The feasibility of low cost algae-based sewage treatment as a climate change adaption measure in rural areas of SADC countries

Focus areas of presentation:

1. SADC countries
2. Self-sustainable technology requiring no chemicals or electricity
2. Algae bio-reactors
3. Impact pathway

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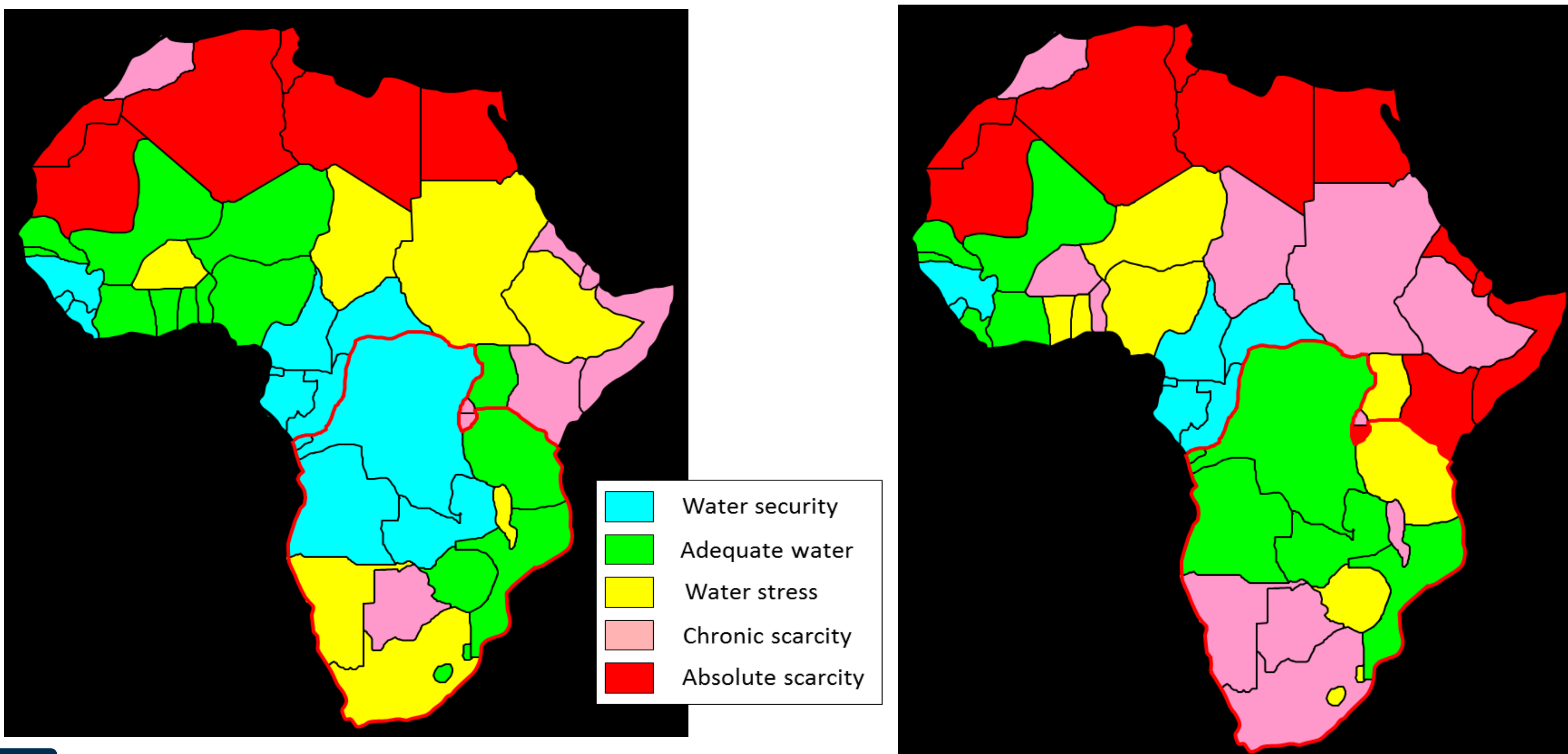
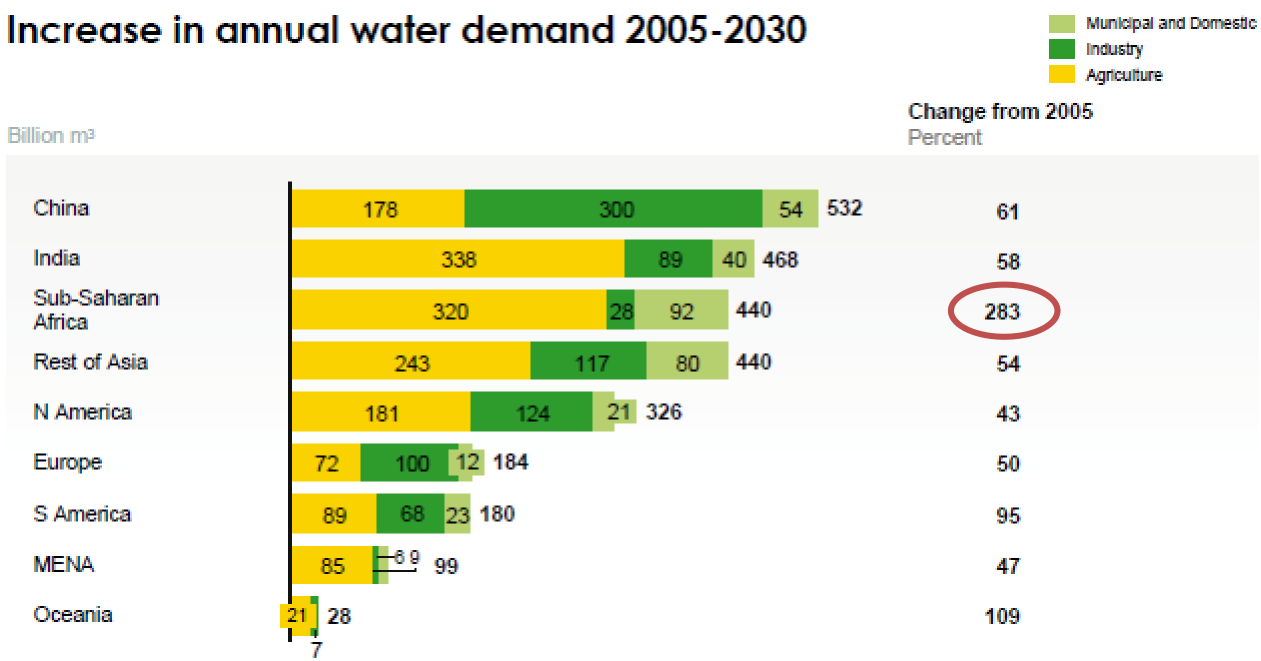
Water availability in Africa

2002 | 2025

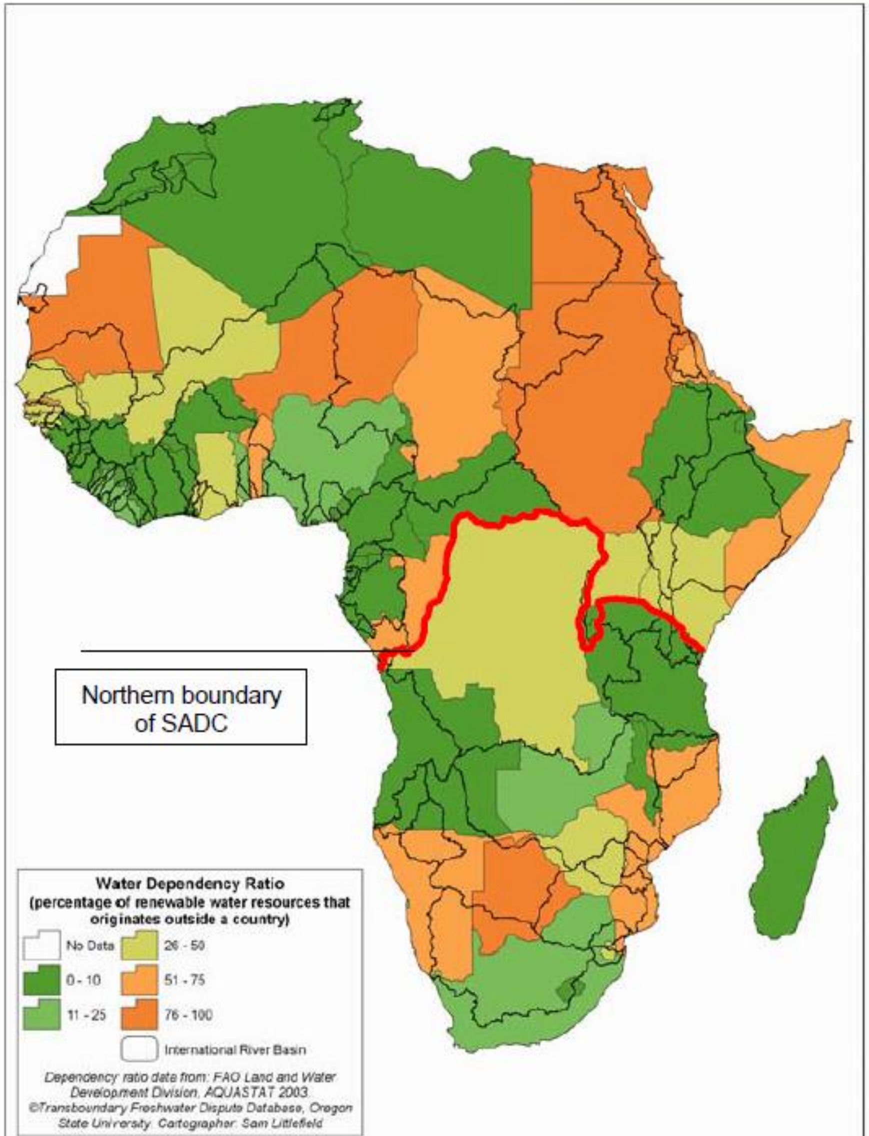


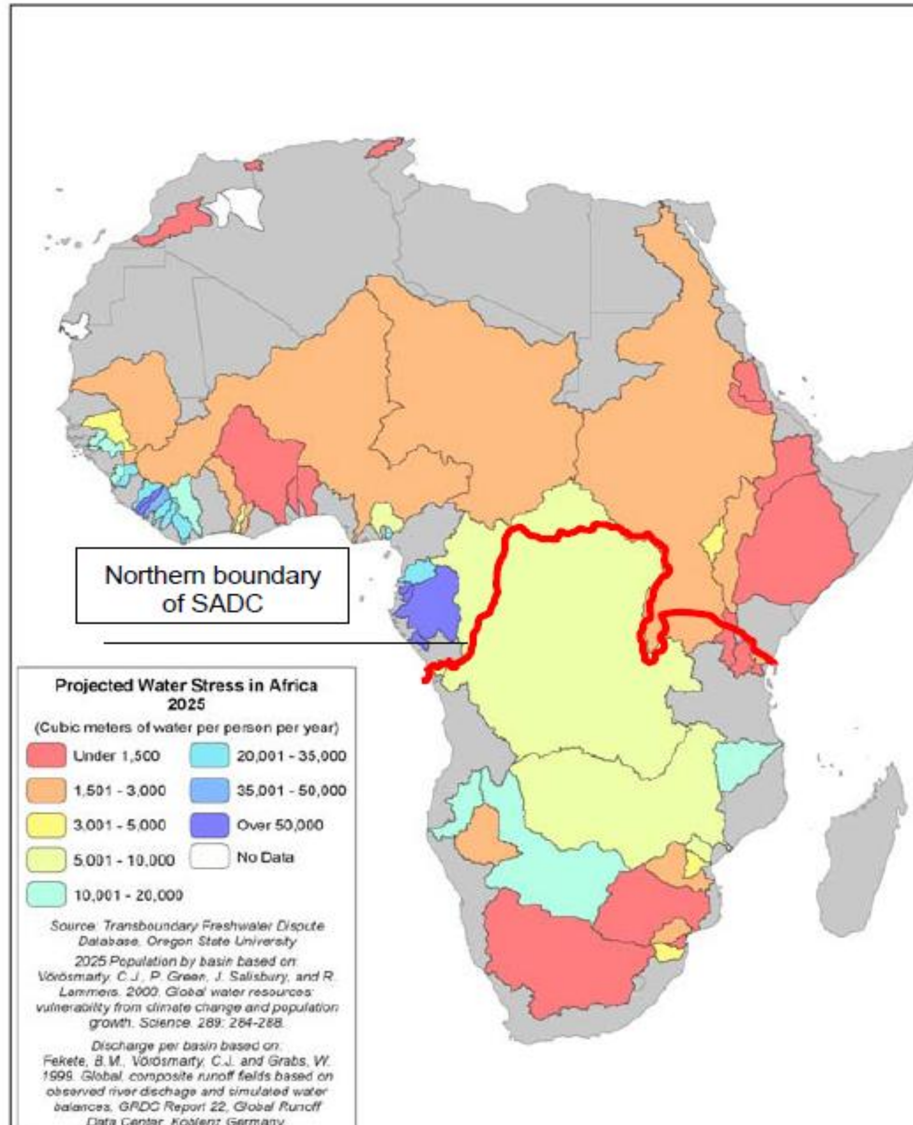
Annual water demand



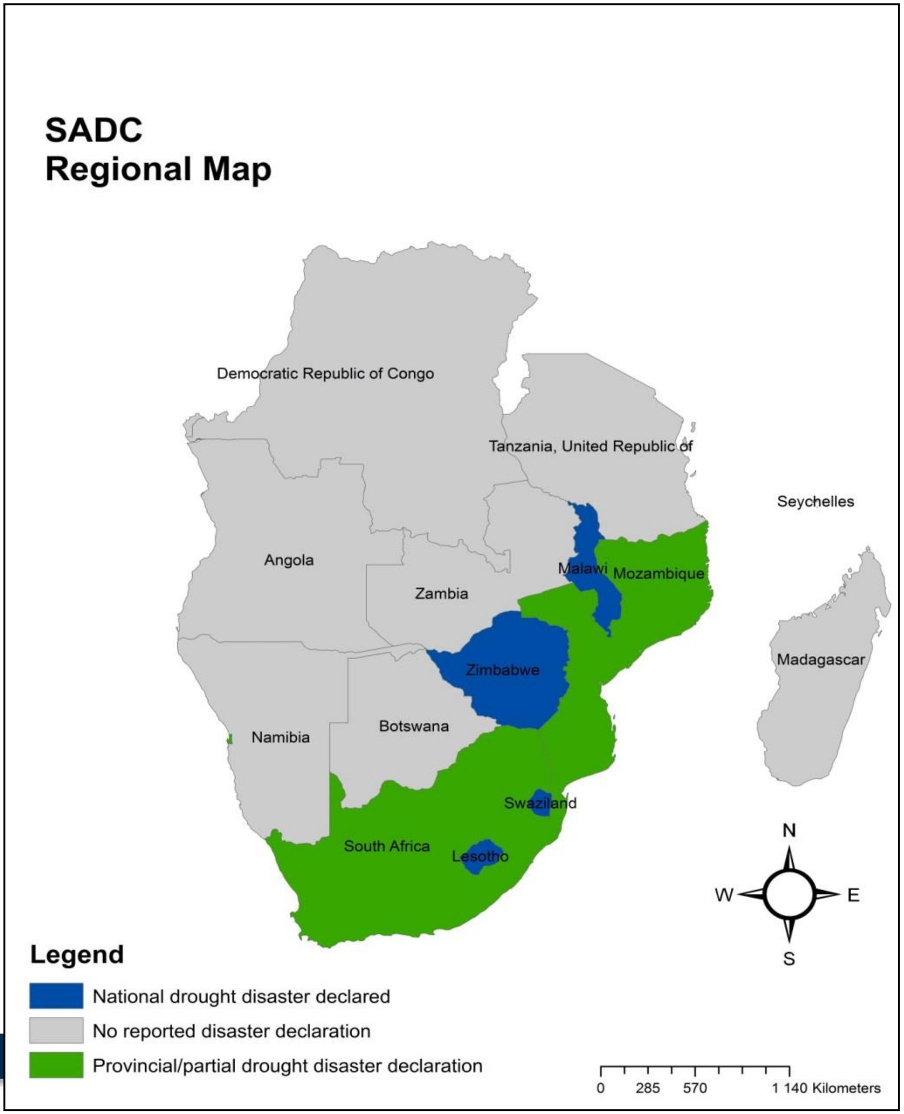
SOURCE: 2030 Water Resources Global Water Supply and Demand model; baseline agricultural production based on IFPRI IMPACT-WATER base case

SADC Water dependency and water stress





Reality check



SADC region is experiencing a devastating drought episode associated with the 2015/2016 El Niño event.

Four member states have declared national drought emergencies (Lesotho, Malawi, Swaziland and Zimbabwe). South Africa has declared a drought emergency in 7 of the country's 9 provinces (2017)

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Some of the Biggest challenges of climate change to SADC

1) Climate change pose a serious challenge to sustainable economic and socio-economic development, due to their reliance on climate sensitive natural resources, including rain fed agriculture.

2) The southern Africa region is semi-arid with high rainfall variability and frequent droughts and floods

3) Aging water treatment infrastructure

4) Skill shortage

5) Accessibility to safe drinking water

5) Phosphorus sensitive catchments (Changing habitat conditions and reduction of ecosystem services causing eutrophication)

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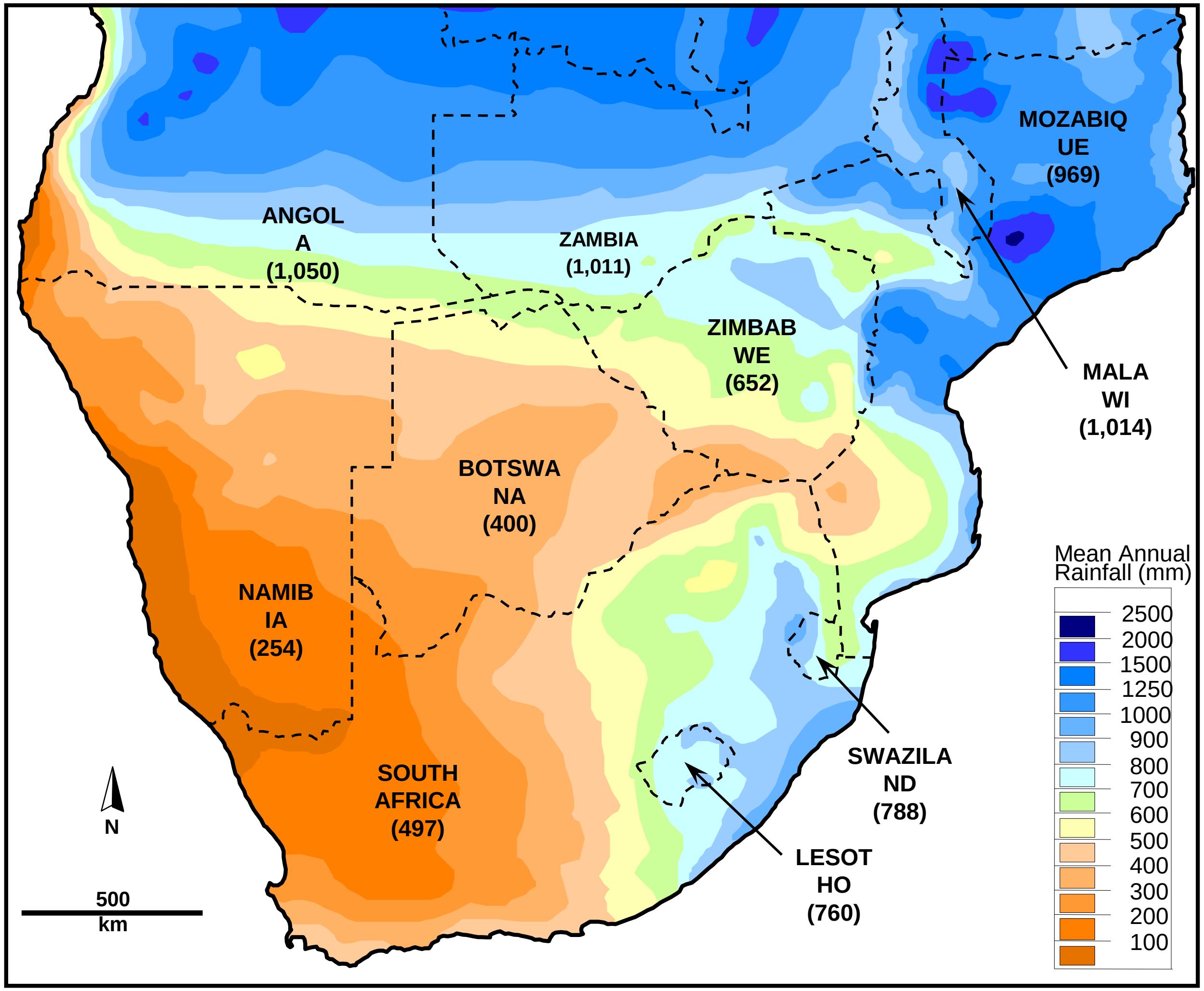
Mean Annual Rainfall in Southern Africa



South Africa is semi-arid with an average rainfall of 470 mm/a, well below the world's average of 840 mm/a

Water requirements already exceeded the demand in 10 out of the 19 WMA in the year 2000

Quality and quantity plays a major role in water reuse with the current climate change scenarios

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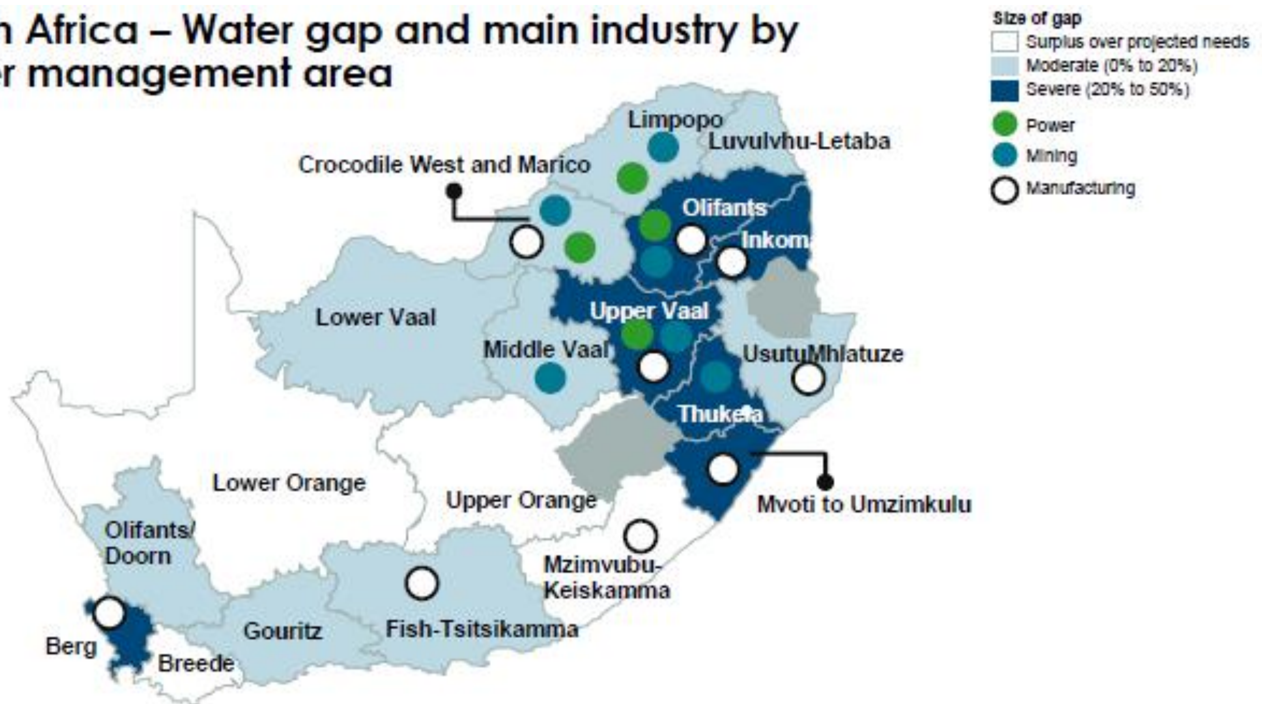
Water gap

South Africa – Water gap and main industry by water management area



SOURCE: National Water Resource Strategy; DWAF; 2030 Water Resources Group

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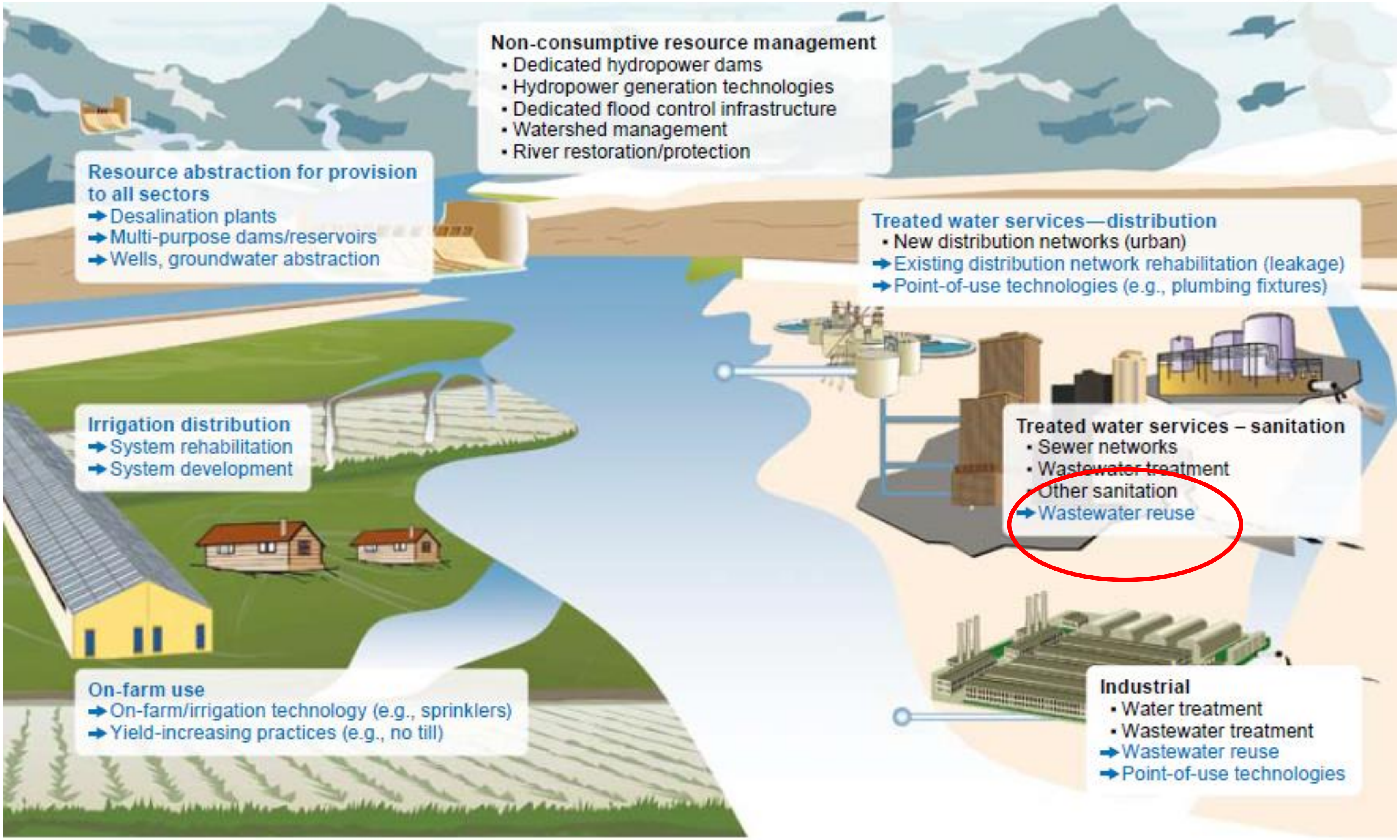
Water reuse



Non-consumptive resource management
• Dedicated hydropower dams
• Hydropower generation technologies
• Dedicated flood control infrastructure
• Watershed management
• River restoration/protection
Resource abstraction for provision to all sectors
➔ Desalination plants
➔ Multi-purpose dams/reservoirs
➔ Wells, groundwater abstraction
Treated water services—distribution
• New distribution networks (urban)
➔ Existing distribution network rehabilitation (leakage)
➔ Point-of-use technologies (e.g., plumbing fixtures)
Irrigation distribution
➔ System rehabilitation
➔ System development
Treated water services – sanitation
• Sewer networks
• Wastewater treatment
• Other sanitation
➔ Wastewater reuse
On-farm use
➔ On-farm/irrigation technology (e.g., sprinklers)
➔ Yield-increasing practices (e.g., no till)
Industrial
• Water treatment
• Wastewater treatment
➔ Wastewater reuse
➔ Point-of-use technologies

Sanitation infrastructure

Water Services Infrastructure Elements	Required Funding (R bn)	Budgeted Funding (R bn)
Municipal water infrastructure	27.8	17.1
Regional bulk (potable) infrastructure	10.1	7.4
Regional bulk (non potable) infrastructure	7.0	4.0
Water resources infrastructure	25.5	14.9
Total water infrastructure	70.4	43.4
Sanitation infrastructure	19.5	13.2
Total water services infrastructure	89.9	56.6
Funding shortfall	33.3	37%

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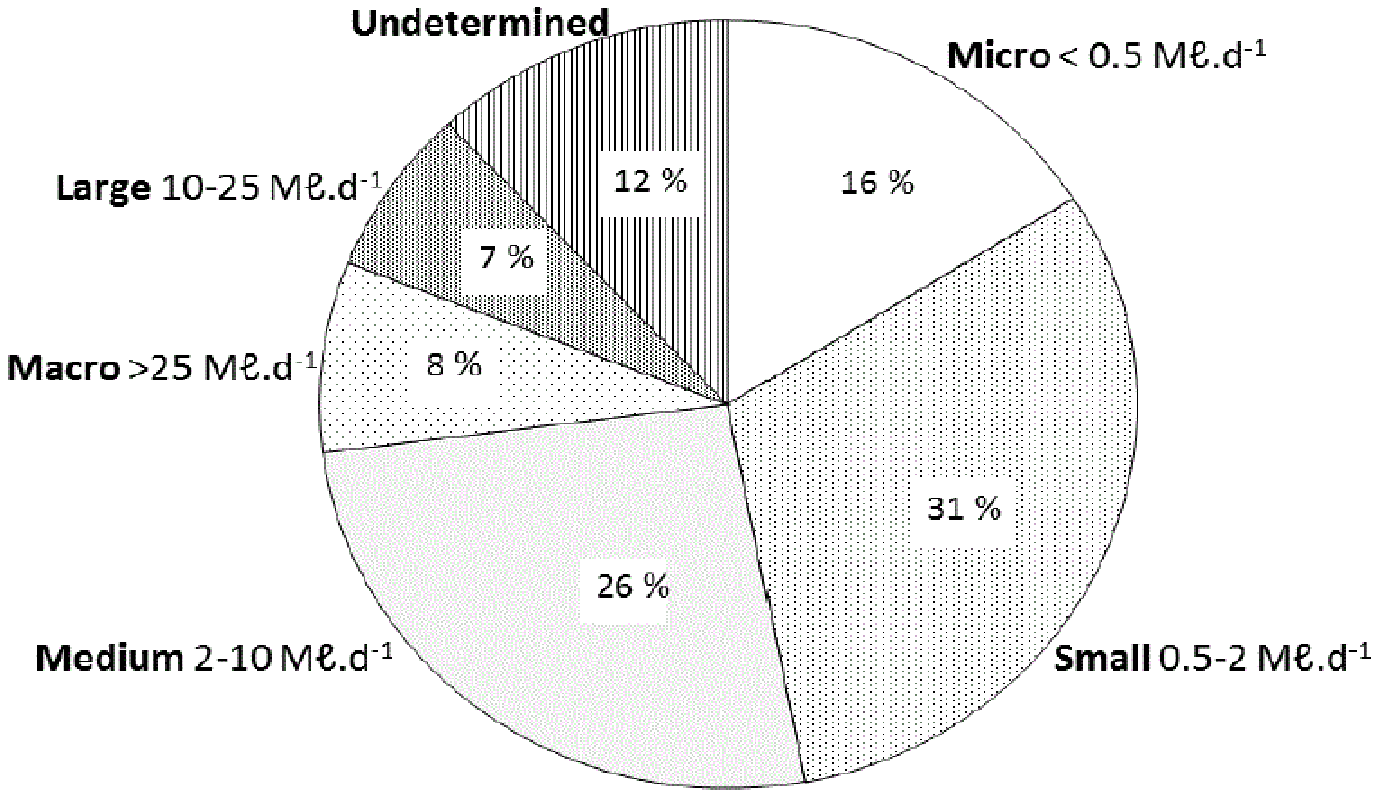
WWTP's in South Africa



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Advanced Integrated Waste water Pond System

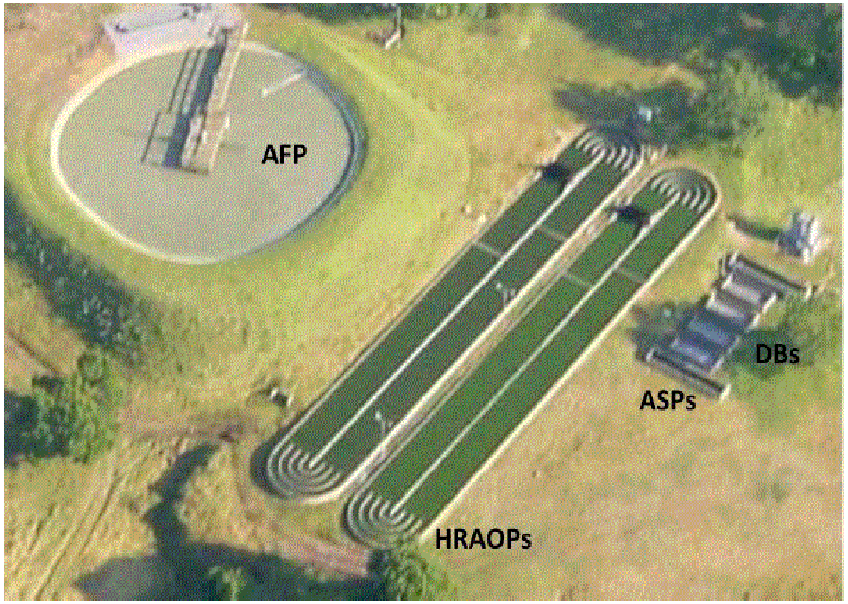

Figure 5 An aerial photograph of the IAPS pilot operating at the Belmont Valley WWTP treating 75 kℓ.d^{-1} municipal sewage. The pilot is composed of an AFP: Advanced Facultative Pond, which is a combination of an I-PD and a primary facultative pond, 2 HRAOPs: High Rate Algae Oxidation Ponds, 2 ASPs: Advanced Settling Ponds and 2 DBs: Drying Beds. Note the absence of an MP required for post treatment.

1) **Use natural algae**
2) **Construction of algae raceway and AFP**
3) **Use of electricity**

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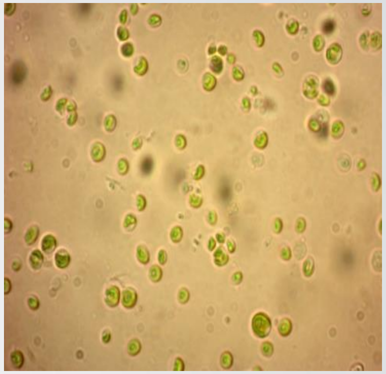
CSIR Algae Technology



1) **No electricity**
2) **No harmful chemicals**
3) **No skill labour**
4) **Use existing infrastructure**
5) **Specific algae consortium**

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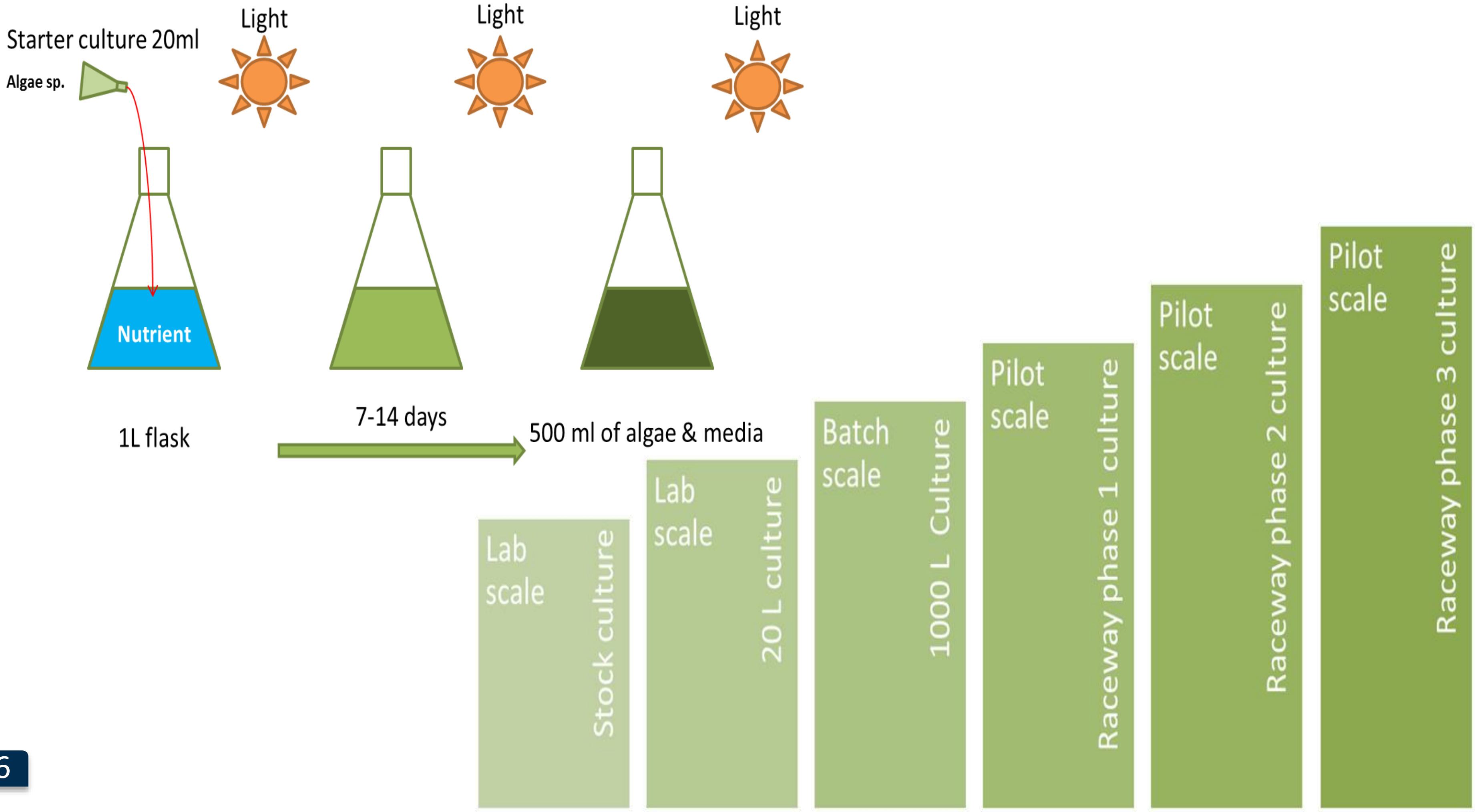
Algae cultivation

After selecting an specific consortium of algae a step wise approach was followed



Pilot study one

Motetema WWTW is situated at the small town of Elias Motsoaledi, Sekhukhune District of the Limpopo province, South Africa. Due to the lack of proper WWTW infrastructure and electricity, a series of ponds are employed at the Motetema WWTW to treat sewage effluent. The WWTW consist of 12 earth ponds organised in two series of six each parallel to one another

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Characteristics of the Motetema WWTW

Six ponds are operated at a time, while the other 6 ponds are dried to remove sludge. The pond system is based on natural overflow from one pond to another. The average total effluent that needs to be treated by the Motetema WWTW is ~ 2.5 Ml/ day (currently treating 4.1 Ml/d.

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Algae bioreactors

Five semi transparent containers of 5000 litres

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Algae culturing steps

1) **Inoculation time (3 to 4 weeks) of algae in the different pond systems depends on season**
2) **Algae are stirred manually every 4 days**

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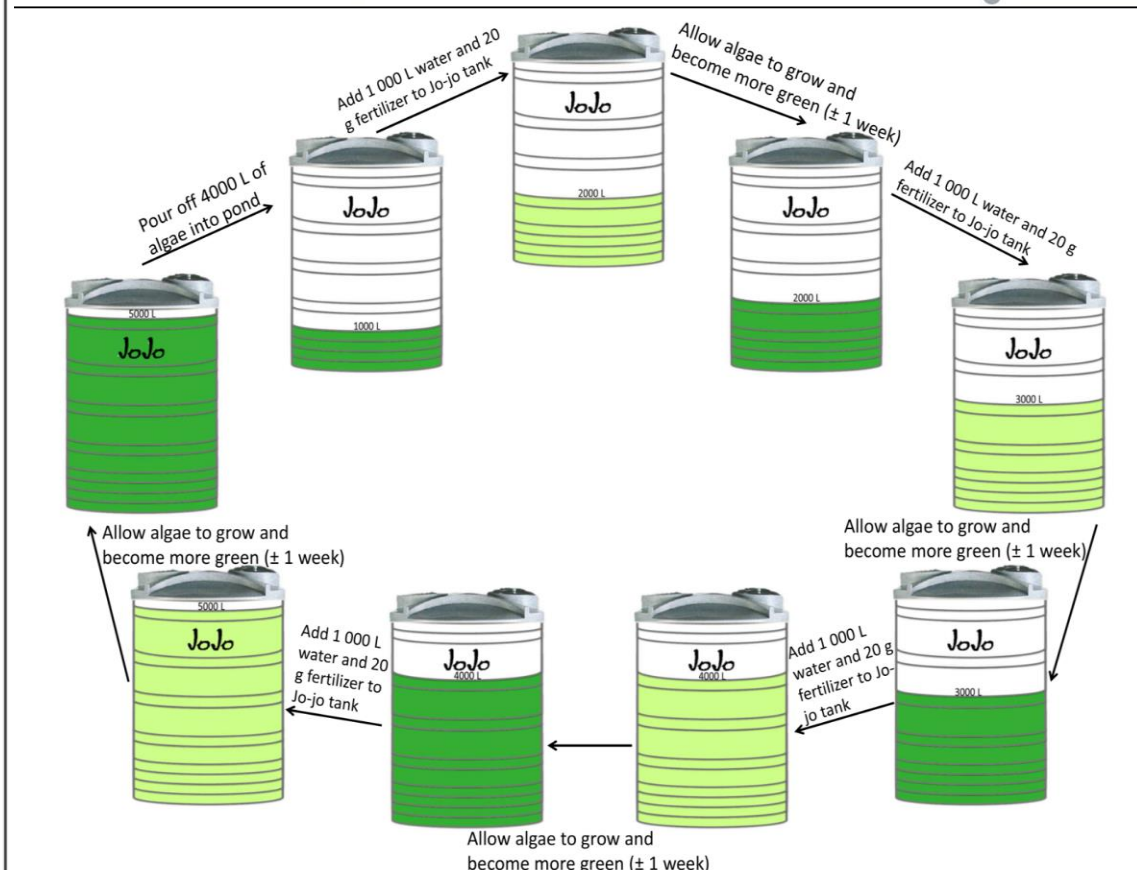
Algae culturing steps



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No 3
DO NOT
DRINK

Data analyses

Table : Average selected parameters for monitoring the efficiency of algae for remediation in Motetema wastewater treatment works (n=5).

PARAMETERS	BEFORE (UNFILTERED)							AFTER (UNFILTERED)							REMOVAL EFFICIENCY (%)		
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 5	Pond 6	Pond 7
Total Nitrogen water (mg/L)	34	30	27	23	58	31	26	47	33	36	36	33	20	18	43.1	35.1	30.7
Total Organic Carbon (mg/L)	99	61	57	47	181	45	37	117	58	77	67	55	35	31	69.6	22.1	16.4
Total Chemical Oxygen Demand (mg/L)	378	238	224	157	567	142	103	479	228	276	272	230	92	93	59.4	35.2	2.0
Total Phosphorus (mg/L)	**34**	**30**	**27**	**23**	**58**	**20**	**18**	**4.6**	**3.2**	**3.6**	**3.3**	**3.3**	**3.1**	**2.8**	**94.3**	**84.5**	**84.4**
Suspended Solids (mg/L)	229	117	115	65	224	54	76	259	118	76	120	123	82	89			
Sulphate as SO_4 Dissolved (mg/L)	87	89	106	109	71	167	153	210	150	155	159	103	122	117	39.7	63.3	23.5
Chloride as Cl (mg/L)	60	61	62	60	76	76	74	89	83	82	84	66	61	60	13.1	19.7	18.9
ortho Phosphate as P (mg/L)	**0.07**	**0.14**	**0.14**	**1.1**	**5.8**	**3.4**	**2**	**1.5**	**0.28**	**1.7**	**1.8**	**1.1**	**0.44**	**0.28**	**81.0**	**87.1**	**86.0**
Ammonia as N (mg/L)	20	17	19	18	37	24	27	33	22	21	22	21	20	18	43.2	16.6	33.3
Electrical Conductivity (mS/m)	104	102	102	98	112	100	116	132	116	120	115	120	116	94			
pH (Lab) (20°C)	8.1	8.1	8.1	8.1	7.8	8.1	8	8	8.3	8	8.7	8.9	8.6	8.2			

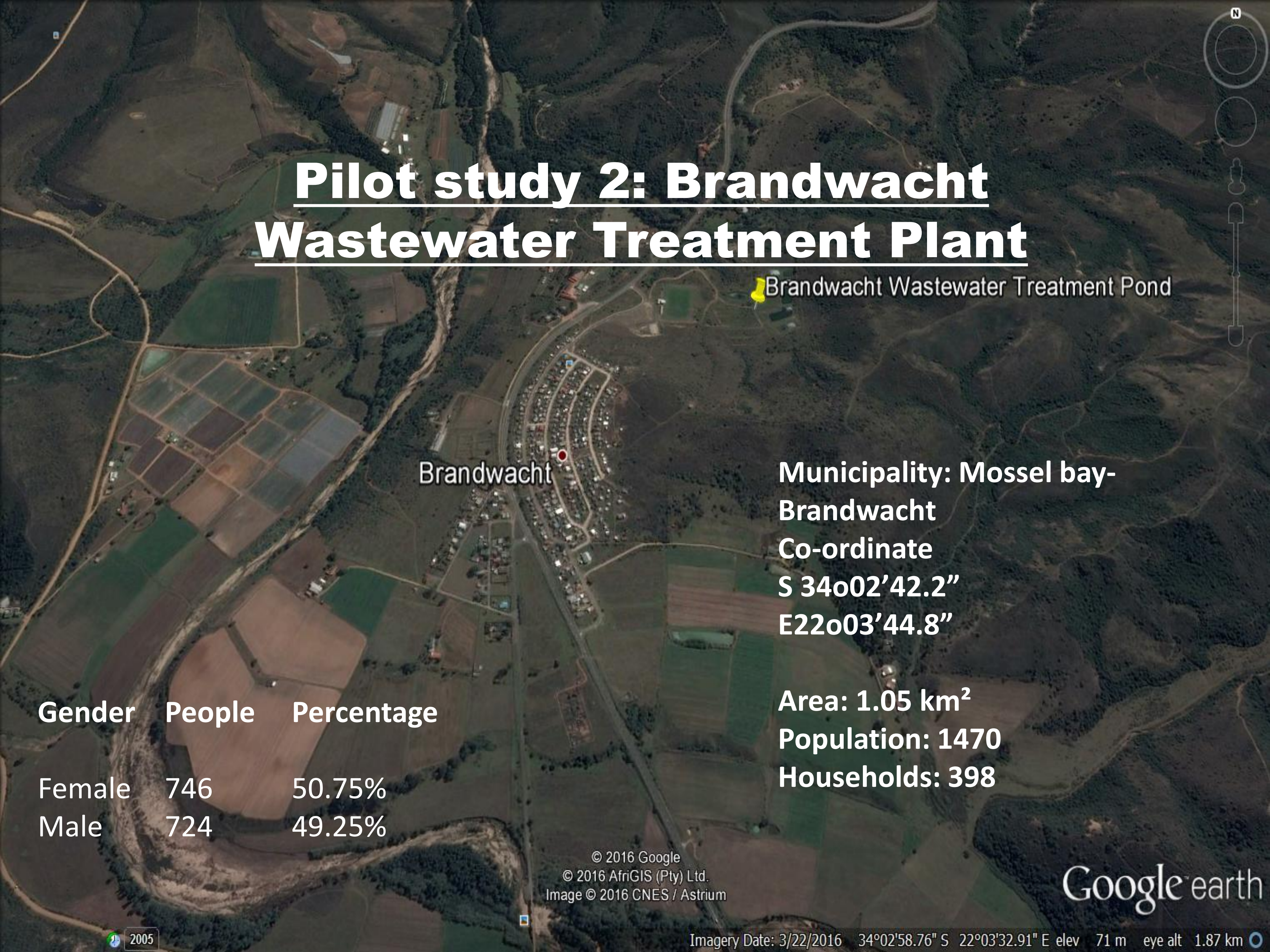
1) *E-coli* was reduce in the effluent of Pond 7 within DWS guideline range: General limit for *E coli* WW 1,000/100ml

Algal communities before and after treatment

Table 3 Composition of algal communities before algae treatment (b) and after algae treatment (a) at ponds 4, 5 and 6 (+ = rare, + + = scarce, + + + = common, + + + + = abundant, + + + + + = predominant). The relative abundance of each algal taxa was grouped into: 1 = ≤ 50 (rare) 2 = 51–250 (scarce), 3 = 251–1000 (common), 4 = 1001–5000 (abundant), 5 = 5001–25,000 (predominant) cells mL^{-1}. *b* before treatment, *a* after treatment

Phylum/class	Major species	Pond 4 (b)	Pond 4 (a)	Pond 5 (b)	Pond 5 (a)	Pond 6 (b)	Pond 6 (a)
Bacillariophyta							
Bacillariophyceae							
	Nitzschia palea	37		24			
	Craticula ambigua	101		43			
	Navicula viridula	18	15	89	32		
	Melosira varians		221	42	35	12	
Chlorophyta							
Chlorophyceae	*Micractinium pusillum*	1740	41	1310	164	890	43
	Scenedesmus chlorelloides	534	32	19			437
	Scenedesmus ovalternus	43	21		9	67	
	Scenedesmus quadricauda	741	42	879	23		
	Eudorina elegans	630	38		29	621	
	Pediastrun duplex	67		92		51	
	Pandorina morum	121		9		96	
	Desmodesmus armatus			+	+		
	Chlorella vulgaris		2130		2761		2386
	Chlorella protothecoides		2910		5101		5341
Euglenophyta							
Euglenophyceae	*Euglena viridis*	411		46			
	Trachelomonas hispida	67		8		11	
	Phacus pleuronectus	623	48				
Cyanophyta							
Cyanophyceae	*Oscillatoria limosa*	274	34	37			

Pilot study 2: Brandwacht Wastewater Treatment Plant

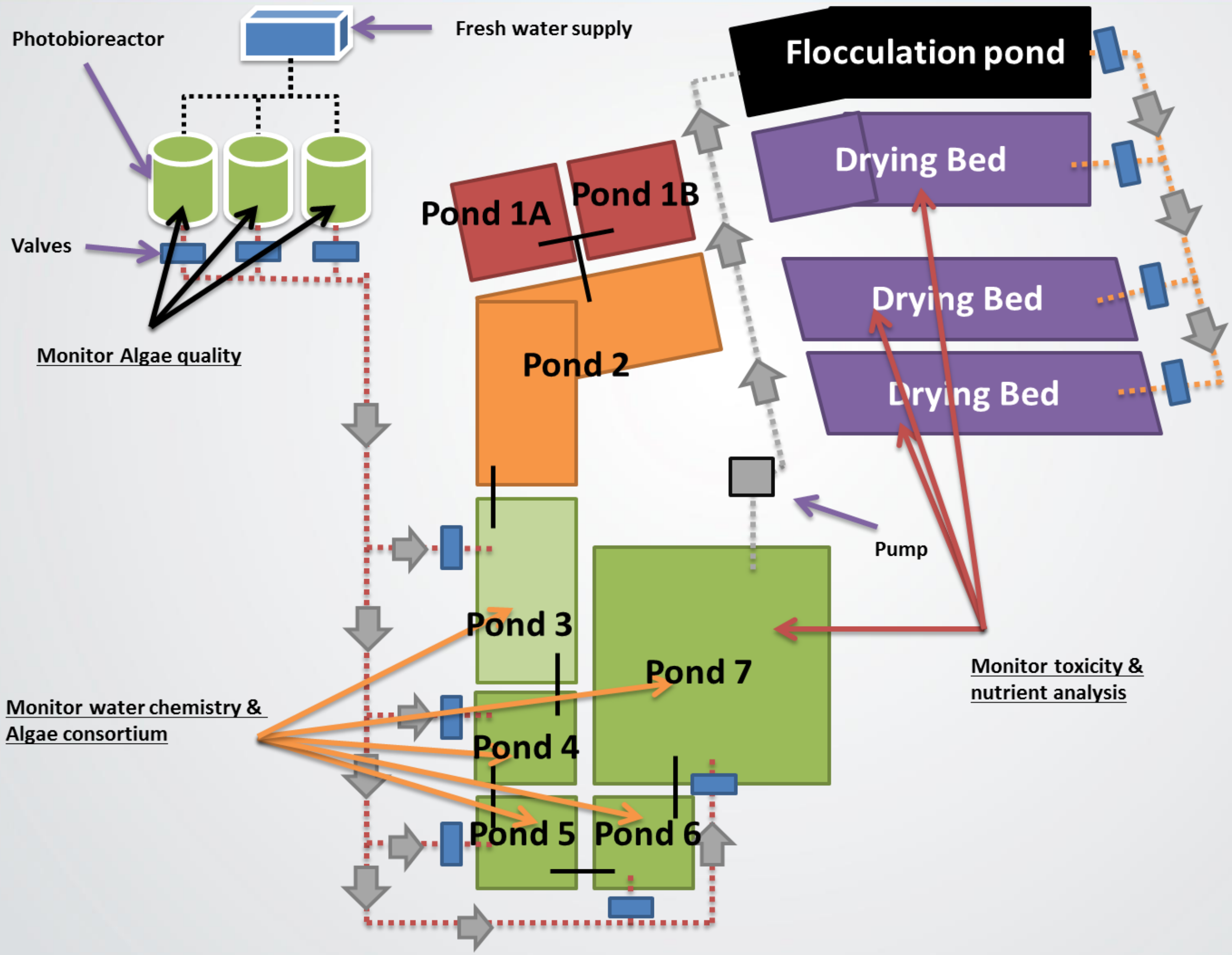


Municipality: Mossel bay-Brandwacht
Co-ordinate
S 34o02'42.2"
E22o03'44.8"

Area: 1.05 km²
Population: 1470
Households: 398

Gender	People	Percentage
Female	746	50.75%
Male	724	49.25%

Design WWTP



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Monitoring – Chemistry

Parameters		Before treatment 2017							DWS LIMITS
	Units	Dam 1a	Dam2	Dam 3	Dam 4	Dam 5	Dam 6	Dam 7	
OP_4^{3-}	mg/L	13	15	16	15	15	12	5.4	10
NH_4^+	mg/L	122	79	43	29	18	8.6	22	6
NO_3^- - NO_2^-	mg/L	42	49	53	54	53	57	67	50
SO_4^{2-}	mg/L	18	44	54	60	59	66	74	200
pH		8.1	8.3	8.4	8.4	8.4	8.4	9.1	5.5-9.5

Parameters		After dosing 2017							DWS LIMITS
	Units	Dam 1a	Dam2	Dam 3	Dam 4	Dam 5	Dam 6	Dam 7	
OP_4^{3-}	mg/L	20.80	18.70	2.15	1.76	1.92	1.76	2.36	10
NH_4^+	mg/L	116.00	84.00	80.00	61.00	55.00	33.00	10.00	6
NO_3^- - NO_2^-	mg/L	180.00	82.00	17.00	21.00	27.000	21.00	23.00	50
SO_4^{2-}	mg/L	10.00	10.00	0	0	0	0	1	200
pH		8.38	8.39	7.95	8.17	7.92	8.02	8.08	5.5-9.5

pH higher before treatment, but poor removal - consortium of algae

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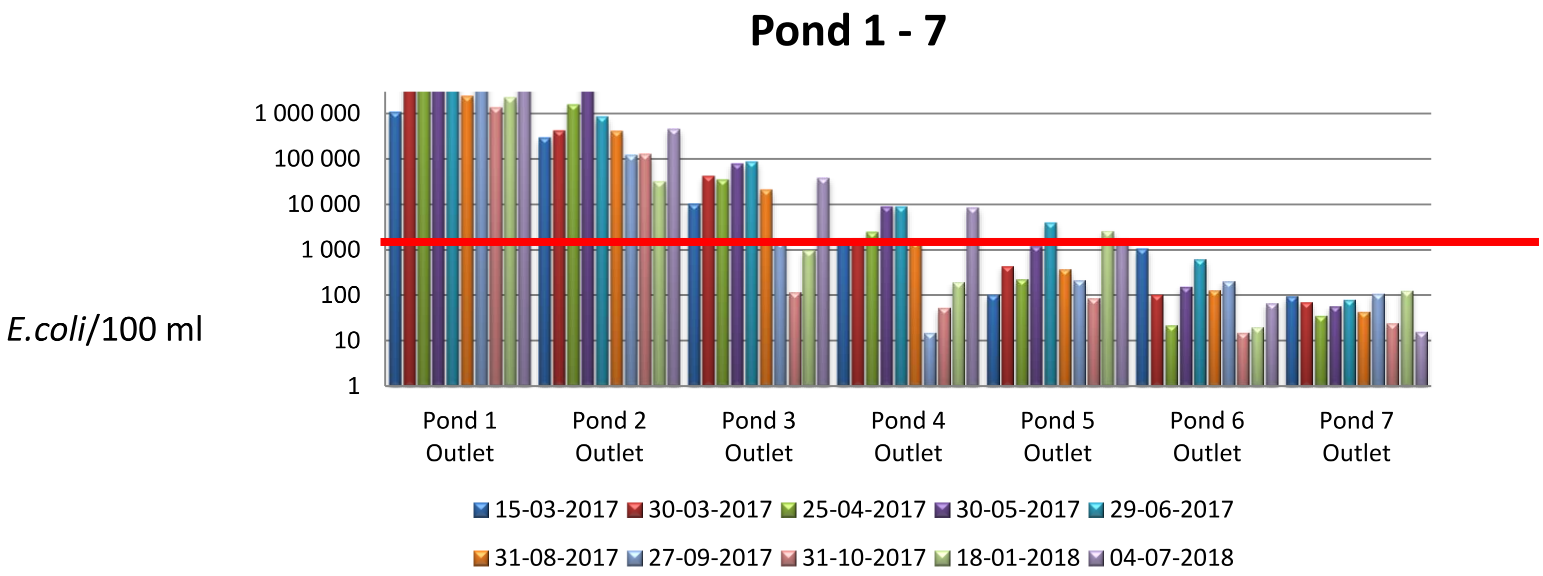
Microbial data



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Removal of algae: Aquaculture

Currently experiments with the University of Limpopo are ongoing to make use of ornamental fish to reduce algae biomass in last matured pond

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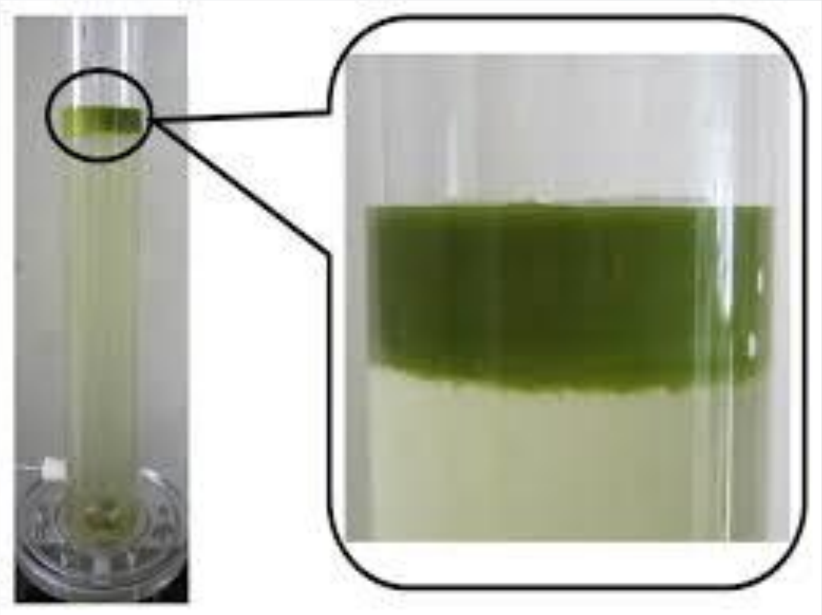
Flocculation

- Aggregation of algae to be removed from last pond
- Use of flocculants - Chitosan & alum
- Biomass was tested for use as eco-friendly fertilizer



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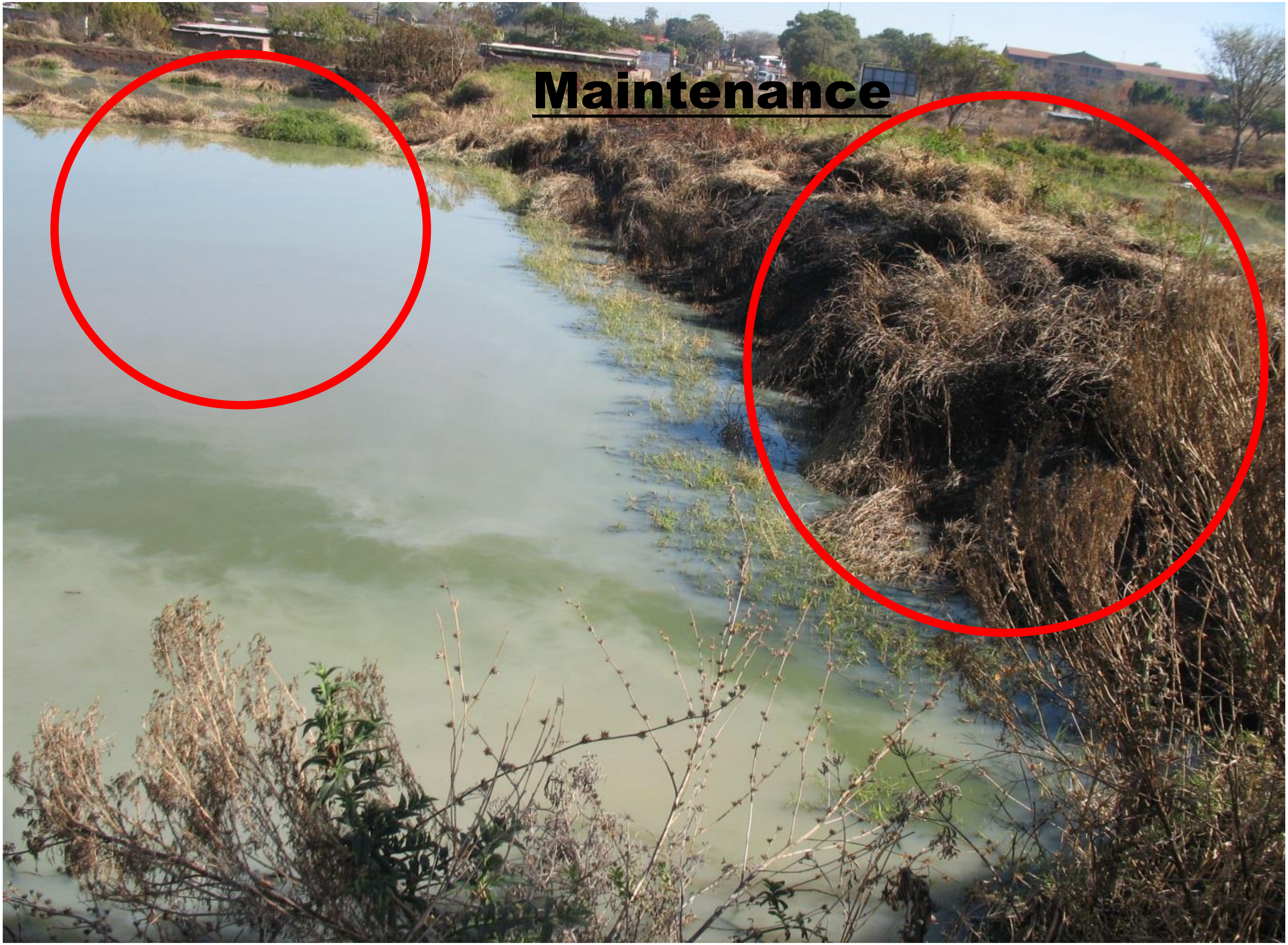
Risk-Operations and maintenance


Maintenance


Field fires


Duckweed, zooplankton

African Development Bank Project

- **Phycoremediation as an Adaptation Measure for Climate Change Vulnerability at Rural Wastewater Treatment plants in Southern African Development Community countries**
- **Partners:**
  - **University of Malawi (UNIMA) and**
  - **University of Botswana (UB)**

Project partner (UNIMA and UB) visit to Brandwacht WWTW, January 2018

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Funding agencies and collaborators

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

UNIVERSITY OF LIMPOPO

AFRICAN DEVELOPMENT BANK
AFRICAN DEVELOPMENT FUND

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Publications

Journal of Applied Phycology
https://doi.org/10.1007/s10811-018-1554-7

The environmental feasibility of low-cost algae-based sewage treatment as a climate change adaption measure in rural areas of SADC countries

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media

Researchers from the University of Malawi (UNIMA) and University of Botswana joined the CSIR and Mossel Bay Municipality representatives for a site visit to the Brandwag water treatment works as part of the African Development Bank Project, in which green technology has been implemented.

Mossel Bay Municipality going green

In developing regions of sub-Saharan Africa the major source of nutrient enrichment of surface water bodies results from untreated wastewater discharged into the environment.

It is estimated that in developing countries only 8% of their domestic and industrial waste is treated before being released into the natural environment.

In South Africa, a national review of wastewater treatment works (Green Drop Report, 2014) showed that more than half of South Africa's 812 wastewater treatment works were, however, not fully functional.

With increased environmental pollution from untreated or partially treated wastewater and resultant nutrient enrichment, there is a growing need for proactive remediation.

Over the last two years, Mossel Bay Municipality has worked with the Council for Scientific and Industrial Research (CSIR) from Stellenbosch to incorporate a low-cost green technology that could not only improve wastewater effluent quality but potentially harvest nutrients.

The use of green technology in the domestic wastewater industry can assist in the effective and efficient removal of nutrients and pathogens in effluents discharged from Wastewater Treatment Works (WWTWs), reducing human health risks by reducing harmful bacteria and creating economic opportunities and entrepreneurship for small agri-business development through the use of by-products.

The specific technology is a passive algae treatment system that makes use of two specific algae species in the existing WWTWs infrastructure. When released into the sewage ponds, the algae multiply by effectively outcompeting resident non-productive species, killing E.coli bacteria and absorbing the nutrients before they can be used as potential animal feed or bio-fertiliser, after which the treated water is discharged into the natural environment.

The technology is largely a self-sustaining system, using no electricity or chemicals, and can be maintained by a semi-skilled workforce.

Over the last two years, Mossel Bay Municipality has worked with the Council for Scientific and Industrial Research (CSIR) from Stellenbosch to incorporate low-cost green technology that could improve wastewater.

This technology package has been implemented in other geographical locations in the country and has attracted significant international interest. The African Development Bank, through the African Climate Technology Centre (ACTC), funded research into the feasibility of implementing this green technology in other SADC countries. Further work focuses on possible job creation from algae biomass harvesting.

According to DBSA (2012) the total sanitation infrastructure investment required is R73 billion, of which WWTWs account for 26% (R19 billion) for South Africa. The proposed technology intervention can extend the useful life and capacity of existing pond-based treatment works, which will delay the requirement for infrastructure investment. If we take a very conservative view, we can say that 20% of the required investment (R3.8bn) can be delayed by five years. Thus, with the intervention implemented at 20% (~400) of the WWTW, the gained interest alone will be R1.28bn (an average saving of R3.2M at each WWTW).

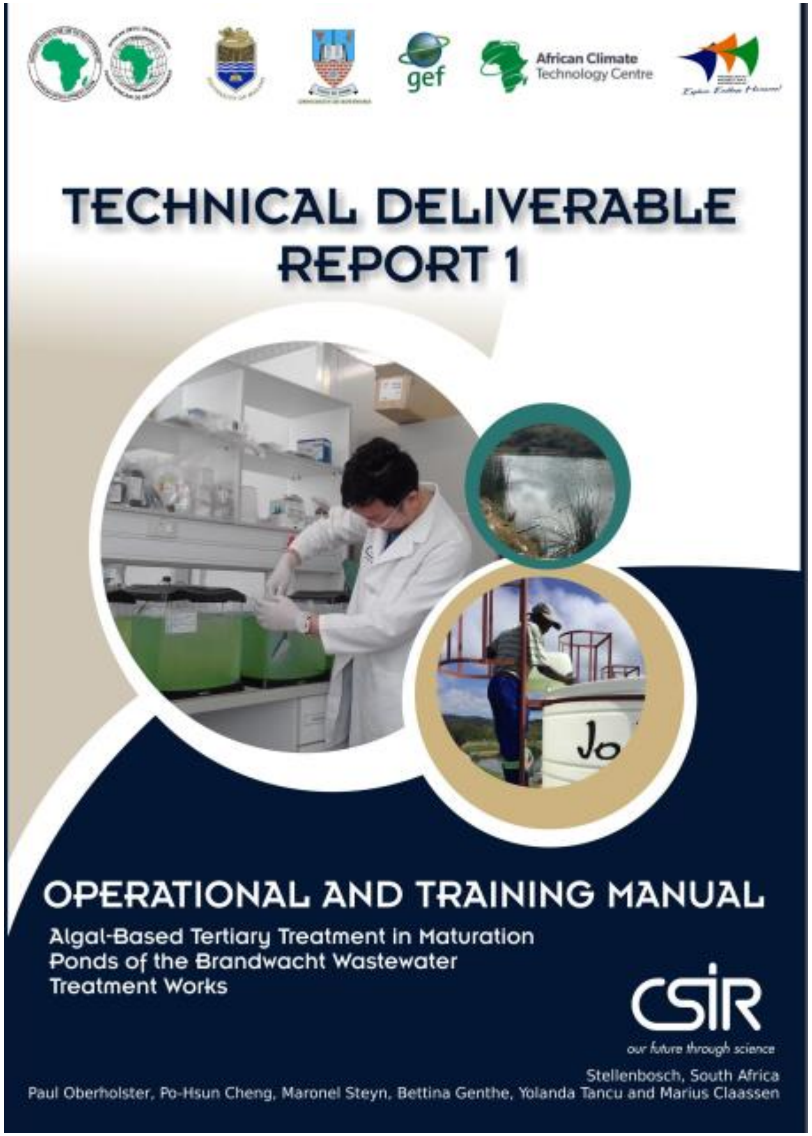
The successful implementation of such a system is especially highly relevant to medium and small municipalities throughout South Africa, since more than 50% of all WWTW's are micro-sized (0.5 ML/d).

The direct benefits to downstream users and improvement in Green Drop certification would be in addition to the direct economic value.

It is difficult to assess the benefits of sanitation services in monetary terms. Benefits from the provision of basic sanitation, such as those implied by the Millennium Development Goals, are many and far outstrip costs. Benefits-to-cost ratios have been reported to be as high as seven to one for basic sanitation services in developing countries.

The green technology reduces health risk and reduces the spread of water-related diseases, since domestic unavailability of water supply in South Africa, especially in rural areas where the poverty rate is about 70% compared with 30% in urban areas, often leads to use of unsafe sources of water.

Treated domestic wastewater effluent prevents the imbalance in water and nutrient fluxes and therefore prevents the distorting of the natural hydrological and ecological regime (phosphorus of sensitive rivers). With South Africa's growing population and current efficiency levels, the country could have a water deficit of up to 3.8 billion M3 by 2030, which is a 17% gap between water supply and demand, making the treatment and reuse of wastewater a major priority for economic growth.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OPERATIONAL AND TRAINING MANUAL
Algal-Based Tertiary Treatment in Maturation Ponds of the Brandwacht Wastewater Treatment Works
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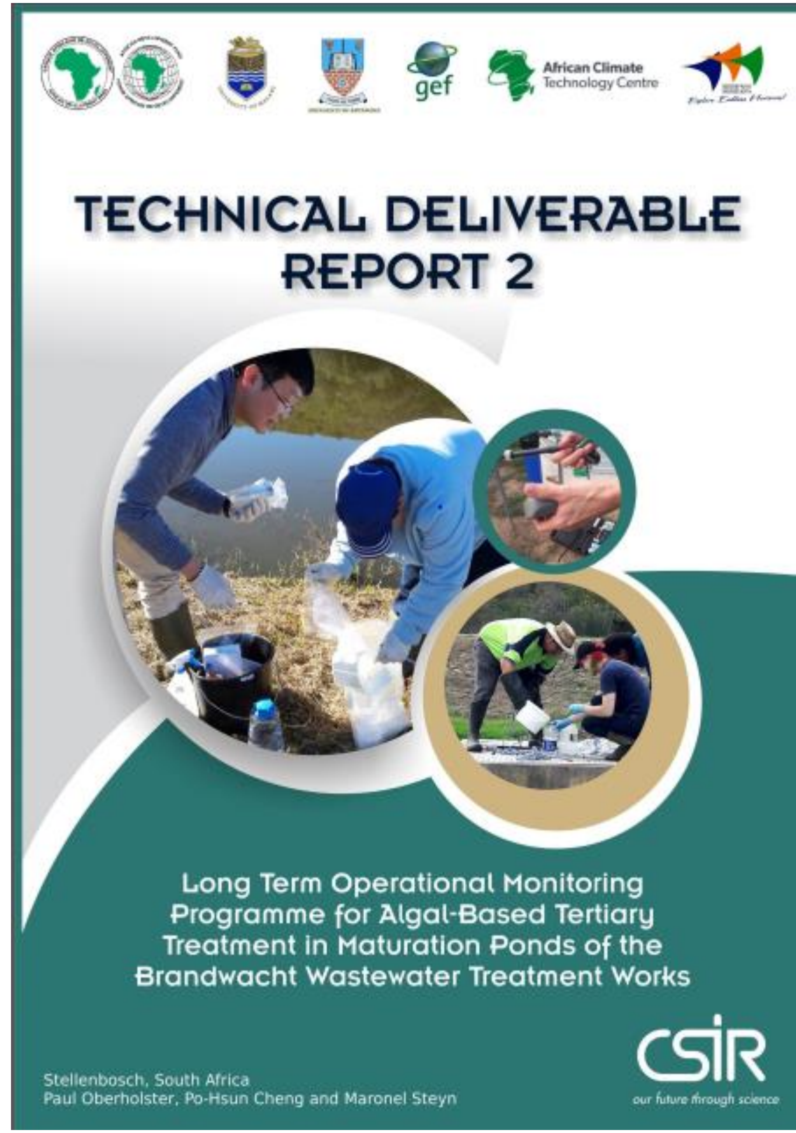
Paul Oberholster, Po-Hsun Cheng, Maronel Steyn, Bettina Genthe, Yolanda Tancu and Marius Claassen


African Climate Technology Centre
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TECHNICAL DELIVERABLE REPORT 2
Long Term Operational Monitoring Programme for Algal-Based Tertiary Treatment in Maturation Ponds of the Brandwacht Wastewater Treatment Works
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Questions