certain **green microalgae** by physical adsorption process can **adsorb metals ion** very quickly just in a few seconds or minutes. Then, these ions are transported slowly into the cytoplasm in a process called **chemisorption**.
- **Polyphosphate bodies** enable microalgae to **store metals** such as Ti, Pb, Mg, Zn, Cd, Sr, Co, Hg, Ni, Cu. These bodies perform two different functions; provide a "**storage pool**" for metals and act as a "**detoxification mechanism**".
- The metal bioremoval process mainly combines two types of mechanism. **Passive uptake (metabolism independent) and active uptake (metabolism dependent).**

Microalgae for wastewater treatment

Phycoremediation (algae-based) processes in wastewater treatment

3. Bioremediation of toxic organic pollutants

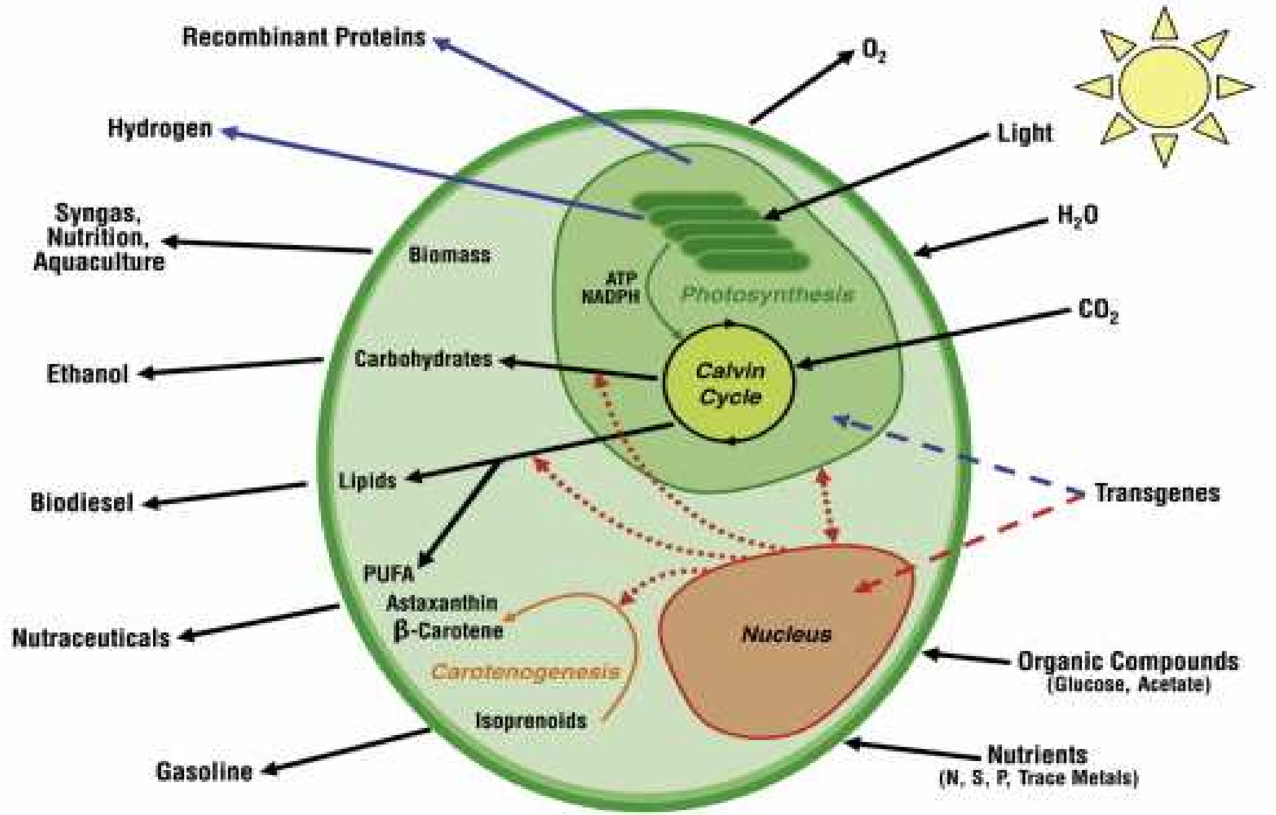
- Walker et al. (1975) performed experiments with the non-chlorophyllous alga ***Prototheca zopfii***, which was found to degrade petroleum hydrocarbons found in Louisiana crude and motor oils.

- Jinqi and Houtian (1992) investigated the degradation of azo dyes by ***Chlorella vulgaris*** and ***Chlorella pyrenoidosa*** and found that certain dyes (e.g. eriochrome black T) could be decolorized and actually be used as carbon and nitrogen sources.

- Lima et al. (2003) reported nitrophenol removal of 50 $mg^{-1}d^{-1}$ by a consortium of **Chlorella vulgaris** and ***Chlorella pyrenoidosa.***

Microalgae for wastewater treatment

Algal cells as biofactories



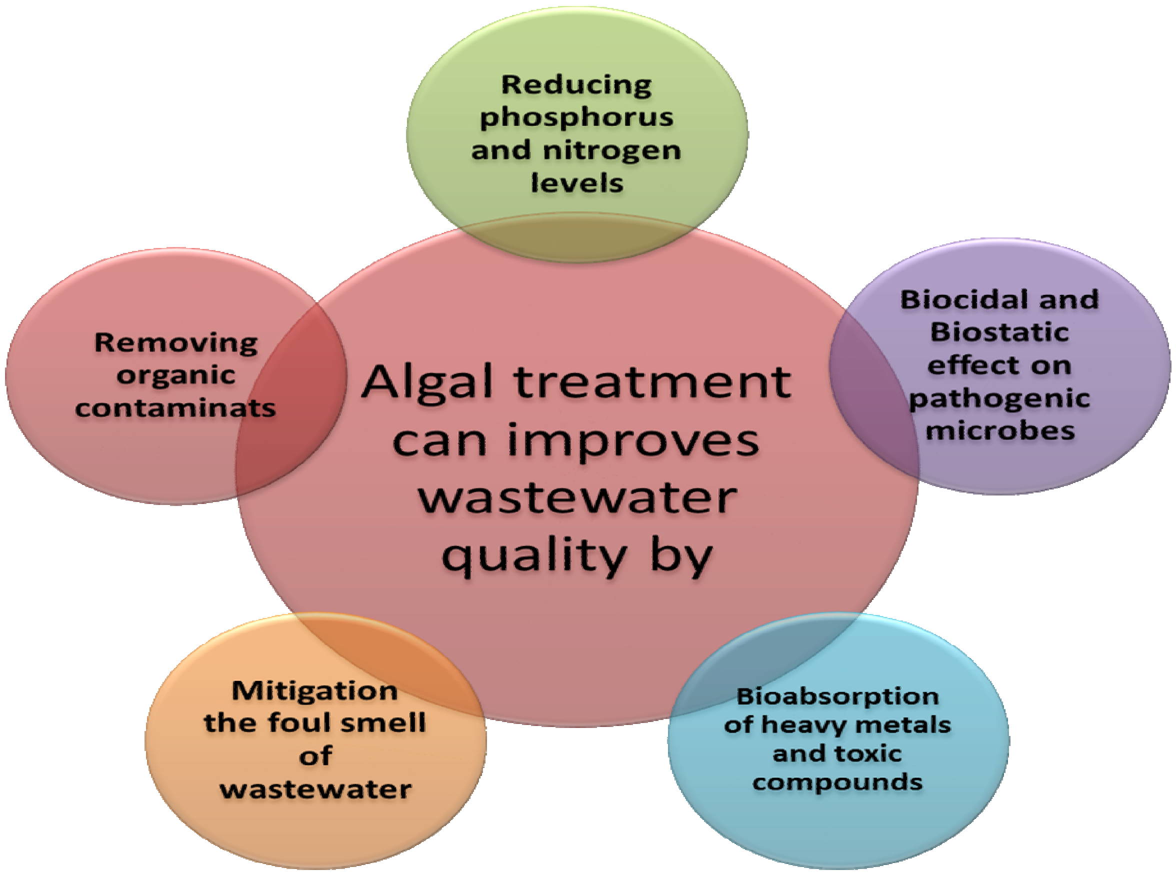
Rosenberg et al. (2008)

Microalgae for wastewater treatment

Some technical problems of combining wastewater treatment with mass production of algae biomass

- The nutrient-rich condition in wastewater, which promotes high productivity without inducing lipid accumulation
- The outdoor growth of certain algae species (e.g. lipid rich species) are hampered by contamination with native algae species and bacteria
- Harvesting of biomass

Microalgae for wastewater treatment

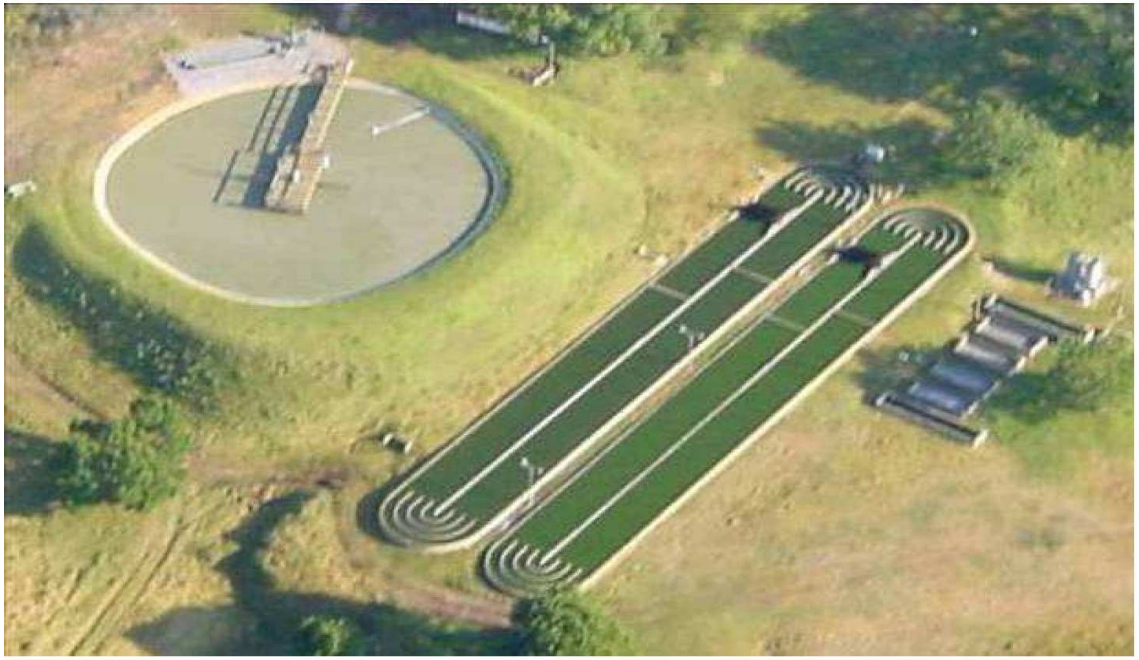


Benefits of using microalgae for wastewater treatment

Microalgae for wastewater treatment

Microalgae for wastewater treatment in action

Integrated Algae Pond Systems (IAPS) utilise anaerobic and aerobic biological processes in wastewater treatment and epitomise the principles of both water and nutrient recovery and reuse. These systems close the cycle of waste to biomass by converting organic waste into an algae biomass rich in protein, while stripping out nutrients.



Integrated Algae Pond System Institute for Environmental Biotechnology, Rhodes University (EBRU), Grahamstown South Africa

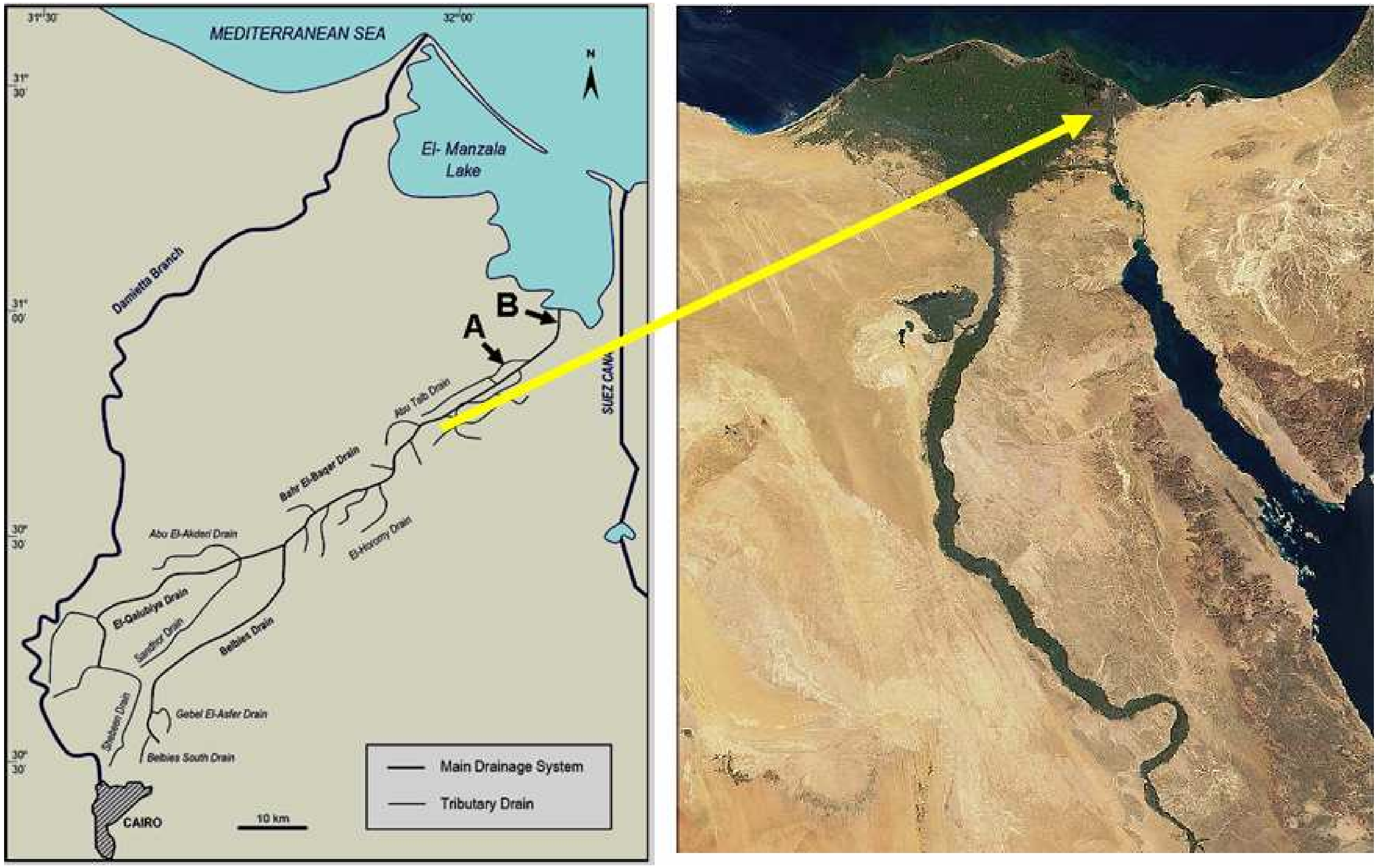
The use of microalgae for wastewater treatment: Egyptian case studies (R&D)

Drainage wastewater

Study area: Bahr El-Baqar Drain

- The main canal for wastewater disposal in the area between Cairo and the north eastern area of the Nile delta.
- The length of the main drain is 170 km and along its way from Cairo down to Lake Manzala.
- Receives about 3 billion m^3 $year^{-1}$ of domestic, agricultural, and industrial wastewaters.

Microalgae for wastewater treatment (Bahr El-Baqar Drain)



Microalgae for wastewater treatment (Bahr El-Baqar Drain)

Site A

Located at the mouth of Abu Talb agricultural drain

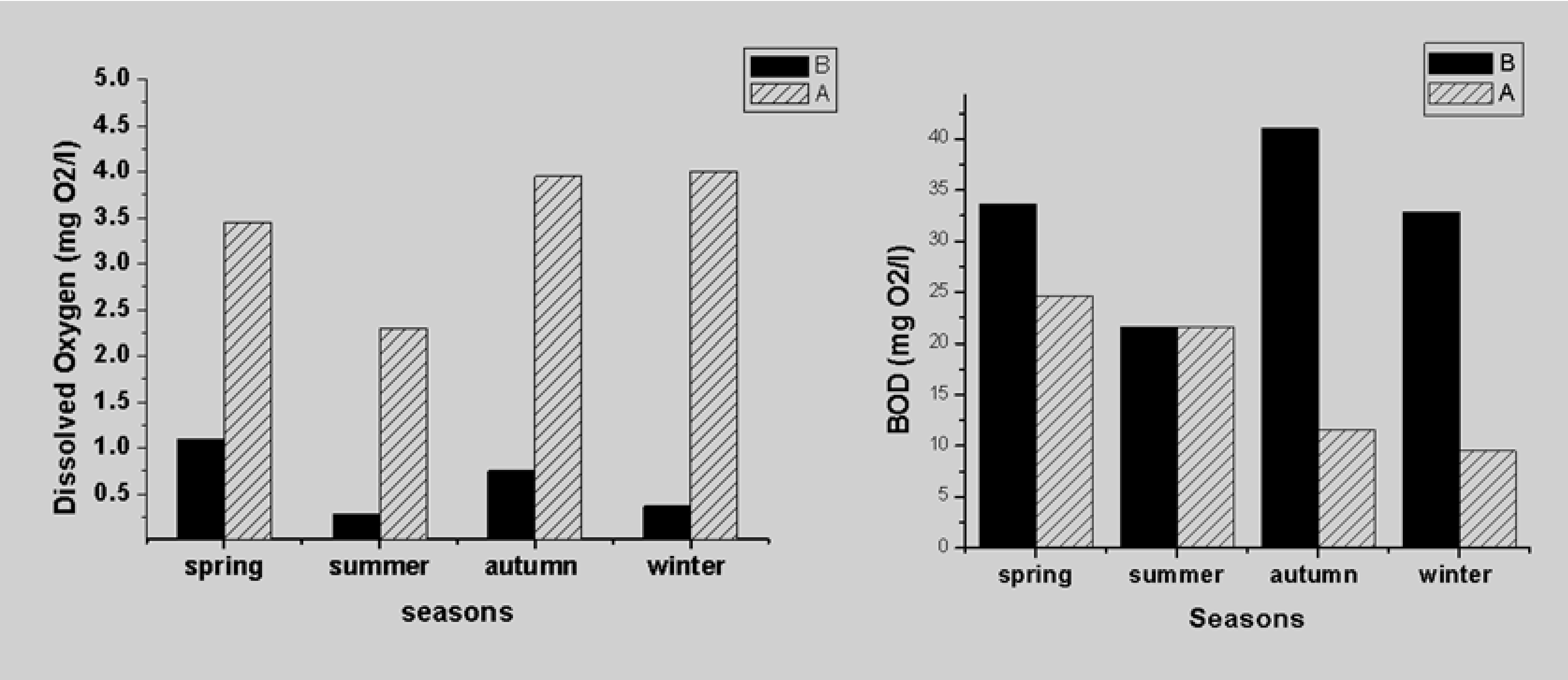
Site B

Located on the main drain of Bahr El-Baqar at 10 km downstream the discharging point into the Lake Manzala.

Map showing the wastewater sampling sites

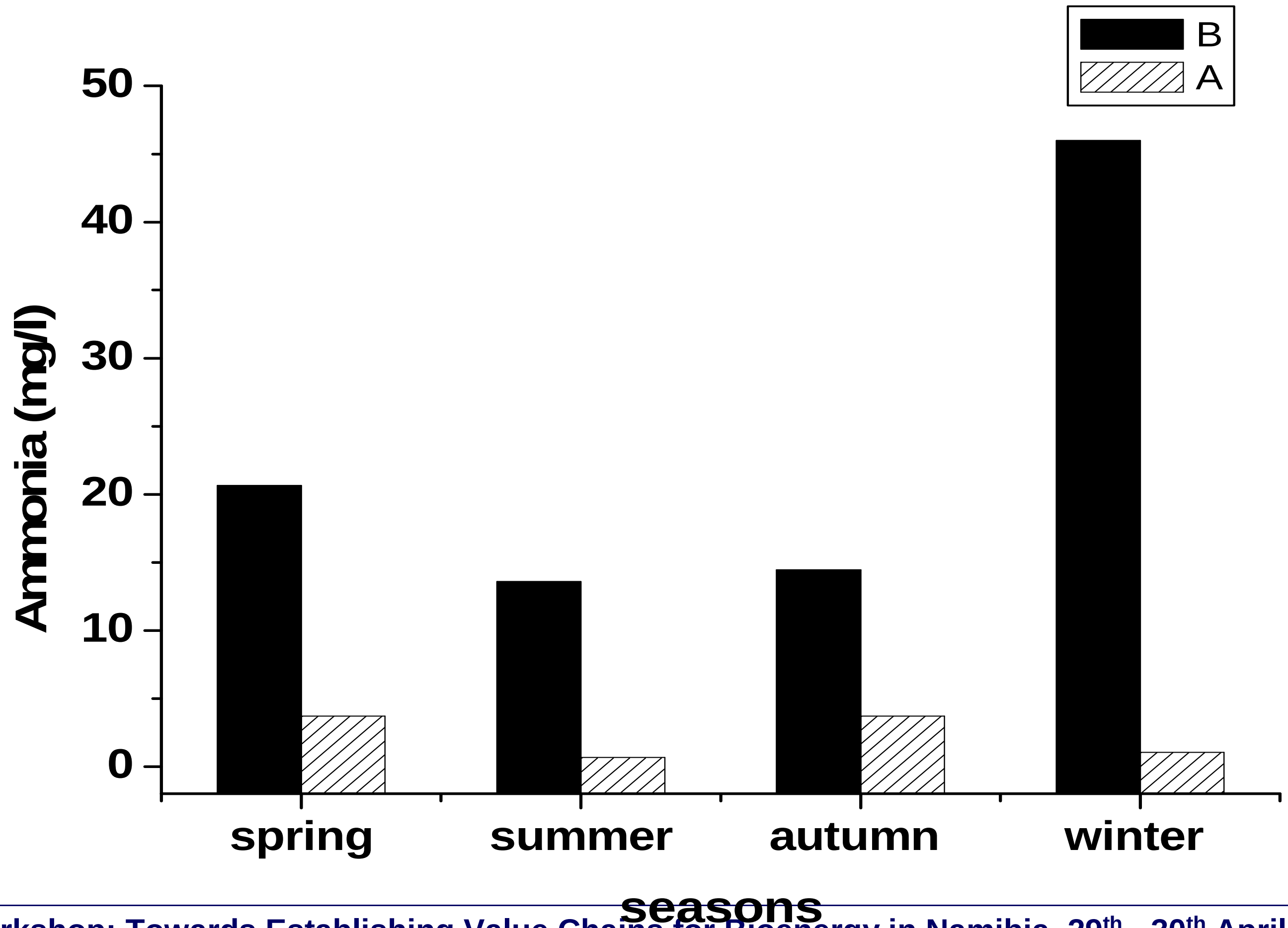
Microalgae for wastewater treatment (Bahr El-Baqar Drain)

Key chemical characteristics



Microalgae for wastewater treatment (Bahr El-Baqar Drain)

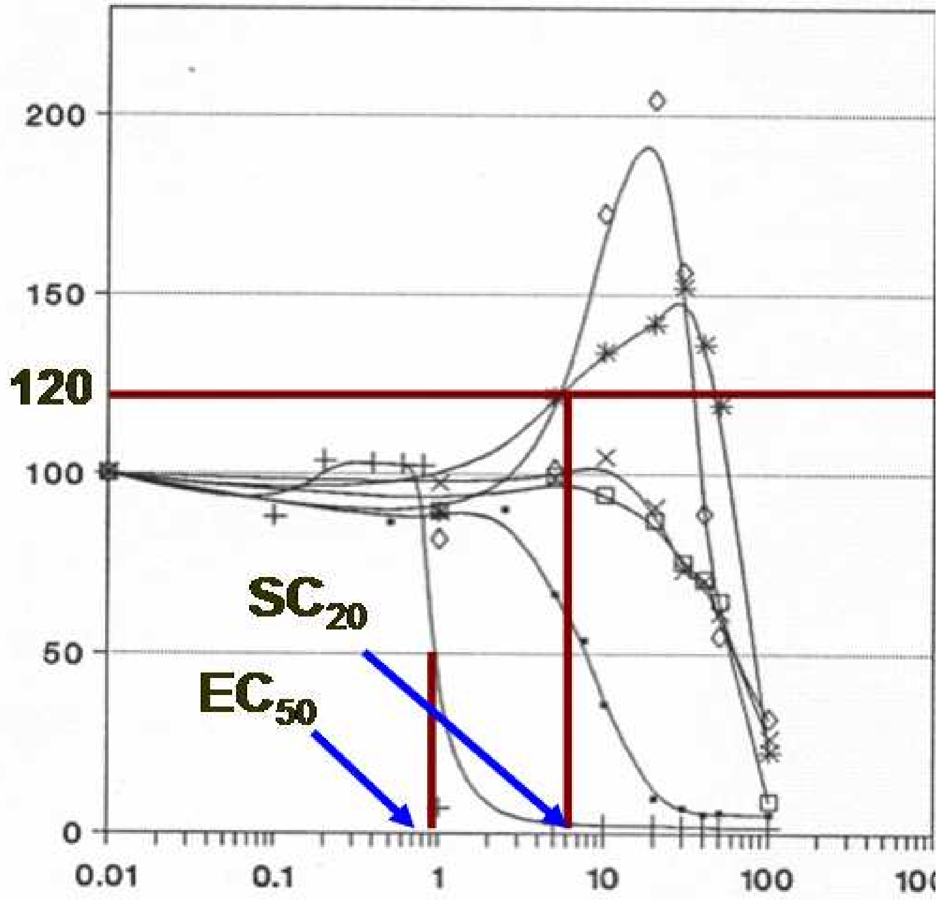
Key chemical characteristics



Assessment of wastewater toxicity (EC50) and fertility (SC20) with ISO standard algal biotest

Calculation of EC_{50} and SC_{20}

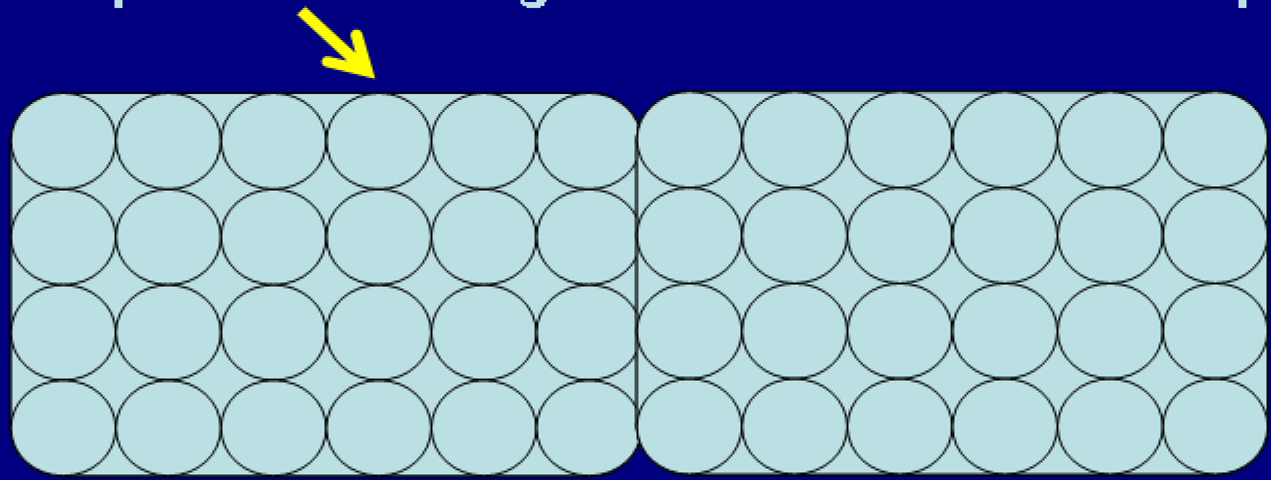
EC_{50} and SC_{20} express the minimum effluent concentrations inhibiting and stimulating the algal growth by 50% and 20% respectively. Growth expressed as dry weight. Values of the four toxicity response parameters were plotted - as relative percents of their controls (control = 100%) - against the corresponding effluent concentration. This allowed the calculation of EC50 and SC20 by the straight-line graphical interpolation method (Walsh et al., 1987)



Wastewater Toxicity and Fertility Bio-testing

Biotests can be carried out in polystyrene microplates containing 6x4 flat bottom wells each of 3 ml capacity

A micro-plate containing 24 well each of 3.0 ml capacity



Tested wastewaters

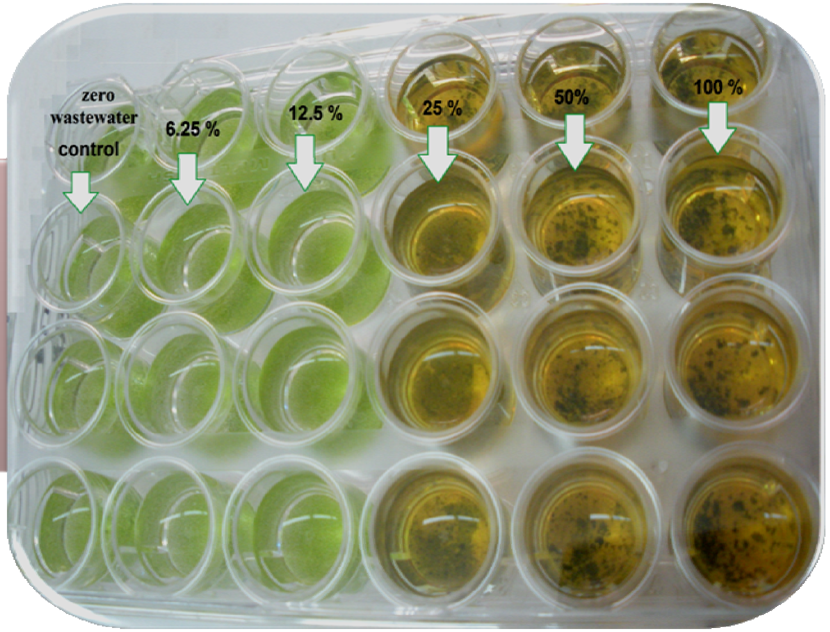
100 50 25 12.5 6.25 3.12 1.56 .78 .39 .195 .097 0.0

% wastewater (v/v)

Assessment of wastewater toxicity (EC_{50}) and fertility (SC_{20}) using standard algal bio-tests

Test microalgae were grown in different % V/V GF/C filtered drainage wastewater levels including 0.0 % (control culture), 6.25%, 12.5%, 25%, 50%, 100%.

Microplates were incubated for 5 days at 22± 2°C under continuous illumination (≅70 $\mu Em^{-2}s^{-1}$) provided by white fluorescent cool tubes.

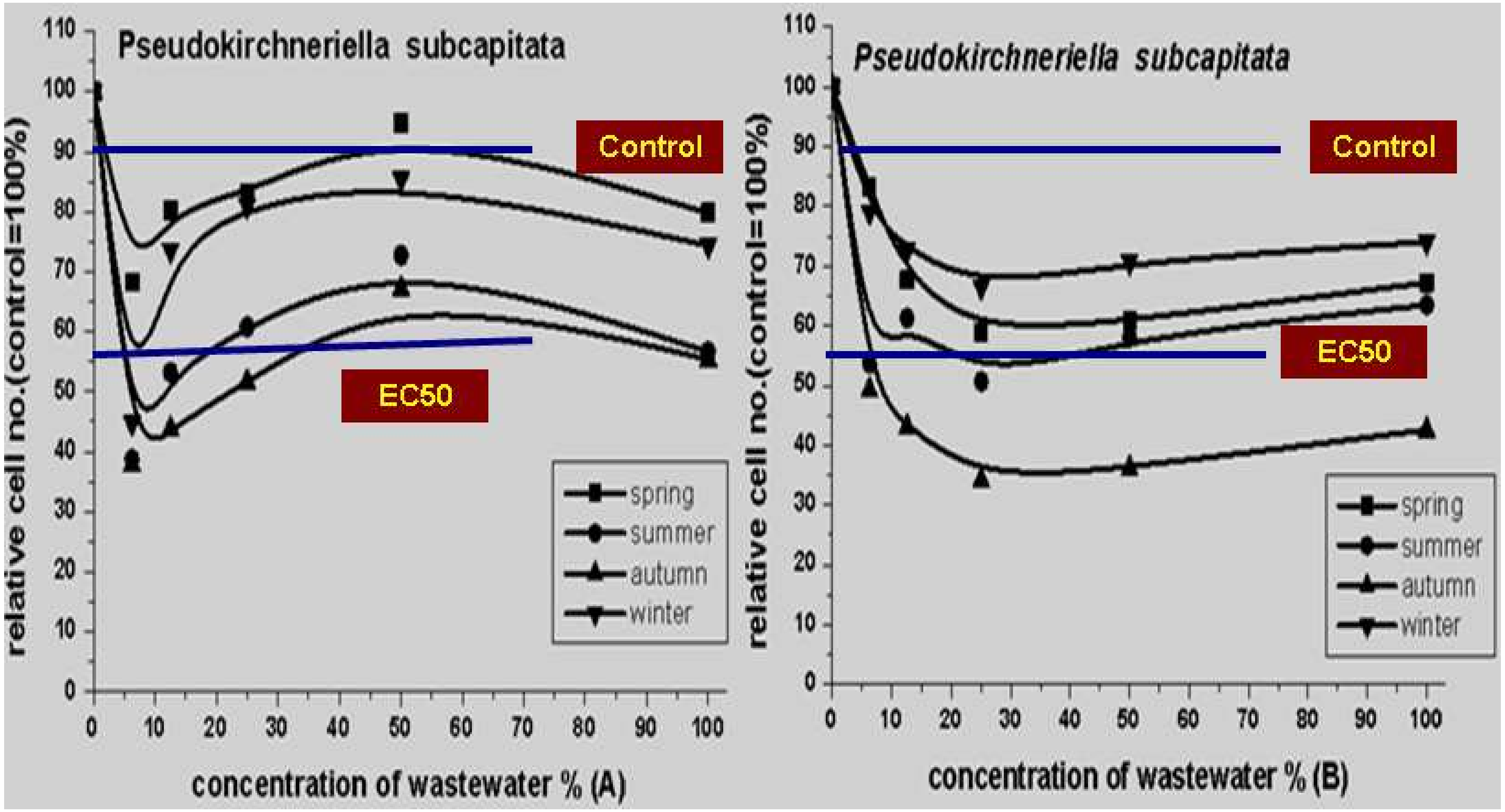


<u>Test microalgae:</u>

Pseudokirchneriella subcapitata, Chlorella sp. strain BIRD CHL 113, 121,124 and 125.

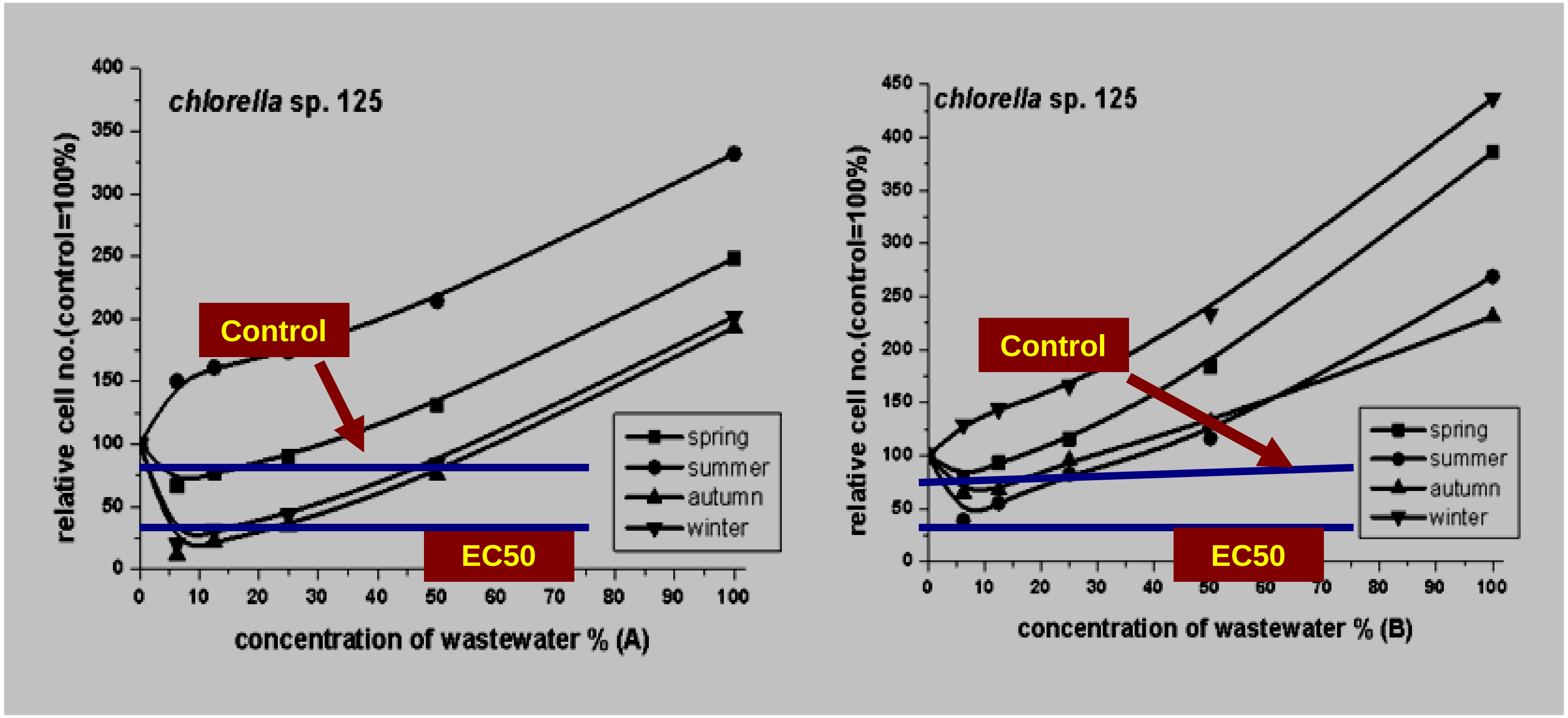
Microalgae for wastewater treatment (Bahr El-Baqar Drain)

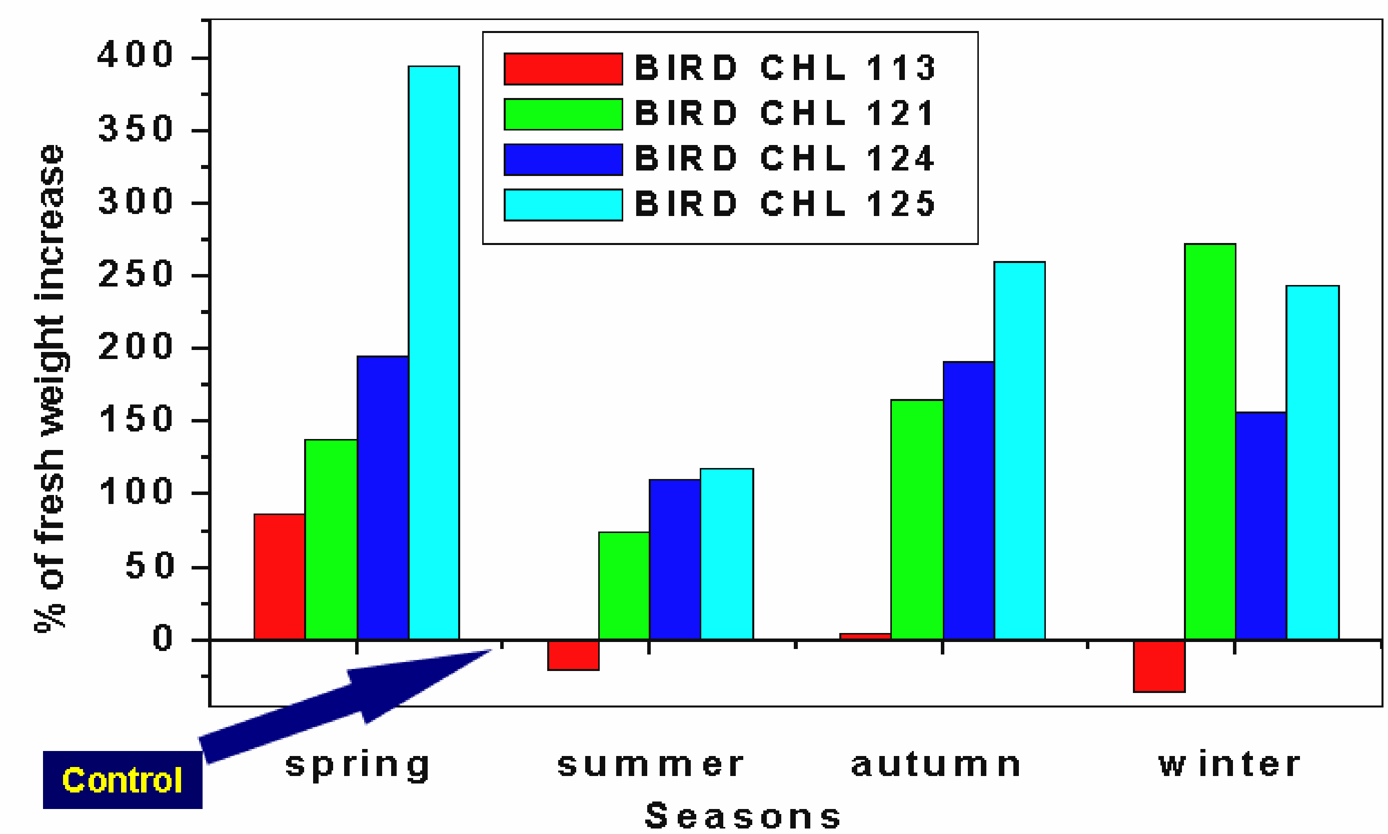
Assessment of wastewater toxicity (EC50) and fertility (SC20) with ISO standard algal biotest



Microalgae for wastewater treatment (Bahr El-Baqar Drain)

Native microalgae isolates





% increase in biomass of *Chlorella* spp. grown in 100% wastewater compared to control cultures

Chlorella **spp. showed extraordinary adaptation to grow in drainage wastewater and to buildup heavy biomass**

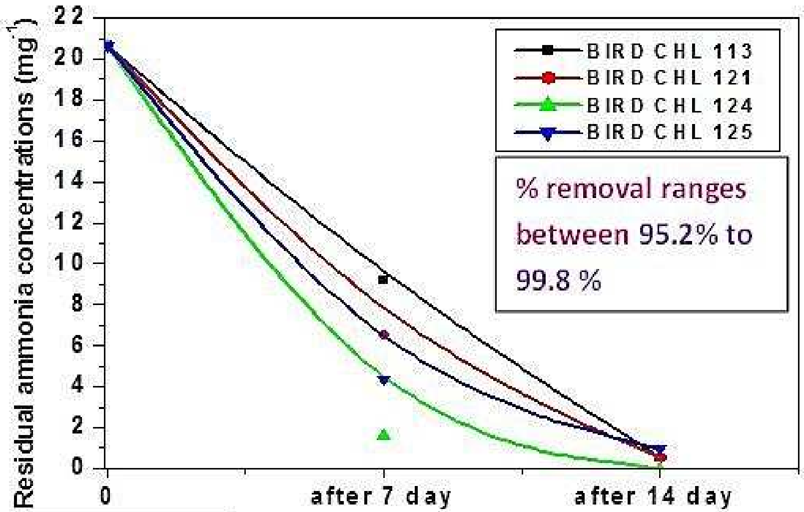


Figure 4-A

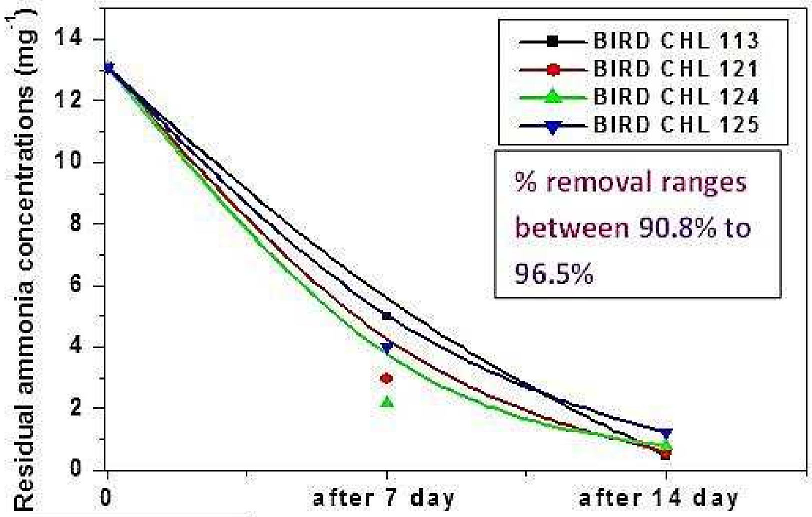


Figure 4-B

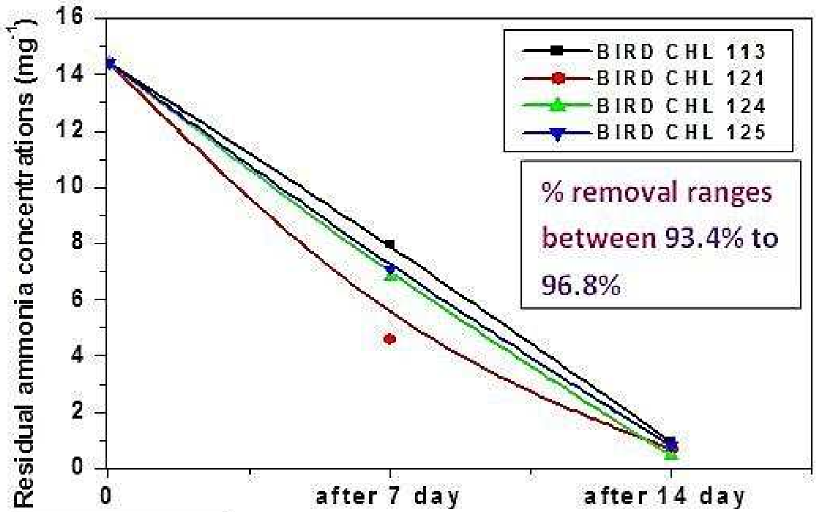


Figure 4-C

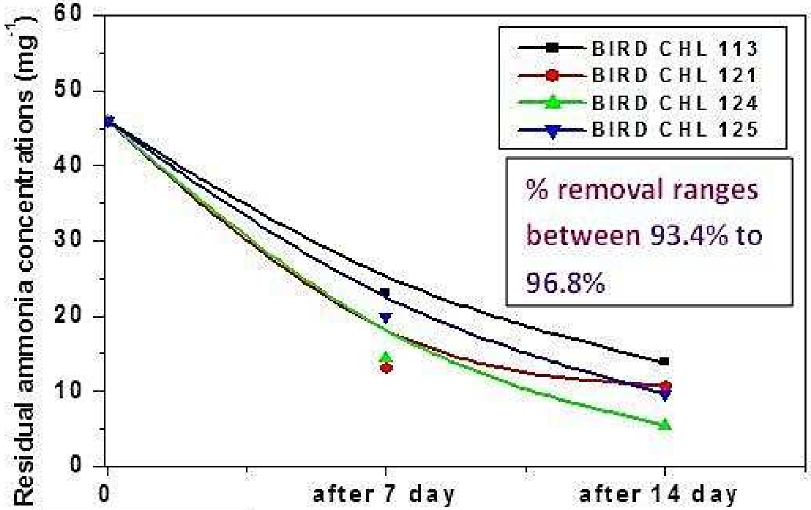


Figure 4-D

Ammonia-N uptake by different test species of *Chlorella*

Industrial wastewater: Case Study

Raw wastewater

Treated wastewater

Massive algal growth in wastewater receiving drain (mixed wastewaters)

Heavy metal analyses of raw and treated (air sparged) wastewater.

Heavy metals	Unit	Inlet raw industrial wastewater	Treated industrial wastewater
Fe	$mg\ l^{-1}$	0.53	0.41
Mn	$mg\ l^{-1}$	0.35	0.29
Cd	$mg\ l^{-1}$	0.83	0.53
Ni	$mg\ l^{-1}$	0.26	0.26
Cu	$mg\ l^{-1}$	0.14	0.15
Pb	$mg\ l^{-1}$	0.06	0.06

ACP S&T PROGRAMME

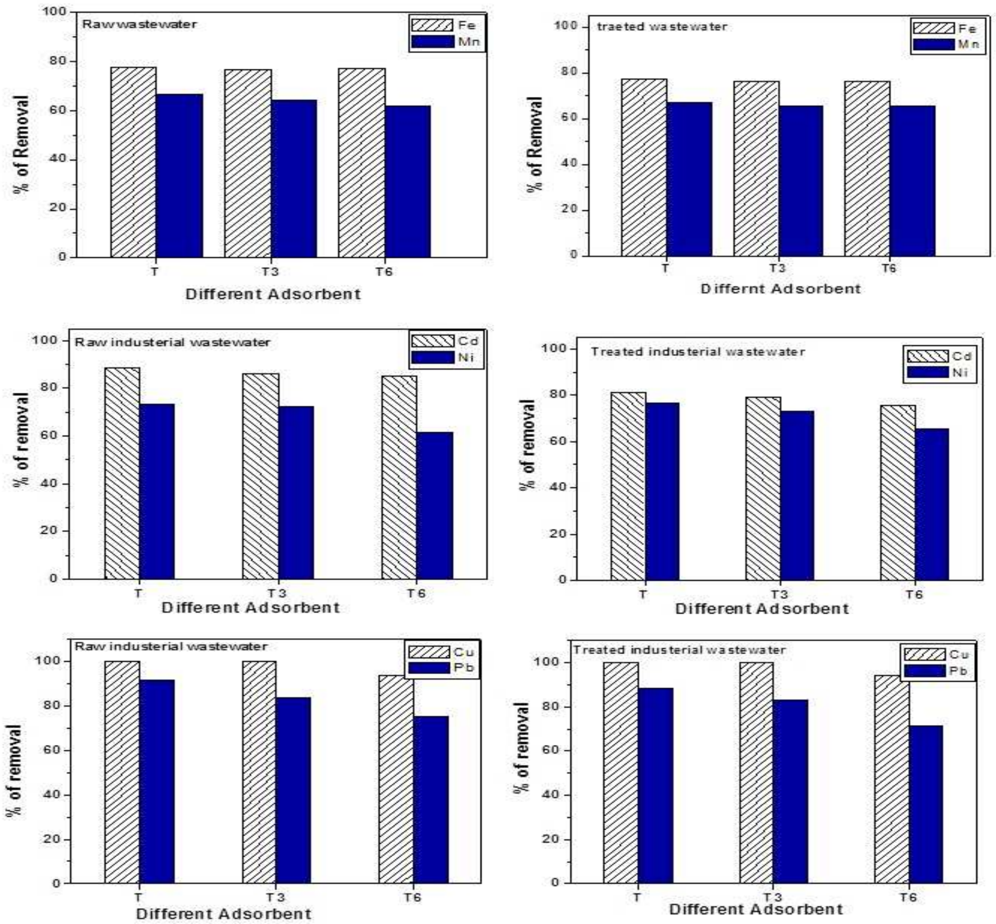
Heavy metals removal with granulated composites blends of a phyco-polymer and calcareous soil

The use of **biopolymers alone** to remove heavy metals from industrial wastewater may be an **economically exhaustive process**

•

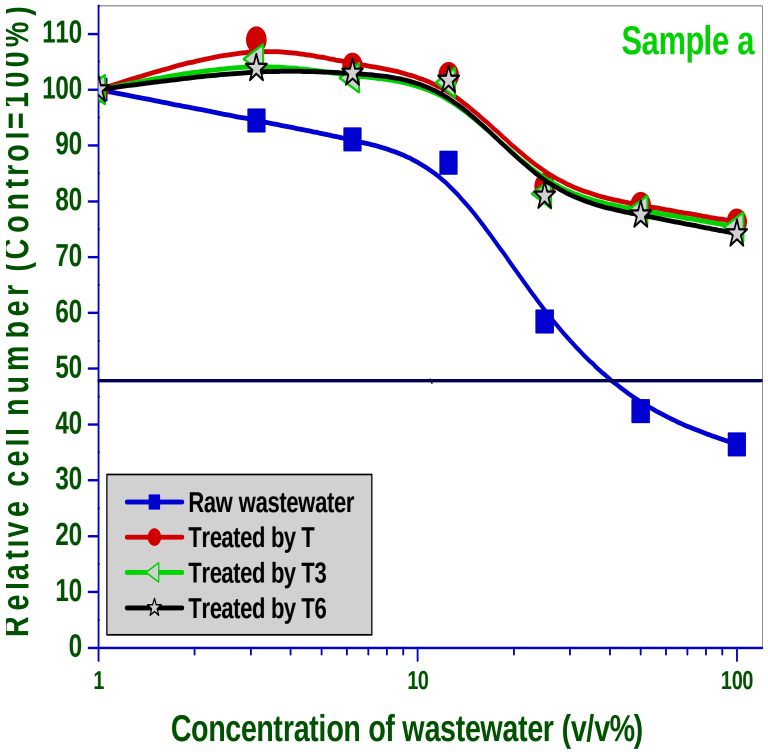
The use of **soil alone** for the same purpose may impose **technical problems** related to the separation of soil particles from the aqueous system.

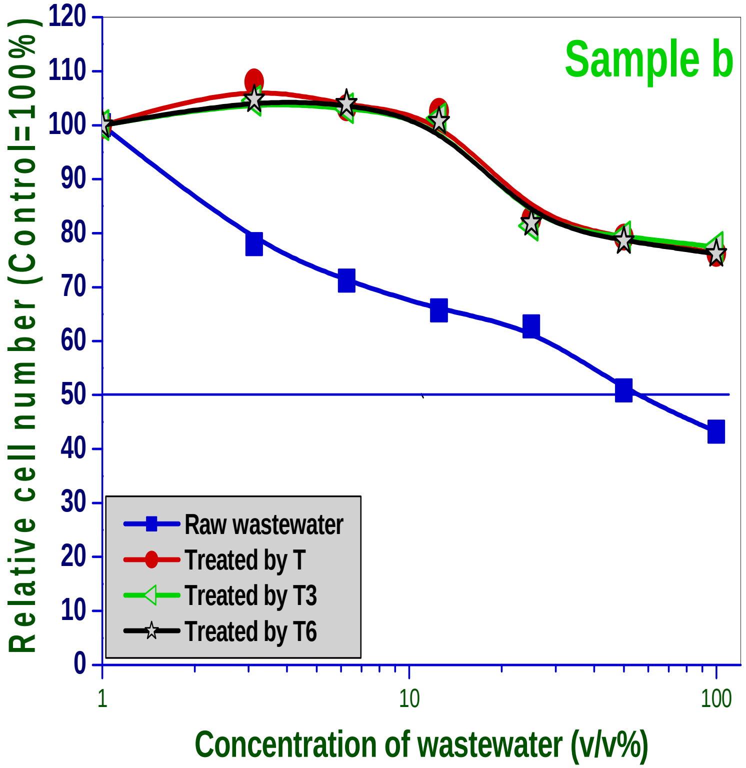
The use of **granular blends of calcium biopolymers and soil** may resolve these problems.



Reduction in heavy metals (60.5% - 100%)

% of removal of Fe (III),Mn (II),Cu (II),Pb (II),Cd (II) and Ni (II) from raw and treated industrial wastewater using pure phyco-polymer, 1:3 and 1:6 phyco-polymer: soil beads.





Toxicity assessment of wastewater using standard algal biotest.

The wastewater toxicity (EC_{50}) was greatly reduced after being treated with the phycopolymer- soil composites

Wastewater as Potential input for feasible algae biomass production

Agricultural drainage water in Egypt

The agricultural drainage water volume in Egypt is about **12.0 billion cubic meters (BCM)** a year Agricultural drainage water is fertile containing high concentrations of essential nutrients (mainly N and P) and could be used as feed water for algae cultivation

Treated Sewage in Egypt

Egypt today produces some **8 billion** cubic meters of treated wastewater annually.

Industrial Wastewater in Egypt (around 4 BCM)

Potential inputs , Agricultural drainage fertile water (Lakes of Wadi Rayan)

Potential inputs , treated sewage as source of nutrients

Wastewater as Potential input for feasible algae biomass production

Potential requirements for sustainable production of algal biomass for biofuels;

1) Vast areas of nonarable land

2) Sun shines all the year round (light energy)

3) Massive amounts of wastewaters

2) 2000 km coasts

4) CO_2, nutrients and energy much cheaper (electricity, fuel)

5) Human resources (population size 80,330,000)

Recommended publication for further reading

UNEP(2010) http://www.unep.org/pdf/SickWater_screen.pdf

Wastewater : Act locally and think globally

It is true that a healthier future needs urgent global action for smart, sustained investment to improve wastewater management

Key Messages:

1. **Wastewater production is rising**
2. **Wise and immediate investment will generate multiple future benefits**
3. **Improved sanitation and wastewater management are central to poverty reduction and improved human health**
4. **Successful and sustained wastewater management will need an entirely new dimension of investments, to start now**

A word of gratitude

It is a pleasant duty to express my sincerely thanks to the Organizing Committee of the workshop "African, Caribbean and Pacific (ACP) Group States Science and Technology Programme" 29-32 April, 2013, Ministry of &Marine Resources, Swakopmund, Namibia. Special thanks are due to Anna Ipangelwa and Philip Hooks and W for their professional and sincerely cooperation. Thanks are also extended to the programme stakeholder and partners.


To your kind attention,
I am deeply grateful
&
Thank you very much