An Evaluation of the Potential for Spirulina Production at Selected Thermal Springs in Limpopo, South Africa

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ABSTRACT

South Africa is located in a geologically stable zone. Despite this, the country is relatively well endowed with thermal springs. Eighty seven thermal springs, with temperatures ranging from 25°C to 67.5°C have been documented to date. This paper focuses on the evaluation of the potential for spirulina production in selected thermal springs in the Limpopo Province of the country. Spirulina is known for its high nutritional values and is useful as a therapeutic agent and in cosmetics. Spirulina production relies on maintenance of high temperature for optimum growth (35°C), media preparation and drying the biomass during processing. An analysis of the physicochemical water quality parameters of the thermal springs indicated that the thermal spring water can be used to control temperature ideal for growing spirulina throughout the year. The springs are alkaline and are also rich in some minerals essential for spirulina production. It is proposed that to save on development costs, processing can be made at the now closed Musina Spirulina production site, a distance of up to 100km from the selected thermal springs. One of the reasons for closure of the Musina Spirulina production plant is that the temperature in winter was dropping below the required level for growing spirulina or microalgae. The use of hot spring water for heating purposes will therefore be a most welcome cost effective development for the production of spirulina.

1. INTRODUCTION

The Republic of South Africa is located at the Southern tip of Africa. It stretches from 22˚ to 35˚ S and 17 to 33˚E. Its surface area is 1,219,090 km^2. It is divided into 9 provinces. To the north lie the neighboring countries of Namibia, Botswana, and Zimbabwe; while Lesotho is an enclave surrounded by South African territory. It is the 25th largest country in the world by area and its population is about 51 million (OpenEI, 2014).

1.1 South Africa thermal springs

South Africa is located in a geologically stable zone. Despite this, the country is relatively well endowed with thermal springs. Eighty seven thermal springs, with temperatures ranging from 25˚C to 67.5˚C have been documented to date (Kent, 1969; Olivier et al., 2008). Majority of thermal springs are found in Limpopo Province (Tshibalo and Olivier, 2010). Figure 1 shows the location of thermal springs in South Africa and their associated geology.

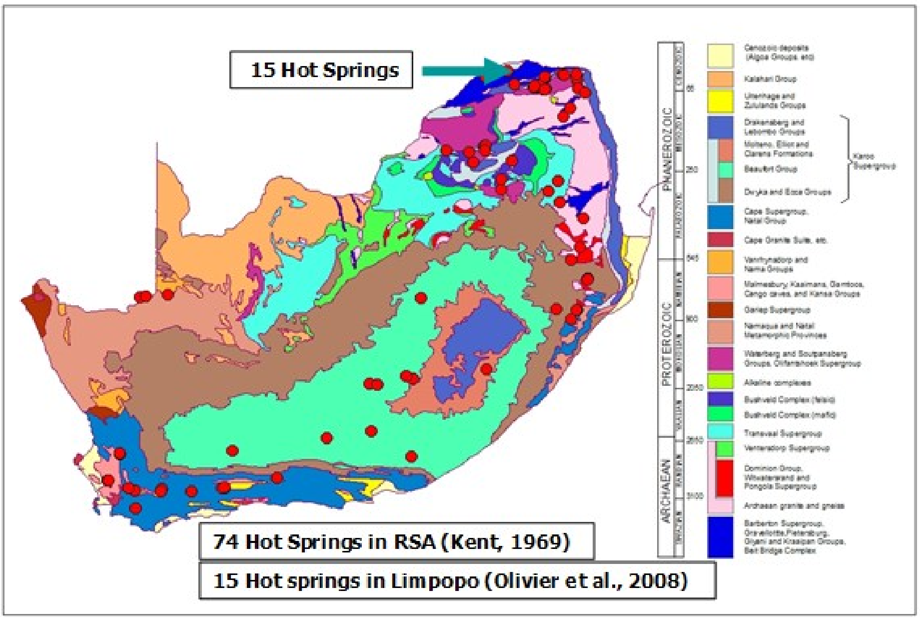

Figure 1: Distribution of thermal springs in South Africa (Kent et al., 1969 and Olivier et al., 2008)

South African hot springs are of meteoric origin (Olivier et al., 2008). The hottest geothermal spring is Siloam (71°C) in Limpopo Province. This implies that South African hot springs are classified as low temperature geothermal resources and can be used for activities that require temperatures below 70°C (Olivier et al. 2013).

The thermal springs in South Africa are mostly underdeveloped and those that have been developed are being used for recreational, medicinal, irrigation, extraction of salt (Die Eiland and Soutini in Limpopo Province) and domestic purposes such as washing and drinking (Olivier et al. 2013). Worldwide the use of geothermal sources by category as of 2005, was approximately 32% for geothermal heat pumps, 30% for bathing and swimming (including balneology), 20% for space heating, 7.5% for greenhouse and open-ground heating, 4% for industrial process heat, 4% for aquaculture pond and raceway heating, <1% for agricultural drying, <1% for snow melting and cooling, and <0.5% for other uses (Lund et al., 2005). Due to the environmental friendly nature of geothermal energy, the equivalent annual savings in fuel oil amounts to 170 million barrels (25.4 million tonnes) and 24 million tonnes in carbon emissions to the atmosphere (Lund et al., 2005).

1.2 Thermal springs in Limpopo

At least 15 thermal springs are found within the Limpopo Province of South Africa (Olivier et al. 2008). Thermal springs found in Limpopo Province include: Zimthabi, Die Oog, Rhemardo, Mphephu, Sagole Spa, Forever Eco Tshipise, Forever Eco Eiland, Makutsi Safari, Liberstas, Moreson, and Vischgat (Olivier et al., 2013). This paper focuses on the following four springs located north of Limpopo Province: Mphephu, Siloam, Tshipise and Sagole.

1.2.1 Geographical characteristics of the selected thermal springs

Mphephu

Mphephu lies within the Nzhelele valley which is surrounded by the Soutpansberg mountain range. The Mphephu thermal spring is situated at the foot of the northern flank of the Tswime Mountain at an elevation of around 850 m. There are 2 eyes approximately 1.5 km apart. The westernmost eye has been sealed off and the water is used to fill the pools at the Mphephu holiday resort. The second eye is undeveloped and has been used by the Dopeni community for bathing ever since the Mphephu Resort was closed for general public use. Mphephu is at a distance of about 100km from Musina.

Siloam

This hot spring is situated in the Siloam village on the property of one of the members of the community. Siloam is situated approximately 2 km northeast of Mphephu at the foot of the south-western flank of the Thononda Mountain. Water temperature is at 63^{0}C and it is about 100 km from Musina

Tshipise

This spring is located within the Honnet Nature Reserve, approximately 30 km from Musina, just off the R525 road to the Kruger National Park. The Tshipise hot spring is situated at the foot of a 188 m high hill, surrounded by fairly flat terrain. It is a very well-known and popular holiday resort with 58 chalets, many camping sites, a restaurant and numerous conference and recreational facilities.

Sagole

The Sagole thermal spring is located in the extreme north-east section of the Limpopo Province. The northern part of the Kruger National Park lies east of Sagole Spa. The absolute location according to the grid reference is the 22°, 31' 30" South and the 30°, 40' 40" East (Olivier et al., 2008). The thermal spring is about 57km to the east of Tshipise.

1.2.2 Geology and geological structures associated with thermal springs in the northern part of Limpopo Province

The geology and geological structures associated with the four thermal springs: Mphephu, Siloam, Tshipise and Sagole is shown in Table 1.

Table 1 Geology and geological structures associated with four thermal springs

Sampling site	Description of surface geology	Lithostratigraphic Unit	Geological structure
Mphephu/ Dopeni	Sandstone and quartzite	Wyllie's Poort and Nzhelele Formations, Soutpansberg Group	Reverse fault between Waterberg Group quartzite and Dominion Reef lava (Sendedzane)
Siloam	Basalt, minor tuff	Sibasa Formation, Soutpansberg G	Not determined
Tshipise	Basalt, minor andesite Cream-coloured sandstone Dolerite sills and dykes	Letaba Formation, Lebombo Group, Karoo Supergroup Tshipise Member, Clarens Formation, Karoo Supergroup	Intersection of 2 post-Permian faults in upper Karoo
Sagole	Mudstone, shale, subordinate micaceous sandstone Shale, carbonaceous shale, silt-stone, micaceous sandstone	Mikambeni Formation Madzaringwe Formation, Karoo Supergroup	The area is underlain by igneous rocks, while the earth's surface consists of rocky outcrops, lithosoils, and deep steep inclines.
According to the Messina Map Sheet (Geological Survey, 1981)			Source: Kent (1949; 1969)

1.2.3 Location of the four thermal springs from Musina

Figure 2 shows the distribution of thermal springs in Limpopo Province. The four springs (Mphephu/ Dopeni, Siloam, Tshipise and Sagole) are located in the northern part of Limpopo Province. Mphephu/Dopeni, Siloam and Tshipise are located south of Musina, while Sagole is located south-east of Musina. The distance in Kilometers between Musina and Tshipise is 30.3 km. Sagole is about 86 km from Musina, while Mphephu, Dopeni, and Siloam are about 100 km from Musina by tarred road. .

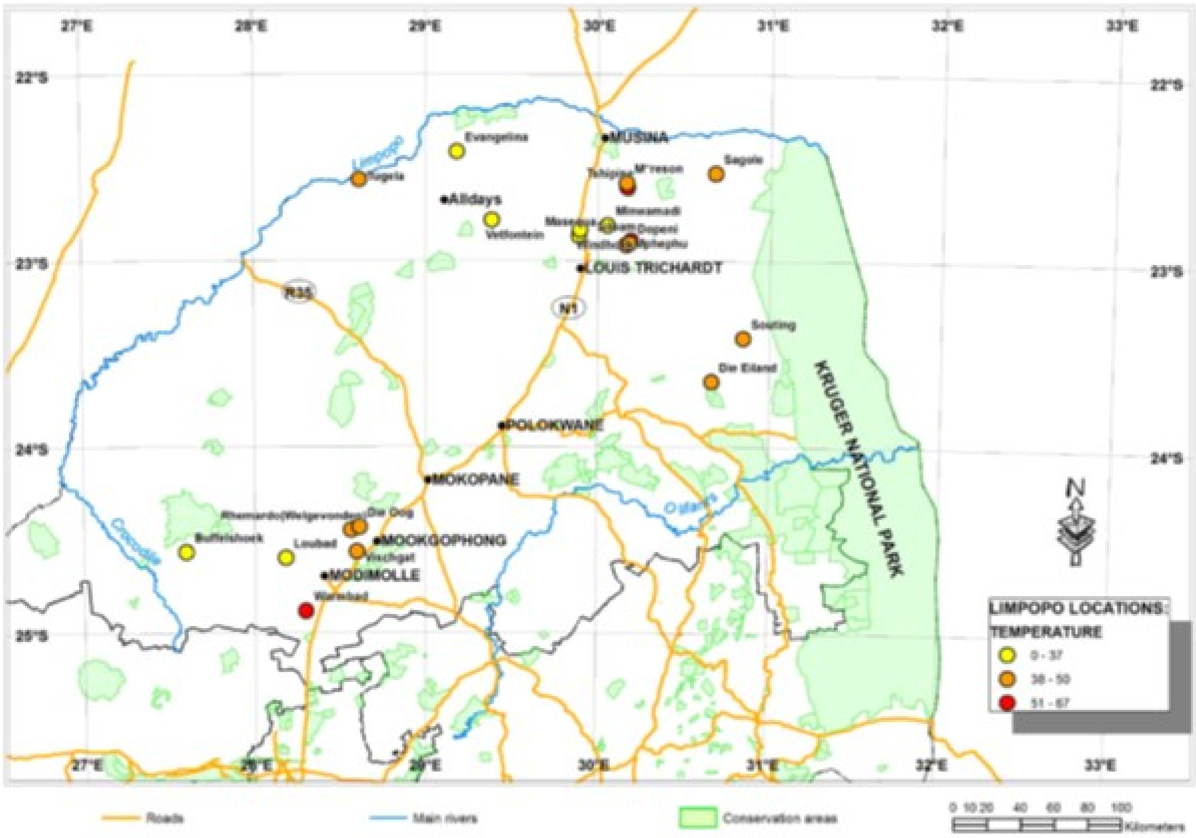

Figure 2: Distribution of thermal springs in Limpopo province (Source: Olivier at al. 2008)

2. MUSINA SPIRULINA PRODUCTION

2.1 Historical background

According to Grobbelaar (2009), the Department of Science and Technology in South Africa identified the development and support of biotechnology as one of the means to address economic empowerment. Spirulina (Arthrospira) was selected for growth and production because of its long history of utilization by man, no known toxicities, easy harvesting and processing, well established products and markets, and extensive literature on its growth, nutritional requirements, properties, and potential health benefits. Also the dietary supplement industry is extremely lucrative (Grobbelaar, 2009) and, since all algal supplements consumed in South Africa are imported, it was decided to start a project producing algal biomass for the health food market (Grobbelaar 2009). The town of Musina in the northern part of Limpopo was selected for the setting up of a spirulina plant because of its favourable conditions in terms of the following criteria:

- Temperature: Annual temperature regime higher than 18˚C (Average maximum temperatures May-August = 24˚C, Dec-Feb = 37˚C);
- Precipitation: Minimal precipitation and few days with cloud cover (<250 mm precipitation per annum and <25 days with cloud cover);
- Minimal air and water pollution: Sand-filtered water is available in Musina. Water from Limpopo River is fresh since there is no large city in its catchment;
- Basic infrastructure: Musina is a small town with 30,000 inhabitants supporting mining and agriculture);
- Access: rail and road network available;
- Available land: Land and preferably of low agriculture value (area is semiarid and supports mainly cattle and wildlife farming);
- Labour: Musina serves a community with high unemployment rate (Grobbelaar, 2009)

Local Economic Development funding of 562 142,43USD was secured for the Spirulina project at Musina, and the town was made the principal shareholder. The investor decided on the construction of open race-ways production ponds, 200mm deep and lined with high density polyethylene. Fin paddle provided the mixing of the culture. The Spirulina project was launched in 2007 in Sandton (van der Merwe, 2013) and Fig 3: shows a picture of Musina Spirulina plant.

Figure 3: Musina Spirulina plant (Zoutnet2013)

2.2 Productivities of Spirulina (Arthrospira) in open raceways ponds in Musina

Table 2 shows the average areal productivities of Spirulina (Arthrospira) in open raceway ponds with different surface areas, measured during December 2005 and January 2006.

Table 2 Productivities of Spirulina (Arthrospira) in open raceways ponds in Musina

Pond surface area (m^2)	**Average productivity g/dwt/m^2 /day**	**Standard deviation**
25	10,69	4.51
500	10,04	2.94
2 000	19,78	9.5

(Source: Grobbelaar, 2009)

2.3 Challenges of productivities of Spirulina (Arthrospira) in open raceways ponds in Musina

Grobbelaar (2009) mentioned a number of changes which include:

- construction companies having limited experience in building algal production ponds;
- Inoculating large outdoor cultures requires good planning and adequate indoor culture facilities to provide a seed culture of at least 25% the volume of the smallest outdoor pond;
- Dealing with power and water outages'
- Bureaucracy, civil service pace, lack of business and marketing expertise, and personal greed when using public fund.
- No production during the winter months because the temperature fell below the acceptable levels (Tshibalo, 2011).

The last problem was identified during a visit to the production plant (Tshibalo, 2011). It is identified as major problem for continuous production throughout the year.

3. GROWING AND PRODUCING MICRO-ALGAE PRODUCTION

Growing micro-algae and producing Spirulina demand special knowledge, skills and favorable environments. The sections below explain what Spirulina is, uses and ideal conditions for growing and production.

3.1 What is Spirulina

Micro-algae are microscopic photosynthetic organisms that are found in both marine and freshwater environments (Bowles, 2007). They grow well in environments where they have access to water, sunlight, carbon dioxide, and other nutrients that contribute to conversion of solar energy into biomass. Species of microalgae that are produced for commercial purposes include the Isochrysis, *Chaetoceros, Chlorella, Dunaliella* and*Arthrospira* (spirulina). This paper focuses on the production of spirulina, an edible micro-alga. Spirulina is defined as "a photosynthetic, filamentous, spiral-shaped, multi-cellular and green-blue micro-alga" (Sanchez et al., 2003). *Arthrospira species* (commonly known as Spirulina *spp.)* (Fig 4*)* are multicellular, filamentous blue-green algae (cyanobacteria) that are found in environments ranging from soils and marshes to thermal springs, the ocean and brackish water (Richmond, 1988). In general, *Spirulina spp.* occur in tropical and subtropical alkaline lakes with a high bicarbonate concentration and a pH of up to 11 (Durand-Chastel, 1980; Vonshak et al., 1981; Richmond, 1988; Tomaselli 1997; Borowitzka, 1999).

Figure 4: Microalgae *Spirulina platensis* (magnified 1000 times). Source: Fraunhofer-Gesellschaft (2013)

3.2 Uses of Spirulina

Considerable attention has been focused on the use of micro-organisms as a human and animal food source and for the production of pharmaceuticals, nutraceuticals, bioenergy and extraction of bio-oil (Fournadzhieva et al. 2003). The Cyanobacteria *Spirulina* is recognised as having considerable commercial potential and this stems from its remarkable composition, which consists of up to 70% proteins, ten vitamins, high levels (one of the highest known in nature) of β-carotene and fatty acids such as γ-linoleic acid (Műhling et al., 2005). According to Jimenez et al. (2003) the dried product of *Spirulina* can be used as a valuable food supplement. It is rich in proteins (60-70% by weight), carbohydrates (15-20%), vitamins, and minerals. It contains essential amino acids and fatty acids (18%). Spirulina compares favourably with the best traditional protein sources when measured on a usable protein basis (Li & Qi, 1997). Moreover, Richmond (1988), maintains that spirulina's already first class amino acid profile could be easily modified to increase the levels of sulphur containing amino acids that it lacks (Jassby, 1988). An added advantage is that spirulina has a low nucleic acid content of 4%, which is important, as an excess intake of nucleic acids has been known to cause gout and gallstones (Jassby, 1988). According to Jassby (1988), fully formed Vit A is not found in plants, but spirulina contains high levels of provitamin A carotenoid pigments that are transformed into Vit A in the gastrointestinal tract. Spirulina contains the highest concentration of any biological source; up to 1 g/kg (Jassby, 1988). The iron found in spirulina is exceptionally digestible.

Consumption of spirulina has a multitude of beneficial properties, ranging from the treatment of high blood cholesterol, hyperlipedemia and some cancers (Costa *et al*., 2004). Pre-clinical and clinical studies suggest that it has certain therapeutic effects such as reduction in blood cholesterol, protection against some cancers, enhancement of the immune system, increase intestinal lactobacilli, radiation protection, reduction of hyper-lipidemia and obesity. It has corrective properties against viral attacks, anemia, tumor growth and malnutrition (Sanchez et al. 2003). Spirulina extracts have also shown some success against the HIV-1 by inhibiting the replication of the virus in human cells (Hirahashi et al., 2002) and may assist with the absorption of toxic minerals such as lead, and mercury form the liver. Compared to other natural sources, spirulina offers the simplest and most cost effective means to produce β-carotene that is ready for consumption (Romay et al. 1998).

3.3 Ideal conditions for growing Spirulina

The quality and economic efficiency of growing and producing spirulina is site specific and highly dependent on factors such as climate, water CO_2 content and overall composition, environmental conditions, and know-how technology. General conditions required for growing micro-algae include the prolonged periods of natural light, high temperatures for optimal growth. Commercial production of spirulina by open ponds methods requires optimal growth temperature of 35-37˚C. The minimal temperature that allows growth is around 18˚C, and the culture deteriorates immediately when maximum daytime temperatures are below 12 ˚C. Tropical and subtropical zones are therefore ideal for commercial cultivation. Other conditions include low average annual rainfall and low concentration of dust particles in the vicinity of the cultivation area (Jimenez et al. 2003). Strict quality control should be implemented to ensure that there is no contamination by toxic micro-organisms and the nutrient levels, pH, gaseous content, temperature and cell density must be monitored on a continuous basis. The latter are not crucial when spirulina is to be produced for biomass burning.

Fortunately the technology for mass production of spirulina is well tested and understood (Li & Qi, 1997). Major production costs arise from the cost of electricity to maintain high temperatures and the preparation of a suitable growth medium. These factors alone may contribute up to almost half of production costs (Belay, 1997). Another alternative is to make use of the thermal properties of hot water springs to heat the ponds. Thermal spring waters are warmer than normal groundwater and alkaline thermal spring waters, containing high concentrations of minerals, can decrease production costs considerably. Moreover, the heat from the thermal spring resource as well as the burning of waste biomass could be used for drying the biomass further reducing the costs. The chemical composition of the springs is then irrelevant. Under these circumstances, springs with temperatures exceeding 35°C would be suitable for *spirulina* production. The heat energy derived from thermal springs would be beneficial in two ways. Firstly it would offset the electricity costs necessary for heating the pools and for drying the biomass and secondly, it would enable production throughout the year. Currently, *spirulina* production at Musina (renowned for its high temperatures) has to be halted due to low temperatures during winter. With a drop in production costs, the possibility of tapping into new, previously unexplored markets becomes very real.

Spirulina grows in solutions of specific minerals with the correct chemical balance and a pH of 8-11. The hot springs characterized thus far in Limpopo have pH in the alkaline ranges (8.19 to 9.50) and this can be explored in spirulina production. A good amount of sunlight is useful if the culture has a reasonable temperature and concentration. The Limpopo Province is one of the hottest region in the North of South Africa. Average midday temperature for Musina range from 23,9˚C in July to 32,1˚C in January. The area is the coldest during July when the temperature drops to 7.6˚C on average during the night. (SA Explorer, 2000-2014).

An estimate for the total production costs however is 5-7 euros per kg of spirulina. The main costs involved in the local production of spirulina are labour, nutrients, packaging, capital and administration. The costs of course depend on the local availability of materials. (Akvopedia, 2013) An option to circumvent this is to use integrated production systems. Farms need to integrate nutrient resources, refine production systems and produce a variety of end products, from valuable extracts to inexpensive protein. Hot water from hot geothermal sources may provide heat to grow algae year-round in cooler climates. The farms may be co-located next to animal feed lots, digesting and recycling animal waste nutrients to grow algae.

Farms may build integrated aquaculture systems where fresh wet algae can be added directly to fish ponds or to a dry feed ration. Integrated farms could cultivate a variety of algae, shifting species during warm and cooler seasons, and produce a variety of products. Some may specialize in pharmaceutical compounds, enzymes or medicines. Biochemical plants will make concentrated vitamin, fatty acid and pigment extracts (Akvopedia, 2013). Figure 4 shows a diagram of an integrated Spirulina farm.

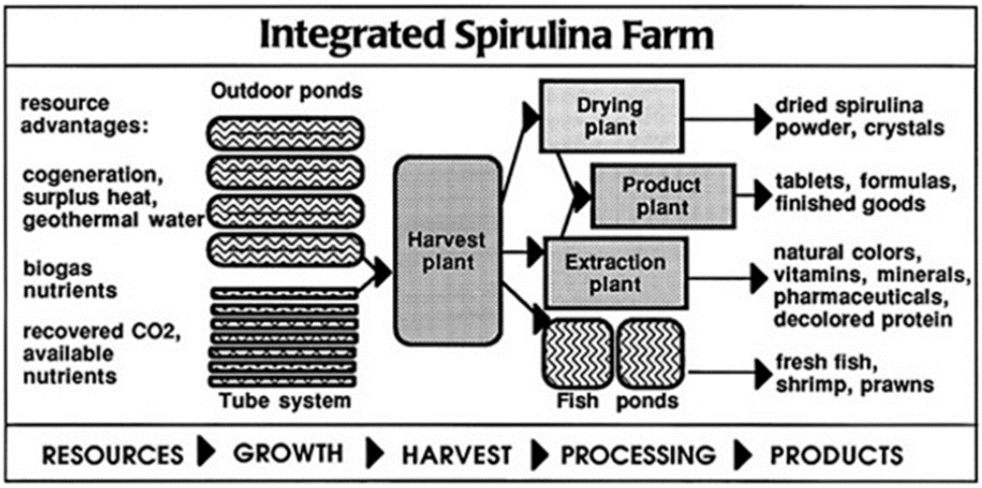

Figure 4: Integrated Spirulina Farm (Henrikson, 2011)

Integrated village systems are also a concept that has been tried in Africa, Asia and South America. In Togo, Spirulina was produced in a remote village and the solar dried spirulina was distributed at clinics for supplementation to undernourished children with success (Henrikson, 2011).

4. EVALUATION OF SPIRULINA PRODUCTION USING THERMAL SPRINGS

4.1 Criteria for evaluation

The suitability of a thermal spring is mostly depended on its physical and chemical characteristics. These characteristics include: Alkaline pH, temperature of above 30˚C, suitable minerals (beneficial and nontoxic). Availability of land, location accessibility, availability of manpower and machinery are also the other requirements around the successful exploitation of a spring for spirulina. Table 3 and table 4 show the physical and chemical characteristics of the water and trace element concentration in the springs at Tshipise, Mphephu , Siloam and Sagole water springs.

Table 3: Physical and chemical characteristics of water in the four thermal springs

Parameter	Hotspring			
	Mphephu	**Tshipise**	**Sagole**	**Siloam**
Temperature	43°C	58°C	45°C	63°C
Dissolved Ooxygen	65.3%	34.7%	9.9%	40.0%
pH	8.19	8.94	9.24	9.50
Total Dissolved Solids (ppm)	199.36	460.56	203.76	197.32
Conductivity. (mS/m)	44.00	81.00	39.00	39.00
Sodium (mg/l)	44.37	156.31	65.15	66.24
Potassium (mg/l)	1.14	4.25	1.10	2.82
Calcium (mg/l)	13.73	5.58	1.31	1.38
Magnesium (mg/l)	11.25	0.17	0.07	13.33
Fluoride (mg/l)	3.16	5.63	1.01	6.11
Nitrate (mg/l)	2.12	0.61	0.00	0.00
Chloride (mg/l)	39.38	168.97	47.85	44.35
Sulphate (mg/l)	9.26	53.17	18.20	10.44
Phosphate (mg/l)	0.00	0.00	0.00	0.00
Carbonate (mg/l)	0.00	6.00	18.00	14.40
Bicarbonate (mg/l)	151.28	126.88	102.48	107.36

4.2 Analysis of the physical and chemical analysis of the four thermal springs

4.2.1 Distance factor

When we consider the distance from Musina to the four thermal springs, Tshipise seems to be most favoured since it is only 30,3km from Musina. There can be a lot of saving in terms of transport cost of dried micro-algae for processing at Musina. More transport cost can be incurred when Sagole, Mphephu, and Siloam are selected.

4.2.2 Thermal springs water chemical characteristics

The spring water has some high total dissolved solids which is positive for spirulina cultivation. The concentration of some chemicals however is too high and toxic for human consumption. The level of fluoride, for example at Tshipise and Siloam is above 6mg/l. In these cases, only heat from the springs can be used to control the temperature of the outdoor ponds.

Spirulina grows in solutions of specific minerals with the correct chemical balance and a pH of 8-11. The hot springs proposed here have pH in the alkaline ranges (8.19 to 9.50) and this can be explored in spirulina production.

4.2.3 Temperature

Temperature is one of the most critical factors for the growth rate of spirulina. The thermal springs are found in a hot and sunny climatic region of South Africa, Limpopo Province and the spring water temperatures range from 43- 63^{o}C. These temperatures are high enough to provide for heating to ensure optimum temperatures for spirulina production and processing.

Table 4: Trace element concentration in the thermal spring's water

Element	Tshipise	Sagole	Mphephu	Siloam	Element	Tshipise	Sagole	Mphephu	Siloam
	ug/ℓ	ug/ℓ	ug/ℓ	ug/ℓ		ug/ℓ	ug/ℓ	ug/ℓ	ug/ℓ
Antimony	0.02	0.31	0.02	0	**Manganese**	0	0.20	0	0.75
Arsenic	0.14	2.88	0.43	0.27	**Mercury**	0.33	0	0.23	0.53
Barium	13.63	5.14	51.90	4.22	**Molybdenum**	1.41	1.06	0.91	2.23
Beryllium	0	0	0	0	**Nickel**	37.19	0	0	0
Bismuth	0	0.02	0	0	**Platinum**	0.01	0.07	0.01	nd
Boron	200.60	56.48	45.92	57.91	**Selenium**	2.35	0.20	0	0.72
Bromine	366.30	102.00	102.90	93.14	**Strontium**	213.30	52.18	40.14	20.35
Cadmium	0.02	0.01	0	0	**Tellurium**	0	0.03	0	0.02
Chromium	0.70	0.49	1.20	0.97	**Thallium**	0.01	0.02	0.04	0
Cobalt	0.10	0.01	0	0.05	**Titanium**	3.03	4.01	3.09	6.14
Copper	0	0	0	0	**Tungsten**	4.19	1.54	0.48	0.45
Iodine	115.20	6.41	3.25	1.90	**Uranium**	0	0	0.45	0
Lanthanum	0.01	0	0.02	nd	**Vanadium**	1.81	0.42	10.64	2.30
Lead	0.08	0.12	0.16	0.05	**Zinc**	2.48	2.05	1.95	3.46
Lithium	94.24	25.25	9.25	17.05					

5. DISCUSSION AND CONCLUSIONS

The use of geothermal waters (thermal spring waters) in algal technology provides a high optimization of the cultivation process and considerable reduction in production costs. As already indicated the production of spirulina at plants in Musina, Limpopo, South Africa and in Imperial Valley, California, came to a halt during the winter months because the water temperature fell below acceptable levels (California Energy Commission, 2005; Tshibalo, 2011). When geothermal water was used in Bulgaria, the surface temperature reached its optimum for algal growth even during winter months and increased production by 20% and reduced the production cost by 40%. Growing micro-algae at thermal springs such as Sagole, Mphephu and Tshipise can increase production and reduce production cost.

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