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Orkustofnun, Grensasvegur 9,
IS-108 Reykjavik, Iceland

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GEOTHERMAL ENERGY UTILIZATION MODEL FOR NKHOTAKOTA GEOTHERMAL SPRINGS IN MALAWI

Kondwani Thapasila Gondwe
Mzuzu University
Private Bag 201, Mzuzu 2
MALAWI
gondwe.k@mzuni.ac.mw

ABSTRACT

Malawi is endowed with huge potential of low-enthalpy geothermal as manifested by several hot springs in different geothermal fields across the country. None of these fields have been developed into useful economic activities. The main purpose of this study was to come up with potential direct utilization technologies for economic development of Malawi's geothermal fields. Three geothermal fields of Kasitu, Linga and Benga in Nkhotakota district were considered. Four technologies which included swimming pools and spas, greenhouse tomato production, indoor fish drying and raceway aquaculture of tilapia were analysed. Using the heat loss method for greenhouses, swimming pools and spas and aquaculture raceways, and the mass and energy balance method for the fish dryer, energy and hot water requirements were calculated. In addition, economic feasibility was done on each of the technology by calculating internal rate of return (IRR), payback period and net present value (NPV) discounted at 10% discount rate for a 10-year period.

Results indicate a total energy requirement of 5.2 MWth with 4.2 MWth being for aquaculture demanding total hot water requirement of 35 l/s for Linga field and 26 l/s for Kasitu field. Excluding aquaculture, the total energy requirement is 1 MWth with corresponding hot water requirement of 8 l/s for Linga and Benga fields and 6 l/s for Kasitu field. Economic evaluation indicates positive IRR ranging from 17% for aquaculture to 29% for spas and positive NPV for all the technologies with highest being with aquaculture at US$ 2.1 million and the lowest being US$ 0.04 million for greenhouse tomato production.

Based on the findings, Malawi can effectively develop greenhouse tomato production, swimming pools and spas, indoor fish drying and intensive aquaculture of tilapia in its geothermal fields dependent on the source temperatures. This would greatly boost the tourism industry and achieve sustained availability of high quality tomato and fish (both fresh and dried) throughout the year, thereby contributing to food security and improved livelihood in the areas of development. However, to achieve and maintain flow rates required for aquaculture, there is need for shallow drilling up to 300 m into deeper aquifers below. The use of greenhouses to produce vegetables and intensive fish farming will bring awareness among policymakers and the general public on the potential of the technologies to improve quality and quantity of yields throughout the year.

1. INTRODUCTION

Malawi is endowed with low-enthalpy geothermal resources as manifested by the numerous hot springs along the rift on the western side of Lake Malawi and through Kirk Range and the Shire Valley and through Zomba, Phalombe and Mulanje districts. However, these resources have not been put into economic use except the Nkhotakota's Mawira springs which were used for hot water supply during the colonial era (Harrison and Chapusa, 1975). Currently most hot springs are only used for local bathing while some springs in Nkhatabay are used for curing cassava for flour production. This project looks at some of the economic uses by which the low-enthalpy geothermal water could benefit Malawi in its economic challenges. The target areas are in Agriculture through greenhouse vegetable production, Fisheries through aquaculture and fish drying and Tourism through nature baths (spa) and swimming pools based on the hot springs in Nkhotakota district.

National development goals and related policy targets

Malawi development is guided by the Malawi Growth Development Strategy II (MGDS II) in line with the Vision 2020. MGDS II recognizes food security as being important to economic growth and creating wealth. Strategic objectives of MGDS II for agriculture and food security are:

- To increase agricultural productivity and diversity;
- To ensure sustained availability and accessibility of food to all Malawians at all times at affordable prices;
- To move up the value chain in key crops and increase agro-processing for both domestic and export markets;
- To increase agricultural production and productivity through intensification of irrigation.

In line with the MGDS II, the Agricultural Sector Wide Approach has come up with the five key focus areas of:

- Food security and risk management;
- Commercial agriculture, agro processing business and market development;
- Sustainable land and water management;
- Technology development and dissemination;
- Institutional development and capacity development (Ministry of Agriculture and Food Security, 2011).

Some of the energy policy strategies are: *"to ease pressure on destructive natural resources exploitation, particularly the depletion of forests for wood fuel, the improvement in availability and quality of energy services to the poor by creating jobs both farm and nonfarm, thus reducing overall unemployment and opening up more diverse livelihood.*" In addition, the energy policy recommends that for the energy sector to be effective, it is important to invest in the other beneficial sectors of the economy (Ministry of Energy and Mining, 2003).

The tourism policy promotes the need for community involvement in projects to ensure direct benefit for the hosting communities.

Sector status for agriculture, fisheries and tourism

Malawi agriculture is basically rain based and the effect of drought and flooding due to climate change has greatly affected food security. More than 2.8 million people will suffer due to hunger. About 47% of under-five children suffer from stunting with 13% being underweight due to malnutrition (World Food Programme, 2015).

Fish farming is in its early stages with most of the fish ponds being for small scale production. Currently most of the fish available in Malawi is the catch fish. There is very high demand for fish, making Malawi a net importer of fish. Fish production contributes 4% of GDP and captured fish is the one that contributes greatly to the national food security. There is a very high potential for aquaculture both for commercial and small scale production to meet the ever increasing fish demand (FAO, 2008; Chimatiro and Chirwa, 2005).

Geothermal energy development efforts
Geothermal application at hot springs in Malawi has been there for quite a long time. Notable use has been in Mawira in Nkhotakota, which was used to supply hot water through pipes that run 2 km to the district administrative centre where it supplied St Anne's hospital. The water was taken from collection tanks at the spring site all the way to the distribution tanks near the hospital.

With support from the British Geological Survey, most of the hot springs were recorded in the geological survey bulletin. In early 2000, the Geological Survey Department, through Dr. Dulanya, visited the documented springs (Dulanya et al., 2010). In 2010, Geothermal Development Company under the auspices of the Geothermal Projects Malawi conducted a reconnaissance of the documented springs. In the same year Gondwe and Allen carried out a cataloguing exercise where additional undocumented springs were added to the list.

A number of persons have been trained in geothermal energy resource exploration and specialized courses with the United Nations University Geothermal Training Programme (UNU-GTP) since 2010 and the government with support from World Bank has since identified a consultant to carry out detailed feasibility study for possible geothermal development.

The project
This project seeks to promote investment in the energy beneficial sectors of Agriculture through greenhouse vegetable production, in Fisheries through aquaculture production and fish drying and in Tourism and Health Sectors through promotion of hot spring sites, swimming pools and spas. Training in swimming will contribute to physical education and investment in education, youth, sports and culture. Greenhouses and aquaculture farms will be able to recruit local personnel thereby contributing to the reduction of the overall unemployment. Fish dryers will provide both employment and fight the ever increasing deforestation caused by burning wood for fish smoking. The spas and swimming pools are intended to contribute to human health and employment while enhancing tourism development.

The use of greenhouses to produce vegetables and intensive fish farming will bring awareness among policymakers and the general public on the potential of the technologies to improve quality and quantity of yields throughout the year. This will help to have sustained growth of vegetables and fish throughout the year and at faster growth rates. Fish drying will reduce fish loss due to spoilage and bring awareness to the general public on good quality of dried fish. Improved quality will be attained throughout the year irrespective of the weather. Sustained production of vegetables and reduced loss of fish during drying will contribute to the national food security.

2. GEOTHERMAL POTENTIAL IN MALAWI

2.1 Current status

Geothermal manifestations
Malawi is located in the western arm of the great East African Rift valley. It is to the southern end of the rift at 8-18° South and 32-36° East. Geothermal manifestations are mostly through hot springs and altered grounds though the existence of geothermal grass as an additional manifestation in some of the sites has been recorded (Omenda, 2010).

The hot springs are guided by the faulting within the rift. The greatest faulting occurs in the Vipya mountainous area from northern part of Nkhotakota, to the northern part of Nkhatabay, bounded by the pre-rift dislocation zone. The greatest number of hot springs is within the mountainous faulting zone of Kajilirwe/Kavuzi area to the south west of Mzuzu. They lie along the rift from Chinunkha in Chitipa at northern end all the way to Muloza in Mulanje at the southern end.

The highest recorded temperature is 84°C at Chiweta followed by 78°C at Chiwi hot springs. Chemical geothermometry indicate reservoir temperatures of as high as 270°C on average for Kanunkha hot springs (Msika, et al., 2014) also referred to as Karwe hot springs in Nkatabay. Chemical geothermometry of some hot springs is shown in Table 1.

No advanced exploratory work that would lead to actual locating of production wells for power production has been done. The resource lies untapped despite the fact that there is massive shortage of electricity in the country, marked with massive power cuts. The outage is greatest in the world at 77 days per annum (Foster and Shkaratan, 2010).

TABLE 1 Geothermometry temperatures of some hot springs in Malawi
(Dulanya et al., 2010; Msiska et al., 2014)

Hot spring	District	Surface temp. (°C)	Temp (°C) SiO_2	Temp (°C) Na-K	Temp (°C) Na-K-Ca
Chiweta	Rumphi	84	-	-	-
Chiwi	Nkhotakota	78	-	-	-
Mtondolo	Nkhatabay	74	-	126	144
Mawira	Nkhotakota	65	130.5	100.2	99.5
Liwonde	Machinga		-	182.1	142.9
Chikwidzi	Nkhotakota	55	124.2	88.9	93.3
Chombo	Nkhotakota	64	-	-	-
Ling'ona	Nkhotakota	61	-	-	-
Mwankenja	Karonga	53.4	117.3	106.8	104.0
Chinunkha	Chitipa	29	-	213.6	164.6

Underground aquifers
Documentation on aquifers in Malawi is limited to a depth of less than 100 m as applied to boreholes for potable water use. The aquifers are grouped into the basement and alluvial aquifers. The basement aquifers are low yielding and low mineralised (Mapoma and Xie, 2014) with yield of 1-2 l/s for the weathered and 2-4 l/s for the un-weathered fractured basement. Alluvial aquifers lie along the rift valley and have yield greater than 10 l/s. Most of the alluvial aquifers are semi-confined to unconfined but with high mineral contents (Chimphamba et al., 2009).

Need for detailed exploration
Malawi needs to do detailed geothermal exploration to have a quantified estimate of the energy potential in all the geothermal fields. Currently Malawi is hit with serious energy shortage with electricity just at 10% and biomass dominating in cooking and hot water supply. To come up with a reliable energy sector, diversity in energy source would be paramount. Geothermal energy would provide an environmentally sustainable source to meet the electrical base load and the provision of hot water supply.

There is a need for detailed investigations to include geophysical surveys to delineate the precise orientations of the fault conduits that bring hot water to the surface, combined with continuous discharge and various hydrochemical parameters and isotopic analysis to estimate the depth of these reservoirs (Gondwe et al., 2015). Currently, Malawi has engaged an Italian company to carry out the detailed resource assessment under the World Bank's funded project, Energy Sector Support Programme – ESSP. Not downplaying the donor support, the government should be able to plan and manage its energy sector if it is to grow to a middle income state.

2.2 Geothermal hot springs in Nkhotakota District

Nkhotakota is one of the districts in the central region of Malawi. It is located within 12°S and 34°E. It borders Nkhatabay to the north, Mzimba to the north - west, Salima to the south, Kasungu to the west and Ntchisi to the south - west. It is within the rift plain to the southern arm of the western arm of the Great East African Rift Valley.

The geology of Khotakota is bound with extensive faulting within the Ntchisi Mountains and major faulting along the lakeshore. The outstanding faults are the Liwaladzi, Mphalanyongo and the Sani faults along the lakeshore. The structural map of Nkhotakota - Benga area has been provided in Appendix I. With the new district boundary shifted from Dwangwa to Dwambazi, the additional area can be found in the bulletin for South Viphya (Peters, 1965).

There are three known geothermal fields and a total of five sets of hot springs in the district. Brief descriptions of the fields and their related hot springs have been outlined below. Their locations are shown on the map in Figure 1.

2.2.1 Kasitu geothermal field

There are two springs, one on the beach at the foot of a small Kalari hill at the shoreline of Lake Malawi and one is 10 m into the lake at Kasitu. The temperature recorded is 78°C (Peters, 1965) though lower values that can be obtained in some parts of the year. The difference could be based on the different mixing rates with cold water depending on the period of the year. They occur on the north-northwest trending faults and are at the intersection point of the Kaungozi fault and the lines of Khuyu and Mkoma II faults. So far, this is the second hottest spring in Malawi and the hottest in Nkhotakota, located 78 km north of Nkhotakota boma.

The hot springs are within the fishing village of Kasitu and a small tourist beach lodge is being constructed at the top of the Kalari hill. The beach is 3 km from the town centre and the main lakeshore road, M5. Chiwi hot springs are also referred to as Kalari hot springs or Kasitu hot springs.

2.2.2 Linga geothermal field

There are three sets of hot spring in the field within a radius of 5 km from the district headquarters. The hot springs are of nearly same average temperature.

Chombo hot springs

Chombo hot springs are about 1.5 km south of Chombo primary school and about 4 km north - west of Nkhotakota boma. The most referenced spring is a pool at the base of the bank of the Chombo marsh. The measured temperatures are 64°C close to the edge of the pool at the bank and 36°C in the pool 5 m away, this is a clear indication that there is a lot of cold water mixing within the same spot.

Recent revelations indicate that there are several springs over a range of 200-300 m with the main pool being close to mid-way. A flexible deposition of close to 60 cm overlay a mass volume of hot water below it for a length exceeding 50 m, though with an undetermined water depth. The springs are at the lower end of the Mphalanyongo fault close to its junction with the Sani fault towards the mouth of Kaombe River (Harrison and Chapusa, 1975).

Mawira hot springs

Mawira hot springs are located 2 km south of Nkhotakota boma, and within 100 m to the west of M5 road. There are about 7 hot springs with the average temperature of 65°C. A cold spring is just 14 m from the hottest spring indicating a bounding structure between them. The hot Mawira stream flows into the cold Mchandilu stream just 8 m away. The springs are to the east of the Sani fault.

Ling'ona hot spring

Ling'ona hot spring is about 1.5 km southwest of Mawira hot spring. It flows at the bank of Ling'ona River. The measured temperatures are 61°C at the source and 38°C in the bathing pool. The springs lie along the Sani fault.

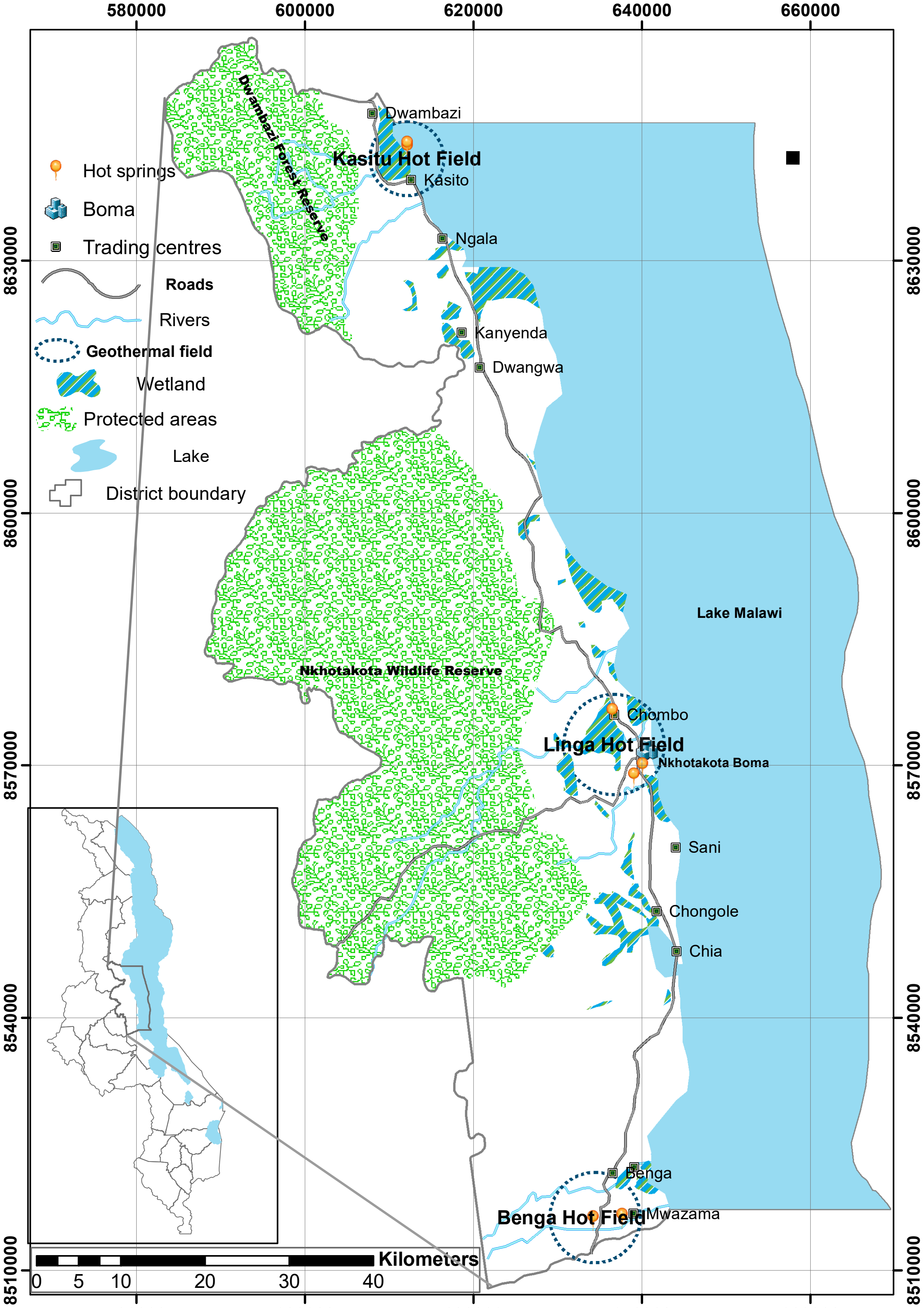

FIGURE 1: Map of Nkhotakota District showing the three geothermal (hot) fields (modified from Nkhotakota District Council, 2010)

2.2.3 Benga geothermal field

There are two hot springs at Chikwidzi, 1.5 km apart. This is about 10 km south of Benga and 56 km South of Nkhotakota Boma. The hotter spring with a temperature of 55°C lies about 100 m to the west of M5 road at Chiwidzi Bridge. Water bubbles from several places. The second spring is 1.5 km east of the road and has a measured temperature of 42°C. Benga is one of the vegetable growing areas of Nkhotakota. Benga is the southernmost geothermal field in the district.

2.3 Potential utilization

Depending on the nature of the geothermal resource, different applications can be used. Electricity generation using flash systems requires temperatures greater than 150°C while binary plants can start at as low as 80°C depending on the cycle used. Industrial application can vary from low to high temperature depending on the final required temperature.

Much as Malawi has high temperatures even for power production, this report considers direct utilization especially in agriculture and agro-industry. The potential uses of geothermal energy in agriculture and agro-industry are shown in Figure 2. Small binary production will be considered where there is need for electricity to power auxiliary equipment. Potential uses other than those shown in Figure 2 can be obtained from the standard Lindal diagram provided in Appendix II.

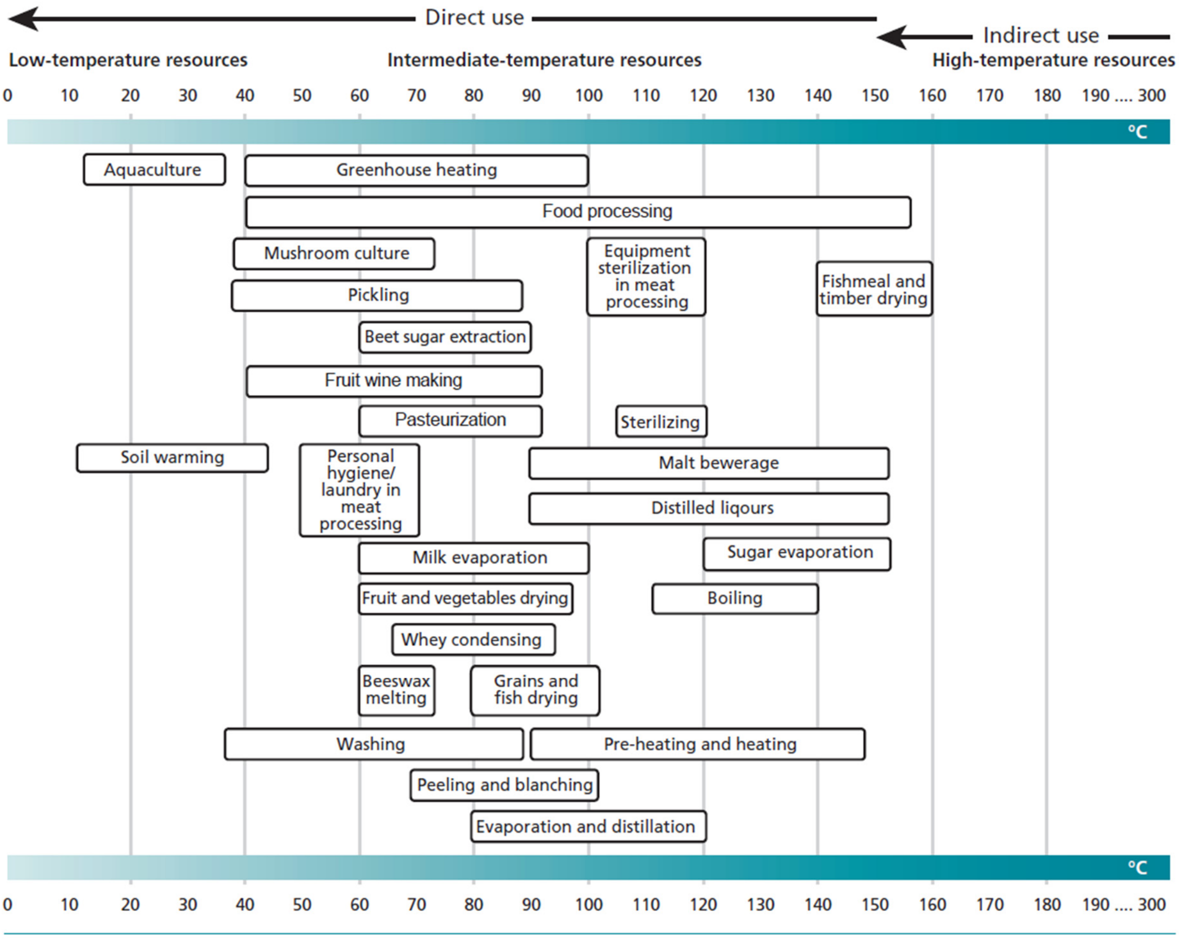

FIGURE 2: Lindal diagram of potential uses of geothermal energy in agriculture and agro-industries (Van Nguyen et al., 2015)

3. DIRECT UTILIZATION MODEL OF NKHOTAKOTA HOT SPRINGS

3.1 Selected direct uses

Considering that the fields in Nkhotakota are of temperatures 78°C, 65°C and 55°C on surface, respectively, and expected reservoir temperatures for Linga and Benga fields are 130.5 °C and 124.2°C (no records for Chiwi), the following applications have been selected.

Tourism and health: Activities being considered are swimming pools for Linga and Kasitu fields, and spas for all fields.

Agricultural activities: Activities to be considered are greenhouses for vegetable production, aquaculture farms and fish drying. Greenhouses are targeted for all the three fields while aquaculture and fish drying are being targeted for Kasitu and Linga fields.

In addition to the technologies covered in this report, other applications to be considered for future work are *district space cooling* and *binary power production*.

3.2 Swimming pools

Swimming pools in Malawi are basically in hotels and some very few well to do homes. This is associated with the well-to-do group. This project however wants to break that mentality by bringing awareness that the pools can be used for different purposes. In this section we will have two swimming pools of same surface area but with different depth to allow for the beginners to get trained in swimming. The pools will be heated and maintained at 28°C during the cold period May to August when the average temperature is 15.1°C (LaCroix et al., 1991).

3.2.1 Swimming pool dimensions

The size of a swimming pool is determined based on its intended purpose. Swimming pools could basically be used for recreational purposes, swimming competition and swimming lessons or just bathing for those who don't know how to swim. According to Karras (1996), there are three approved lengths that meet the international standards for swimming competitions. The lengths are 50 m for the Olympic Standards, 25 m for up to 400 m swimming and 33.3 m as an intermediate. Lane requirement for each swimmer is 2 m width.

Depth should be 1 m on the shallow side and 1.8 m on the deep side for a professional pool (Karras, 1996; Svavarsson,1990) and 0.8 m on the shallow side and 1.2 m (maximum) on the deep side for the non-swimmers (Jalili-Nasrabadi, 2004). Jalili-Nasrabadi further states that if the swimming pool is to be used only for swimming (excluding diving), a depth of 1.5 m or less at the deeper end for a professional pool would be more appropriate.

This project therefore considers two swimming pool sizes, one for professional swimming of up to 400 m and the other for swimming lessons and bathing for non-swimmers. Both pools will be 25 m long and 13 m wide. The depth for the professional pool will be 1 m on the shallow side and 1.8 m on the deep side while the pool for the swimming lessons will be 0.5 m and 1 m, respectively. This gives a surface area of 325 m^2 and volumes of 455 m^3 and 243.75 m^3, respectively.

Given the space requirement of 4.5 m^2 per swimmer in the deeper pools (Maharjan, 1995; Karras, 1996) and 2 m^2 per person for the shallower pools (Maharjan, 1995), the total capacity for the pools would be 72 persons for the professional pool and 162 persons for the regular pool. Considering a two thirds capacity at maximum patronage, the appropriate numbers would be 48 persons for the professional pool and 108 persons for the regular pool.

3.2.2 Swimming pool and pipe layout

There will be 28 inlet sprouts points for either pool. The main inlet and outlet lines are at the deeper end of the pool. The sprouts will be evenly distributed at the pool base while the outlet will be trough overflow around the pool. To achieve full circulation of the pool water in 6 hours, the flow rate of 21.1 l/s (Volume (m^3) × 1000 (kg/m^3) ÷ (6 hr × 3600 s/hr) is required for the professional pool and 16.93 l/s for the regular pond with a water change of 4 hrs. The outlet is through two overflow collection lines connected to a single line leading to a balance tank. The basic layout of the pools is given in Figure 3.

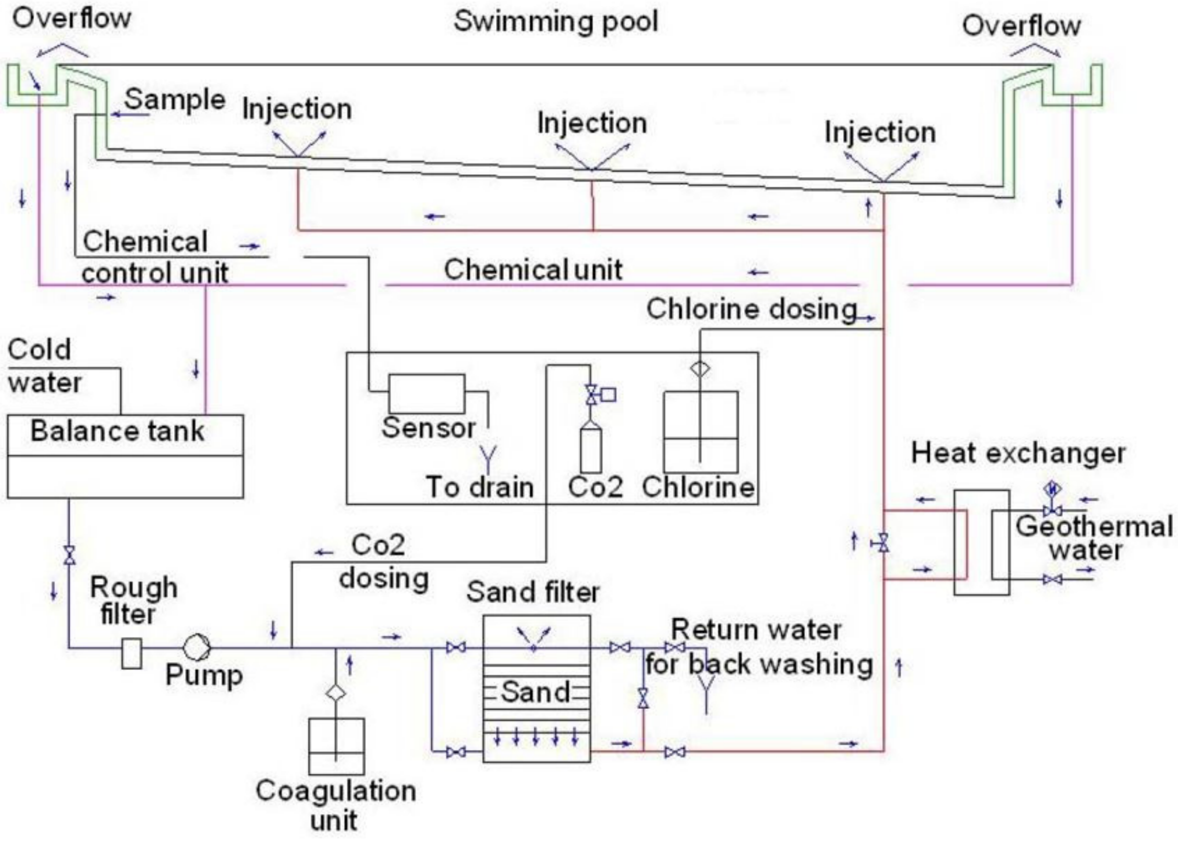

FIGURE 3: Proposed swimming pool layout (Jalili-Nasrabadi, 2004)

3.2.3 Pipe and equipment selection

There are two ways to go about the pipe selection. The pipe sizes are basically selected based on their maximum allowable pressure drop. This can be done by going to pipe sizing sheets provided by the manufacturers. Table 2 shows pipe selection chart for swimming pools and spas based on swimming pool installation manual. In this report however the pipe selection sheet as provided by pipe manufacturers were applied. It must be clearly stated that values in Table 2 fall out of range in the manufacturers flow sheet where the velocity is limited to 5 ft/s (1.52 m/s). Table 3 (a and b) has been developed based on the pipe manufacturers. Conversions used in Tables 2 and 3 are: 1 ft = 0.3048 m, 1 ft/s = 0.3048 m/s, 2.3 ft/ 100 ft = 22.46 kPa/100 m. Total pressure drop calculated is 41 kPa, which a pump has to overcome in addition to the elevation head at the site.

TABLE 2: Pipe selection based on maximum velocities
(modified from Sta-Rite Industries: Basic Training Manual, 2003)

Flow rate at water velocity of 2.1 m/s (l/s)	**Flow rate at water velocity of 2.4 m/s (l/s)**	**Flow rate at water velocity of 3.1 m/s (l/s)**	**Pipe diameter (“)**	**Pipe diameter (mm)**
0.8	0.9	1.1	¾	19
1.1	1.4	1.8	1	25
2.1	2.3	3.0	1 ¼	31
2.8	3.3	3.9	1 ½	38
4.7	5.4	6.9	2	50
6.9	7.4	7.9	2 ½	63
10.1	11.7	14.8	3	75
17.4	19.6	24.9	4	100
34.1	45.7	53.6	6	150

TABLE 3a: Pressure drop in regular swimming pool circulation system

Flow rate (l/s)	**Line component**	**Quantity**	**Inside diameter (mm)**	**Length (m)**	**Equivalent length (m)**	**Total equivalent length (m)**	**Pressure drop (kPa/100m)**	**Line press. drop (kPa)**
0.75	Pipe	1	65	4		4		
	Pipe	7	65	0.3		2.1		
	Elbow	1	65		2.1	2.1		
	Adapter	7	65		1.68	11.76		
						19.96	2.47	0.49
1.5	Pipe	1	80	4		4		
						4	1.12	0.04
2.26	Pipe	1	80	4		4	2.7	0.11
3.01	Pipe	1	80	4		4	4.04	0.16
3.76	Pipe	1	80	4		4		
	Adapter	1			1.98	1.98		
						5.98	5.84	0.35
4.51	Pipe	1	100	4		4	2.47	0.10
5.27	Pipe	1	100	4		4		
	Elbow	1			3.66	3.66		
	Adapter	1			2.74	2.74		
						10.4	3.14	0.33
21.06	Pipe	1	150	15		15		
	Elbow	2			5.4	10.8		
	Tee	1			9.97	9.97		
						35.77	6.74	2.41
	Loss in pipes							**3.99**
21.06	Heat exchanger	1						25
21.06	Sand filter	3						12
	TOTAL							**40.99**

Pump and filter selection:
Based on past reports, filters of Astral (865) were selected. Data for other type of filters were not available so the same filter has been adopted for this purpose. However, locally available filters in Malawi will be assessed and calculations revised appropriately. Astral 865 filter´s specifications are presented in Table 4.

With the pool volume of 455 m^3 and a recycle time of 6 hrs, the flow is 75.8 m^3/h or 21.06 l/s. The regular pool is 243.75 m^3 and recycle time is 4 hrs and the resulting flow is 61 m^3/h or 17 l/s. This would require 3 filters for the professional pool while 2 filters will be enough for the regular pool. Pumps less than 1 kW will be required for each of the pools. Detailed specifications will be obtained from swimming pool installers in Malawi.

TABLE 3b: Pressure drop in professional swimming pool circulation system

Flow rate (l/s)	**Line component**	**Quantity**	**Inside diameter (mm)**	**Length (m)**	**Equivalent length (m)**	**Total equi-valent length (m)**	**Pressure drop (kPa/100m)**	**Line press. drop (kPa)**
0.6	Pipe	1	65	4		4		
	Pipe	7	65	0.3		2.1		
	Elbow	1	65		2.1	2.1		
	Adapter	7	65		1.68	11.76		
						19.96	1.8	0.36
1.21	Pipe	1	65	4		4		
	Elbow	1			2.1	2.1		
						6.1	6.51	0.40
1.81	Pipe	1	80	4		4	1.57	0.06
2.42	Pipe	1	80	4		4	2.02	0.08
3.02	Pipe	1	80	4		4		
	Adapter	1			1.98	1.98		
						5.98	4.04	0.24
3.63	Pipe	1	80	4		4	5.84	0.23
4.23	Pipe	1	80	4		4		
	Adapter	1			1.98	1.98		
						5.98	7.64	0.46
16.93	Pipe	1	150	15		15		
	Elbow	2			5.4	10.8		
	Tee	1			9.97	9.97		
						35.77	4.27	1.53
	Loss in pipes							**3.36**
16.93	Heat exchanger	1						25
16.93	Sand filter	2						12
	TOTAL							**40.36**

TABLE 4: Specification of Astral 865 sand filter

Capacity	30 m^3/h
Filtering speed	20 m^3/m^2h
Filter surface area	1.54 m^2
Volume	2 m^3

3.2.4 Heating energy requirement

Energy required for a pool is energy required to compensate for energy losses from the pool through convection, evaporation, conduction, radiation and the effect of rain and the energy required to heat fresh water for the pool. Based on formulae provided in lecture notes (Ragnarsson, 2015), the energy losses are computed as follows:

Convection heat loss

Convection heat loss is basically dependent on the atmospheric air temperature (ambient) and the wind speed just above the water surface. Convection heat loss has been calculated using Equation 1:

$$Q_c = h_c(T_w - T_a) \tag{1}$$

where Q_c = Convective heat loss [W/m^2];
h_c = $k + 1.88\, v_2$ [W/m^2 °C];
k = $3.89 + 0.17\,(T_w - T_a)$;
T_w = Pool water temperature [°C];
T_a = Ambient air temperature [°C];
v_2 = Wind velocity 2 m above the ground [m/s].

Values of $(T_w - T_a)$ and v_2 can be obtained in Appendix III.

Evaporative heat loss

Evaporative heat loss is the energy lost due to evaporation of the pool water. In addition to the dependence on ambient air temperature and wind velocity, evaporative heat loss is also greatly affected by the difference in partial pressures of steam just above the water surface and that in air above the pool. Computing evaporative heat loss is done using Equation 2:

$$Q_e = (1.56k + 2.93v_2) \times (\mathrm{e}_w - \mathrm{e}_a) \tag{2}$$

where Q_e = Evaporative heat loss [W/m^2];
e_w = Partial (saturation) pressure of steam in the air at the water surface [mbar];
e_a = Partial pressure of steam in the air above the water surface [mbar]; (saturation pressure at air temperature × relative humidity).

Values of $(\mathrm{e}_w - \mathrm{e}_a)$ can be obtained from Appendix III.

Radiative heat loss

Radiative heat is mainly dependent on the solar radiation and effect of cloud cover. The standard formula for computing radiative heat loss is given in Equation 3 (Ragnarsson, 2015) and can also be found using Equation 4 (Karras, 1996):

$$\begin{gathered} Q_r = 4.186((13.18 \times 10^{-9} \times (0.46 - 0.06\,\mathrm{e}_\mathrm{a}^{0.5})T_a{}^4 - G_o(1-a)) \times \\ (1 - 0.012N^2) + 13.18 \times\ 10^{-9}(T_w{}^4 - T_a{}^4)) \end{gathered} \tag{3}$$

$$Q_r\ = 0.51 \times 10^{-8} \times [(492\ + 1.8T_w)^4\ - (492\ + 1.8T_a)^4\,] \tag{4}$$

where Q_r = Radiative heat loss [W/m^2];
G_o = Solar radiation in clear weather [cal / s m^2];
a = Natural reflection of water;
N = Cloudiness factor (0 – 8);
e_a = Partial pressure of steam in the air above the water surface [mbar]; (saturation pressure at air temperature × relative humidity).

Conductive heat loss

Conductive heat loss is dependent on the thermal conductivity of the construction material and their thickness. The conductive heat loss is calculated by Equation 5. In this report, concrete of thickness 18 cm and rock wool of thickness 6 cm have been used as pool construction and insulation materials respectively:

$$Q_{cd} = \frac{\Delta T_{soil}}{\frac{l_1}{k_1} + \frac{l_2}{k_2}} \tag{5}$$

where ΔT_{soil} = $T_w - T_{soil}$ [°C] (values can be obtained in Appendix III);
T_{soil} = Outside soil temperature [°C];
l_1 = Thickness of construction material (1) – concrete in this case [m];
l_2 = Thickness of construction material (2) – rock wool in this case [m];
k_1 = Thermal conductance of concrete = 1.82 [W/m°C];
k_2 = Thermal conductance of rock wool = 0.042 [W/m°C].

Highest computed values are for the month of August. These values are shown in Table 5.

TABLE 5: Maximum energy losses from the swimming pools

Pool type	Q_c[Wm^{-2}]	Q_e[Wm^{-2}]	Q_r[Wm^{-2}]	Q_{cd}[Wm^{-2}]	Q_f[W]	Q_{total}[kW]
Regular	169	626	74	7	46,339	396
Professional	169	626	68	7	20,595	371

The calculated heat losses are multiplied with corresponding effective area. Summing the products together with loss due to heating the refill water Q_f, gives the total effective energy loss from the pool. The areas considered in this report are L × W for Q_c, Q_e and Q_r while the area for conductive heat loss is the total interior wall surface area. This is given by; $(L \times W) + (2 \times L{\times}D) + (2 \times W{\times}D)$ where D is the average pool depth, L is the length and W is the width.

Considering a water renewal of 30 l/person and that the operational time is 8 hrs per day, the additional cold water flows would be 0.4 kg/s for the professional pool and 0.9 kg/s for the other pool. The energy required for heating fresh water, originally at ambient temperature is 20.60 kW for the professional pool and 46.34 kW for the regular pool. This has been computed using Equation 6:

$$Q_f = m_f C_p (T_w - T_f) \tag{6}$$

where Q_f = Energy needed to heat refilling water [kW];
T_f = Refill water temperature [°C];
m_f = Mass flow rate of fresh cold water [kg/s];
C_p = Specific heat capacity of water [kJ/°C].

The total energy required from the geothermal water will thus be 370.66 kW for the professional pool and 396.07 kW for the regular pool. To estimate the required flow rate of geothermal water, different surface temperatures of 55°C, 65°C and 78°C have been considered, as well as respective temperatures of 78°C and 95°C at 400 m depth for Linga and Kasitu. These have been computed using Equation 7 and are shown in Table 6:

$$m_h = \frac{Q_{total}}{C_p (T_h - T_w)} \tag{7}$$

where Q_{total} = Total energy requirement [kW];
T_h = Geothermal water temperature [°C];
m_h = Mass flow rate of geothermal water [kg/s].

TABLE 6: Maximum hot water requirement for the swimming pools at different source temperatures

Pool type	**Power (kW)**	**Hot water requirement (l/s)**			
		55°C	**65°C**	**78°C**	**95°C**
Professional	370.66	3.28	2.39	1.77	1.32
Regular	396.07	3.50	2.56	1.89	1.41
Combined	766.73	6.78	4.95	3.66	2.73

3.2.5 Nature baths

Unlike the use of swimming pools which are used by the elite group, geothermal nature baths are used by the poor locals in the locality. This is basically due to the fact that nearly all sites are not cared for and the areas and the waters are untidy and unhygienic. The waste cases occur with Chiweta hot springs where businessmen treat killed pigs for the removal of the fur from the skin at the hot water source.

This project however aims at improving the sites to a state acceptable to all groups of people including the elite. There will be two sets of spas to be developed which will include commercial spas of the level of the Blue Lagoon in Iceland and non-commercial improvement of the existing pools. The non-commercial ones will be available for the local community for free while the commercial ones will be open to all with locals paying a lower fee. A distinction between the current nature bath at Chombo in Malawi and an improved commercial nature bath of Mývatn in Iceland is shown in Figure 4. Developing the nature bath in Figure 4a into a similar bath to Figure 4b would allow all levels of people to patronize the facility and promote tourism.

(a) Chombo Nature Bath – Nkhotakota, Malawi

(b) Myvatn Nature Bath – Iceland

FIGURE 4: Undeveloped (a) vs. developed (b) nature baths

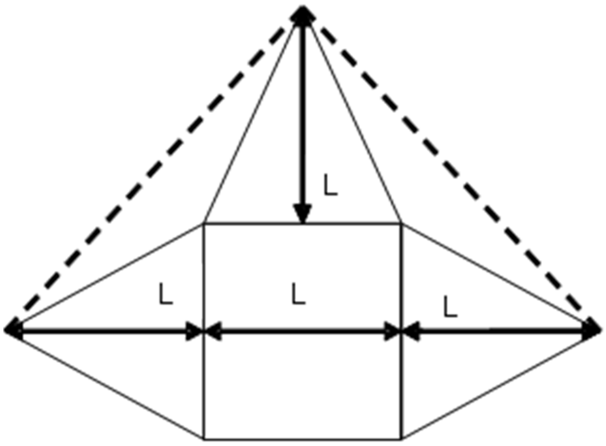

FIGURE 5: Proposed plan for the spa

Pool design and dimensions
The spa will be designed with three triangular segments attached to a central square section as shown in Figure 5. The square section will be at the entry point with the temperature setting of 38°C while the triangular sections will be at 40°C, 42°C and 45°C. For the purpose of this project, the depth of the square section will be 0.75 m while the depth of the triangular sections will be 1 m. The base and height of the triangular shape shall be equal the side of the square section. Computation of evaporation losses, energy losses and the mixing ratios has been based on side length of 3 m as shown in Figure 5.

Based on the operation of the Blue Lagoon (Iceland), the hot brine will be delivered at a central receiving point where it will be distributed to the four sections through smaller pipes. The mixing will be regulated by an automatic control valve based on temperature.

Energy losses and water requirement
Energy losses have been computed based on Equations 1, 2, 3 and 5 in Section 3.2.3. Control of temperature is based on the temperature activated switches allowing just enough amount of water to mix with the pool water to maintain the required temperature. Using Equation 7, the minimum and maximum hot water requirements were calculated and are shown in Table 7.

TABLE 7: Maximum hot water requirement for the spa at different source temperatures

Power (kW)	**Hot water requirement (l/s)**			
	55°C	**65°C**	**78°C**	**95°C**
62.45	0.995	0.597	0.393	0.271

3.3 Greenhouses

Greenhouses are structures covered with transparent or translucent materials that are used to provide desirable climatic conditions for plant growth. Depending on the construction materials and operation control capabilities, greenhouses vary greatly in their cost.

Greenhouses are used to provide the optimum temperature and humidity (Canakci et al., 2013) and light intensity for the crops while protecting them from extreme winds, rain contact, snow and excessively high or low temperatures. In temperate regions the main aim is to protect the crops from extremely low temperature, effect of snow, extreme winds and increase light capture or provide artificial lighting in very short days. In the tropics however the primary reason for using the greenhouse is to exclude pests, protection from excessive solar radiation, protection from heavy rains and wind (Hickman, 2010) and for humidity control.

Greenhouse operation is characterised by an intensive production and year round operation. It involves high investment cost and high energy consumption (Djevik and Dimitrijevic, 2009). Good locations are crucial in planning and production of greenhouse crops (Canakci and Akinci, 2006).

Greenhouse production aims at producing higher quality yield outside the cultivation season, which is possible by maintaining the optimum temperatures at every stage of the crop (Shethi and Sharma, 2008). Greenhouse effectiveness is defined as its capability to increase light input, reduce heat losses during cold weather and maximise heat removal during hot weather (Fabrizio, 2012).

In tropical areas of Africa, very few areas have the optimum growing conditions required for a high value crop. Polyethylene covered, non-ventilated greenhouses are mostly used for a month or two for start-up of vegetable plants. To achieve high quality crop throughout the year, ventilated greenhouses are required (Mrema et al., 2011). Greenhouses in hot and humid environments should be able to protect plants from extreme temperatures, rain, wind and insects, in such a way that the optimal growing conditions are attained. The inside temperature and relative humidity are controlled through natural and mechanical ventilation, evaporative cooling and shading (Shamshiri and Wan Ishmail, 2014).

Some of the advantages of using greenhouses in tropics are:

- Higher yield and better quality
- Better use of fertilizers and pesticides
- Less susceptibility to diseases due to less wetting and exclusion of heavy rainfall
- All year production ensures reliable market availability (Von Zabeltitz, 1997).

3.3.1 Site selection

Site selection is of great importance for the sustainability and profitability of greenhouse vegetable production. Based on Mrema et al. (2011), the factors to be considered in locating a greenhouse include: A nearly level topography with good quality and quantity of water for irrigation, well drained, clear areas with wind break, proximity to road and power networks and labour availability. The area should be flat in the width and 0 to 0.5% slopes in the main axes. Urban areas with high air pollution should be avoided (Castilla and Baeza, 2013).

The sites chosen are all within reach to the main road. Linga and Kasitu are also close to trading centres while Benga trading centre is about 10 km from the greenhouse sites. In addition to these local markets the major market would be in Lilongwe and Kasungu and some share going to Nkhatabay and Mzuzu. Flat areas are located within the geothermal field and the actual site would depend on negotiations with the community leaders, district officials and agricultural extension workers.

In all the three sites, irrigation water could be taken from nearby rivers or from the lake where necessary. Labour availability should not be a problem at Kasitu and Linga while operations at Benga may require additional labour force from other areas.

Despite the fact that all the areas have access to grid electricity, electricity in Malawi is very much unreliable with frequent and extended blackouts and load shedding being the norm of the day.

3.3.2 Climatic data for the selected area

It has been a challenge getting climatic data for Nkhotakota district from the responsible administrators for the district and data used is the best available based on internet sourced data. Considering that the information provided in the District development profile was not consistent within the document, the district official was requested to provide an official stand, however, he opted not to cooperate. For this reason, data used in this report is based on NASA data obtained through RET Screen programme, LaCroix et al., (1991) publication on Orchids of Malawi, Feeble online weather data and some from Metrological department in Malawi in some of their 10-day weather reports. Reasonable mean for each set was established and applied in this report.

Nkhotakota can be described as a sub-tropical climate with mean monthly temperatures ranging from 20°C in cold months (May to August) to as high as 37°C in hot months (September to January). It is however important to note that on a daily basis there is a wide variation between day and night temperatures. On average, temperatures between 8:00 am and 7:00 pm are generally above 17°C in hot months, but those from 7:00 pm to about 7:30 am are basically below 13°C. Mean monthly minimum temperatures range from 15°C in cold season to 22°C in the hot period. Up to 30 days per year experience extreme cases with a daily mean temperature of as low as 7-9°C.

The variation in temperature results in an inverse corresponding relative humidity. In the night the humidity would range from about 64% to as high as 93 % (around midnight) while during the day it can go as low as 30% or even lower between 1:00 pm and 2:00 pm.

3.3.3 Structural design and dimensions

Greenhouses can be made of different materials for both frame and covering. Material used in greenhouse construction range from locally available materials like bamboo stems to most expensive steel frames. Use of cheap poly plastic and wooden poles or bamboo sticks is being promoted to assist small holder farmers in the tropics (Pack and Mehta, 2012).

There are basically two types of greenhouses based on their structural shape. Most polyethylene sheet roofed greenhouses are of Quonset (or D-frame) type where the arched shape allows the transfer of the load to the ground. These can be with or without walls as indicated depending on design. Most glass greenhouses are of the A – frame type. These have trusses that form the roof and the gables and all the load is transferred to the ground through the side walls. A-framed greenhouses could be stand alone or gutter connected multiples (Mrema et al., 2011).

It is recommended that for tropical climates, tall greenhouses should be used. The minimum height from floor to gutter should be at least 3 m with an addition of at least 1.2 m to the ridge. Taller structures provide bigger air volumes which contribute to improved climate uniformity through the slowed response to external weather conditions (Kumar et al, 2009). However, for effective light capture, the greenhouse in the tropics should have an east-west orientation for single span and north-south orientation for multi-span with gutter connection (De Gannes et al., 2014). In this project the construction of the frame will be of aluminium bars and the covering of fibreglass.

The sizes of the greenhouses would be 36 m in length, 7 m in width and the wall height 3 m. A roof slope (pitch) angle between 25 and 30° will be used. A ventilation area of 15-30% of the floor area will be provided based on desired requirements (Kumar et al., 2009; Kittas et al., 2013). To achieve efficient ventilation, openings must be placed at the roof, gable and sidewalls (Kittas et al., 2013). In this project, openings will be on the windward sidewalls for cold air inlet and on the leeward roof for the warm air outlet. A rough sketch of the proposed design is shown in Figure 6.

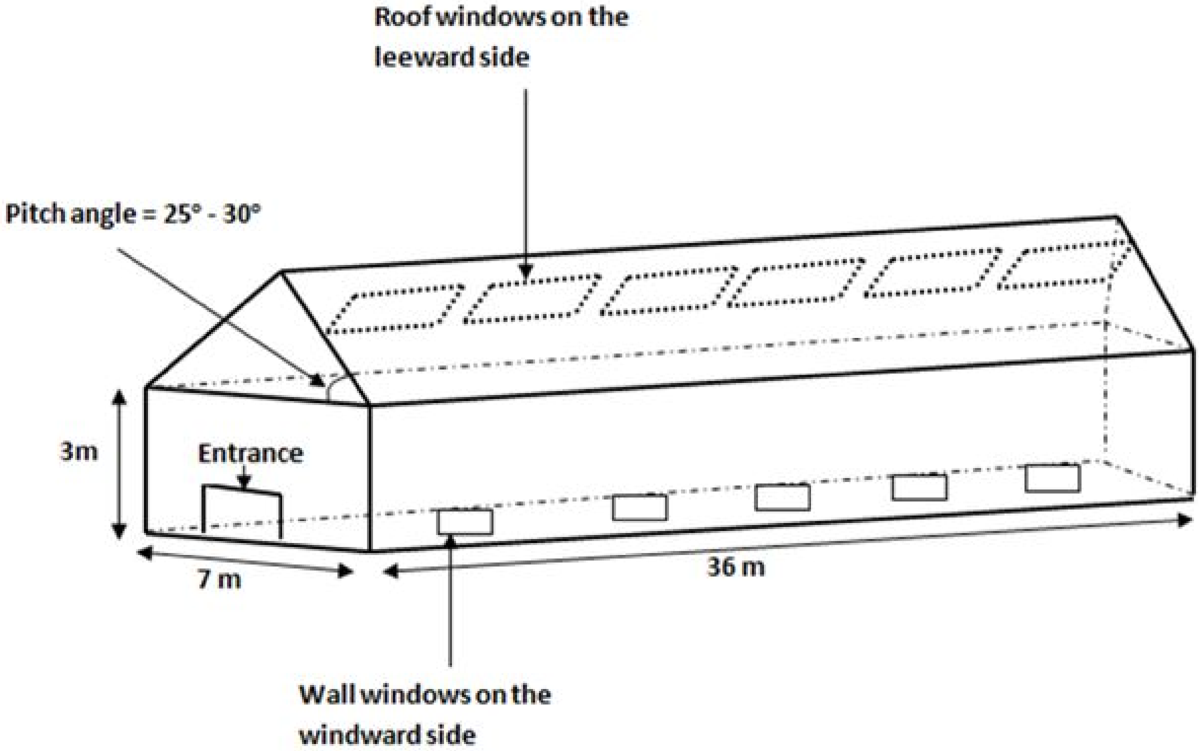

FIGURE 6: Sketch of the proposed greenhouse

Climate control could be either active or passive. Active control is where humidification and dehumidification is done with the help of mechanical devices while in passive control this is achieved through natural convection. Passive climate control is less costly but achieves irregular production and good quality can only be obtained in limited periods while with active control, despite being costly, production is regular and good quality is assured all year round (Montero et al., 2013). It is therefore imperative that both passive and active climate control will be used in this project. The combination will be used in such a way that when passive control can be effective, it is the one to be used and active control will be employed only in extreme cases. This will require lower investment cost while achieving the required production and quality levels.

3.3.4 Heating and cooling requirement

It is difficult to accurately determine the behaviour of greenhouse with static designing methods. But for simplicity, static design can be used with conditions set with no solar gains (Emeish, 1999). This is basically calculated for the worst case which generally occurs at early morning hours in winter (NGMA, 2015). In this project however the assumption affects greatly the cooling design load which is greatest when the solar radiation is greatest. Heating load has been assumed to be during the night or days of very low solar radiation.

To determine the heating requirement, heat losses are required to be known. With the static design method, the heat loss in a greenhouse is composed of two major components; transmission losses through the walls and roof and the infiltration and ventilation losses due to the infiltration of the cold outside air (Kasapoglu and Parlaktuna, 2005). In principle the energy required is the net energy loss obtained by subtracting all energy gains from the total energy losses as given in Equation 10 (Joudi and Hasan, 2013)

$$Energy\ Required\ = \Sigma Heat\ Loss - \Sigma Heat\ Gains \tag{10}$$

Transmission loss through the walls and the roof
Transmission losses through the walls and the roof are given by equation 11:

$$Q_t = UA(T_i + T_o) \tag{11}$$

Where Q_t = Transmission heat loss through walls and roof [W];
U = Heat transfer coefficient [W/m^2°C];
A = Total surface area of the walls and roof [m^2];
T_i = Inside design temperature [°C];
T_o = Outside design temperature [°C].

The heat transfer coefficient (*U*) for the covering materials is dependent on the type of material and on the wind speed of a particular area. This means that the values will be different even if the material is the same but if the wind speeds are different. The *U* values of different covering materials as adopted from Rafferty, 1998 (cited by Kasapoglu and Parlaktuna, 2005) are given in Table 8.

From Table 8 trend lines with the order of three were obtained and used to compute different values of the *U* values at different wind speeds. The higher the order the more precise it becomes but in this project an order of three was thought appropriate. The obtained trend lines are given in Table 9 as polynomials of the order three.

TABLE 8: U values of common covering materials as a function of wind speed as adopted from Rafferty, 1998 (cited by Kasapoglu and Parlaktuna, 2005)

V(m/s) **Material**	**0.00**	**2.24**	**4.47**	**8.94**	**11.18**	**13.41**
Glass	4.34	5.40	5.91	6.47	6.59	6.70
Fibreglass	3.95	4.91	5.39	5.87	6.01	6.12
Single Poly	4.60	5.68	6.19	6.76	6.87	6.98
Double Poly	3.04	3.58	3.83	4.07	4.13	4.18

TABLE 9 : Polynomials for commputing *U*-values with wind speed (v)

Covering material	**Polynomials for computing *U*-value**
Glass	$U = 0.0015v^3 - 0.0475v^2 + 0.5393v + 4.3582$
Fibreglass	$U = 0.0015v^3 - 0.0446v^2 + 0.4958v + 3.9647$
Single Poly	$U = 0.0015v^3 - 0.0483v^2 + 0.5480v + 4.6191$
Double Poly	$U = 0.0009v^3 - 0.0261v^2 + 0.2788v + 3.0494$

Infiltration heat loss
Infiltration heat loss basically depends on the rate at which the inside air is replaced by the cooler air from outside. This is a function of the temperature difference between the inside and the outside air and also the wind speed at the site. The infiltration energy loss is calculated using Equation 12.

$$Q_i = V \times ACH \times \rho_a \times C_p(T_i - T_o)/3600 \tag{12}$$

where Q_i = Infiltration heat loss [W];
V = Greenhouse volume [m^3];
ACH = Air changes per hour;
ρ_a = Air density [kg/m^3];
C_p = Specific heat capacity of air [J/kg°C];
T_i = Inside design temperature [°C];
T_o = Outside design temperature [°C].

Cooling is required if the heat gains are larger than the heat losses. It is basically calculated by Equation 10 and can be considered as the negative heating load. The negative sign to the heating load indicates that the heat has to be removed from the system.

From the Excel calculation on the average temperatures, the system shows that it will require heating between May and September and cooling between October and April. However, the critical heating is required at night throughout the year to avoid condensation when the night temperature falls below dew point.

Heating pipe requirement
The bare pipe length is determined by the empirical Equation 13.

$$L = \frac{3.6Q_t}{11.345A\left[4.422 \times \left(\frac{1}{D}\right)^{0.2} \times (1/(1.8T_{ave} + 32)^{0.181} \times (\Delta T)^{1.266} + 15.7 \times 10^{-10}[(1.8T_1 + 32)^4 - (1.8T_2 + 32)^4]\right]} \tag{13}$$

where L = Pipe length [m];
Q_t = Total heat loss [W];
D = Outside pipe diameter [mm];
T_{ave} = $255.6 + (AWT + T_{air})/2$ [°C];
AWT = $T_{wi} - \Delta T/2$ [°C];
T_{wi} = Heating water inlet temperature [°C];
T_{air} = Greenhouse inside design air temperature [°C];
ΔT = Heating water temperature drop [°C];
T_1 = $255.6 + AWT$ [°C];
$AUST$ = Average unheated surface temperature [°C];
T_3 = $(AUST + T_{air})/2$ [°C];
T_2 = $255.6 + T_3$ [°C];
A = Outside surface area of the pipe per unit length [m^2/m].

The number of pipes required is then obtained by dividing the pipe length by the greenhouse length given by Equation 14:

$$n = L_{pipe} / L_{greenhouse} \tag{14}$$

The pipes will be put at 0.5 m and 2 m above the ground. The value for the number of pipes (*n*) is thus rounded to the nearest even integer in Excel computation. This gives a total number of pipes, 12, with a total length of 397 m. The pipes will be at 1 m and 2.5 m from the walls giving a door passage space of 2 m between the inner pipes. Inputs and calculated outputs for the heat requirement and hot water piping are show in Table 10.

TABLE 10: Input and calculated data for greenhouse heating requirement

Input parameters		**Output parameters**	
Outdoor air temperature	15.1°C	Total energy loss (design)	9954 W
Wind speed	3.86 m/s	Max geothermal water flow rate	0.242 l/s
Greenhouse floor area	252 m^2	Total pipe length	397 m
Total glass area	488 m^2	Number of pipe required	12
Volume	785 m^3	Total energy consumption	188 GJ/year
Inside design temperature	18 °C	Specific energy consumption	0.75 (GJ/m^2) / year
Air changes	3 ACH	Geothermal water consumption	4,575 m^3/year
Tubing outside diameter	32 mm		
Water supply temperature	55°C		
Water temperature drop	10 °C		
Brine density	985 kg/m^3		
Annual load factor	0.6		

3.3.5 Greenhouse cooling

Greenhouses in the tropics require cooling especially between 10 AM and 3 PM during the hot months when the temperatures are above the crop requirement. In Nkhotakota, cooling will be required from end of August to mid-February. There are several ways of greenhouse cooling, however for the purpose of this report only those to be employed are explained.

Natural ventilation
Natural ventilation works on the principle of temperature difference and density. Hot air is lighter and tends to rise. In a greenhouse, openings are on the windward wall side for cold air inlet and on the leeward roof side for the hot air exit. When the air is heated it rises creating space for the cold air. It is mainly used due to its low energy requirement. Its dependency on the natural external conditions makes it non-efficient at times and other techniques have to be used in combination (Montero et al., 2013).

Shading
Shading is used to reduce the incoming solar radiation by providing shading materials either inside or outside the greenhouse walls. These materials could be either shade cloth, shading nets or some other liquid foams. Much shading is good for low-light requiring crops, but it greatly lowers productivity in high-light requiring crops like tomatoes if used over long periods.

Evaporative cooling
Evaporative cooling based on the principle of conversion of sensible heat into latent heat through evaporation of water. It is the least expensive way in greenhouse cooling. According to Kumar et al., 2009, evaporative cooling is the most effective method in greenhouse microclimate regulation. It can be achieved either by passing water through an evaporator pad or through mist or fog spray. Mist spray achieves uniform distribution of both humidity and temperature throughout the greenhouse.

To achieve effective microclimate control, this project will use a combination of natural ventilation, mist evaporative cooling and fan and pad evaporative cooling.

3.3.6 Irrigation water requirement

The irrigation water requirement (IWR) is found by summing the crop water requirement (CWR) and the soil leaching requirement (SLR). To determine the irrigation water requirement, it is thus important to know the evapotranspiration upon which the CWR is greatly dependent.

To determine the evapotranspiration rate, the Penman-Monteith equation is derived and applied. The equation is a combination of the original latent heat flux and the aerodynamic resistance as described in the guidelines for computing crop water requirement (Allen et al., 1998). Reference evapotranspiration is calculated using Penman-Monteith equation as given in Equation 15 and monthly crop water requirement is found using Equation 16 (von Zabeltitz, 2011).

$$ET_o = 0.408 \times \Delta \times (R_n - G) + (\gamma \times \frac{900}{T_{mean} + 273}) \times v \times (u_s - u_a) \div (\Delta + \gamma \times (1 + 0.34v) \tag{15}$$

where ET_o = Reference evapotranspiration [mm/day];
Δ = The slope of vapour pressure curve [kPa/°C];
R_n = Net radiation at crop surface [MJ/m^{2}day];
G = Soil heat flux density [MJ/m^{2}day];
γ = Psychometric constant [kPa/°C];
T_{mean} = Mean daily air temperature at 2 m [°C];
v = Wind speed at 2 m height [m/s];
u_s = Saturation vapour pressure [kPa];
u_a = Actual vapour pressure [kPa].

and

$$CWR_m = CWR_d \times d_m \tag{16}$$

where CWR_m = Monthly crop water requirement [mm/month];
d_m = Number of days in a month;
CWR_d = $AET_c \times (1 + l_i) \times A_{crop}/A_{greenhouse}$ [mm/day];
AET_c = Actual evapotranspiration for a particular crop coefficient [mm/day];
l_i = Irrigation loss factor [%];
A_{crop} = Area covered by the crop [m^2];
$A_{greenhouse}$ = Area of the greenhouse [m^2].

A detailed computation of the irrigation water requirement for each of the three sites need to be calculated using the standard method. For the purpose of this project however, a requirement of 50 millilitres per plant per day for new plants and 2.7 litres per plant per day (Snyder, 1914) has been assumed. With an average plant population of 615, a total maximum irrigation requirement of 1,660 litres per day is needed. Based on Snyder 1914, plant population is calculated by dividing the greenhouse area by 0.37 m^2 per plant (for maximum) and by 0.46 m^2 per plant (for minimum) population.

3.4 Fish dryer

Fish is highly perishable since it contains as high as 80% of water by mass. This calls for drying to remove the water to a level that inhibits microbial growth (Hubackova et al., 2014). In Malawi, fish drying is mostly done through open sun drying for smaller fish like Utaka, Usipa, Matemba and small size Mcheni, while the bigger fish like Chambo (Tilapia), Kampango, Mlamba and Batala are smoke dried. Frequently the smaller fish is also sun dried where they are roasted first and then sun dried or they could be boiled and then sundried. A lot of fish is lost due to spoilage and animals. The quality of fish is usually denatured due to uncontrolled drying. Smoking of fish has also resulted in deforestation along the fishing areas making it even more difficult for such drying, especially during the rainy season.

According to Kapute, 2008, close to 40% of landed fish is lost due to poor processing. It is unfortunate to note that even the national fishing company Maldeco is using traditional ways of drying fish. Due to lack of information in respect to fish quality and safety, most Malawians consume fish with an unacceptable quality. Studies indicate that such fish is sold in most of the supermarkets in the country (Makawa et al., 2014).

Air dryer design
The principle of air drying is to pass air of low humidity over the mass to be dried. As it passes it absorbs the water from the material, thereby drying it. The rate of drying is mainly influenced by the temperature and the humidity difference between the drying air and the material being dried. The velocity of the drying air has also great effect on drying rate.

Drying can be done as a single stage or through two stages. In a two-stage drying system, fish is dried at a faster drying rate at the beginning up to a moisture ratio referred to as critical moisture content. From this point, the fish is transferred to a slower drying for a longer period. This helps to avoid the surface from becoming impermeable to the inner moisture and ensures thorough drying.

Principle of fish drying
In the tropics fish drying is done through simple sun-drying of split fish on racks. Much as it is simple and cheap, huge losses result from spoilage and insects and dust contamination, especially where fish is dried on or near to the ground. Rains and dew, especially at early hours in the morning, leads to spoilage from moulds (Ruddle, 1990). It is usually difficult to obtain a uniform product with sun drying since it is weather dependent (Sankat and Mujaffar, 2004; Al Rawahi et al., 2013).

Optimal drying conditions for tropical fish seem not clearly defined but higher temperatures of 40-50°C with corresponding relative humidity of 50-60% have been used (Mujaffar and Sankat, 2005). However, it is recommended that temperatures between 60 and 63°C be used to prevent microbial growth without denaturing the product (Rahman, 2015). This increases the storage life due to the lower moisture content achievable with high temperature controlled drying (Al Rawahi et al., 2013).

Much as drying rate is of great importance in fish drying, very little information is available on the kinematics of water removal from the fish (Mujaffar and Sankat, 2005). Drying rate is very high at the initial drying stage and then decreases exponentially as the water content decreases (Toujani et al., 2012). It is also dependent on the moisture content, volume and temperature of the drying air (Seveda, 2012).

Mass balance

Mass of water evaporated by primary drying is found by subtracting mass of semi-dried product from the intitial mass before drying while that evaporated by the secondary drying is found by subtracting the mass of the dried product from the mass of the semi-dried product. It must be noted that the solid mass does not change (Sengar et al., 2009). The percentage moisture content is then computed using Equations 17 and 18 below:

$$MC_{wb} = ((W_1 - W_2)/W_1) \times 100 \tag{17}$$

$$MC_{db} = ((W_1 - W_2)/W_2) \times 100 \tag{18}$$

where MC_{wb} = Moisture content wet basis [%] ;
MC_{db} = Moisture content dry basis [%];
W_1 = Product weight before drying [kg];
W_2 = Product weight after drying [kg].

Energy requirement

In principle, the drying product needs energy to raise its temperature from its initial temperature to the temperature of the drying air. To evaporate the moisture to the required level, a further energy of vaporisation at the drying temperature is required. The basic way the energy requirement for drying can be calculated is given by Equation 19 (Seveda, 2012). It is a common practice though to use a combined specific heat capacity of wet fish as opposed to have separate specific heat capacities of water and solid matter and this is then presented as Equation 20 (Sengar et al., 2009; Earle and Earle, 2004).

$$Q = (1 - MC_{wb})W_1 \times C_{pd} \times (T_a - T_f) + (MC_{wb} \times W_1) \times C_{pw} \times (T_a - T_f) + (w \times L_v) \tag{19}$$

$$Q = W_1 \times C_{pf} \times (T_a - T_f) + (w \times L_v) \tag{20}$$

where Q = Energy requirement for drying [W];
C_{pd} = Specific heat capacity of solid fish material [kJ/kg°C];
C_{pw} = Specific heat capacity of water [kJ/kg°C];
C_{pf} = Specific heat capacity of whole fish [°C];
T_a = Drying air temperature [°C];
T_f = Initial fish temperature [°C];
w = Amount of water to be evaporated [kg];
L_v = Latent heat of evaporation of water [kJ/kg].

In this project, since there are two stages of drying, the corresponding equations for the energy requirement are Equation 21 for primary drying and Equation 22 for secondary drying. The total energy required to dry fish from the initial moisture content to the final required moisture content is the sum of the primary and secondary energy requirements.

$$Q_p = W_1 \times C_{pf} \times \left(T_{a_p} - T_{f_p}\right) + (w_p \times L_v) \tag{21}$$

$$Q_s = B \times C_{pf} \times \left(T_{a_s} - T_{f_s}\right) + (w_s \times L_v) \tag{22}$$

where Q_p = Energy requirement for primary drying [kJ];
Q_s = Energy requirement for secondary drying [kJ];
B = Mass of semidried fish [kg];
w_p = Moisture to be removed during primary drying [kg];
w_s = Moisture to be removed during secondary drying [kg];
T_{a_p} = Heating air temperature in the primary dryer [°C];
T_{a_s} = Heating air temperature in the secondary dryer [°C];
T_{f_p} = Initial fish temperature in the primary dryer [°C];
T_{f_s} = Initial fish temperature in the secondary dryer [°C].

To have a good heat transfer between the air and the fish being dried, it is advised to have turbulent air flow within the drying chamber (Maharjan, 1995). Temperatures between 45 and 150°C and air flow of 0.7-8.14 kgs^{-1}m^{-2} are recommended.

Dimensions of the dryer

In the tray dryer the hot air passes over the fish along the length. The drying area is thus the tray area of the fish ($L \times W$) while the area in respect to air flow is the cross-sectional area of the dryer ($W \times H$). These may be the same if the air flow is vertical or in the horizontal flow, if the dryer is a cuboid. In this project, the air flow is horizontal in the primary section and vertical in the secondary section. The primary dryer section is given in Figure 7.

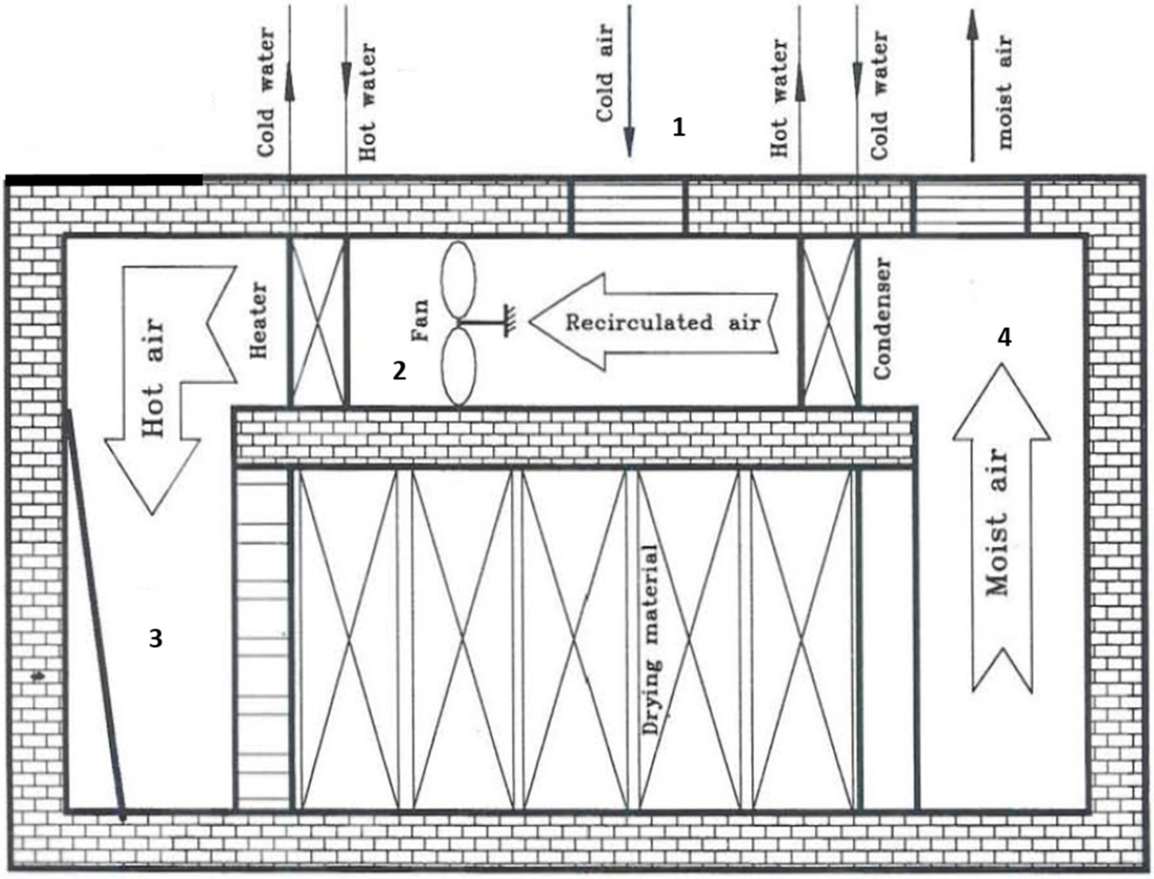

FIGURE 7: Tray dryer, primary section, (modif. from Maharjan, 1995)

The dryer has been designed to dry 10,000 kg of fish with a moisture content of 80% down to 55% in the primary dryer and down to 15% in the secondary one. The dryer is designed for drying Chambo but smaller fish species can also be dried with shorter drying times. Different winter and summer ambient conditions, drying air conditions and exit conditions have been examined. Maximum energy requirement occurs in winter and the results are shown in Table 11.

Air flow required is found by dividing water to be evaporated by the change in moisture ration between point 4 and point 3 in the primary dryer and point 3 and point 2 for the secondary dryer. With w_p = 6000 kg/ h and w_s = 1882.4 kg/h, the air requirement is:

$$Air\ flow\ rate = 6000\ \text{kg/h} \div (6.2/1000)\ \text{kg/kg} = 24{,}193\ \text{kg/h for the primary dryer}$$

and

$$Air\ flow\ rate = 1882.4\ \text{kg/h} \div (3.5/1000)\ \text{kg/kg} = 5{,}378\ \text{kg/h for the secondary dryer}$$

TABLE 11: Air condition at different points of the dryer

Position number	**Air temperature [°C]**	**Relative humidity [%]**	**Moisture ratio (x) [kg/kg]**	**Enthalpy (i) [kJ/kg]**
Primary				
1	19	75	10.2	45
2	25	90	18.3	72
3	45	30	18.3	93.5
4	30	90	24.5	93.5
Secondary				
1	19	50	7	36.5
2	48	9.5	7	66
3	40	24	10.5	66

The energy requirement is found by multiplying the air flow rate by the change in enthalpy $(i_4 - i_2)$ for primary and $(i_3 - i_2)$ for the secondary dryer. This gives:

$$Air\ flow\ rate = 24{,}193\ \text{kg/h} \times 21.5\ \text{kJ/kg} = 520\ \text{MJ/h} = 144\ \text{kW for the primary dryer}$$

and

$$Air\ flow\ rate = 5{,}378\ \text{kg/h} \times 29.5\ \text{kJ/kg} = 159\ \text{MJ/h} = 44.07\ \text{kW for the secondary dryer}$$

3.5 Intensive aquaculture facility

3.5.1 Current status

Fish farming has great interest among smallholder farmers. Facilitated by development agencies, small scale fish farming has been promoted in many parts of Malawi. Over 4000 fish farmers with a total number of fish ponds amounting to 7000 exist in the country at present (Tall, 2009). Most of these are open earthen ponds. Most of these practice extensive system with low inputs and very low yield (Nyanja et al., 2005). The most cultured species are *Oreochromis Shiramus* and *Tilapia Rendalli.* One commercial farm, Chambo Fisheries (Pacific), farms Nile Tilapia using biofloc system. It was difficult to ascertain production levels for the purpose of this report.

Most of these farmers are not satisfied with the slow growth, stunted growth and early maturity of the cultured fish (Chimatiro and Chirwa, 2005). Much as most researchers believe that Chambo is difficult to be cultured to full market size due to its early maturity, others have argued that it is the poor environment and feeding that leads to early maturity. The government's target is to raise the current low production of 750 kg/ha/yr. to about 1500 kg/ ha /yr. but this is very far from reaching the ever increasing demand. To meet the fish demand and achieve an export level, Malawi needs to promote the intensive commercial aquaculture.

3.5.2 Design of an aquaculture farm

Much as the major target is promoting pond farms with smallholder farmers due to its simplicity and cheapness, the farmer has no or little control over the several external factors that affect the fish growth and production. For ideal intensive culture conditions, it is appropriate to use either tank or raceway culture where the farmer can have full control over the inputs (Nyanja et al., 2005). Tanks and raceway farms provides an opportunity for highly intensive fish farming due to the ability to control external factors and inputs (Pillay and Kutty, 2005; White and Rigby, 2003).

Water quality and temperature are critical for good aquaculture production. Good water with high oxygen levels is required for the fish. Waste from the pond should be removed to avoid concentration of ammonia. The growth and reproduction of fish is greatly affected by the water temperature. Spawning and fish growth tend to decrease below or above optimum temperature for each fish species. Optimal temperatures for Tilapia are 27-30°C for growth and 22-32°C for spawning (Ísaksson, 2015). For the Chambo in Malawi, research shows that temperatures between 27 and 29°C are recommended for reduced hatching period and increased hatchability and fry survival (Valeta et al., 2013). It is observed that in unheated earthen ponds and natural waters, the spawning season lasts from August to March with peak between November and December when the ambient temperatures are above 22°C (Banda et al., 2005). It is also observed that fry production and growth greatly lowered in the cold season which normally ranges from May to early part of September (Brummett and Noble, 1995).

Based on the above recommendations the proposed fish farm will have a hatchery with ponds at a temperature of 29°C to reduce hatching period and the rearing ponds with a temperature of 28°C. It may also be considered to have all ponds at either temperature.

To ensure continuous removal of waste from the water, raceway farm will be adopted. Raceways are basically designed in a way that there is continuous water throughflow and the typical ratios of length to width to depth are 30:3:1 (Stinkney, 2005). However, the first test farm will be of sizes 25 m by 4 m by 1.2 m for the rearing raceway ponds and 25 m by 2 m by 0.75 m for the hatching ponds.

3.5.3 Water and energy requirement

Fresh water requirement

The water requirement in a raceway is determined by the rearing density to maintain a good level of oxygen for fish survival. The total pond water requirement is given by Equation 23:

$$Q_r = \frac{\left(V_f + V_{rf} + L_e + L_s + L_c - V_{ra}\right)}{86400T} \tag{23}$$

where Q_r = Annual water requirement [l/s];
V_f = $A \times h$ = Pond volume to be filled [m^3];
V_{rf} = $N_o \times V_f$ = Pond volume to be refilled [m^3];
L_e = $A \times E$ = Evaporation losses [m^3];
L_s = $A \times T \times S$ = Seepage losses [m^3];
L_c = $A_c \times E \times 1.2$ = Canal transmission losses [m^3];
V_{ra} = $A_{eff} \times R_a$ = Inflow due to rainfall [m^3];
A = Average pond water surface area [m^2];
h = Average pond water depth [m];
N_o = Number of refilling per year;
E = Mean annual evaporation [m];

T = Operational time [days];
S = Seepage coefficient [m/day];
A_c = Water surface area of a canal [m^2];
A_{eff} = Total pond area exposed to rain [m^2];
R_a = Mean annual rainfall [m].

In this project, L_s, L_c *and* V_{ra} have been assumed to be zero and L_e is equated to W_p in Equations 24 and 25.

Energy requirement
Like in swimming pools, aquaculture ponds lose heat through evaporation, convection, radiation and conduction. Geothermally heated aquaculture farms are restricted in size based on the maximum available heat from the geothermal source. To determine the total heat requirement, we need to sum all the associated heat losses.

Evaporative heat loss (Rafferty, 2003; Lund, 1996)
This is the greatest heat loss associated with ponds. It is basically considered as the amount of energy required to evaporate the amount of water mass. With heat of evaporation of 2,440 kJ required to evaporate 1 kg of water, the total heat loss through evaporation can be found by multiplying the amount of water evaporated by the unit heat of evaporation. The amount of water evaporated is obtained through the equation describing the rate of evaporation as given in Equations 24 and 25 for outdoor ponds and Equation 26 for indoor ponds:

$$W_p = \left(11.0 + (4.30 \times v)\right) \times (p_w - p_a) \times A \tag{24}$$

$$W_p = \frac{2930v}{1.8T_s + 492} \times (p_w - p_a) \times A \tag{25}$$

$$W_p = 14.46 \times (p_w - p_a) \times A \tag{26}$$

where W_p = Rate of evaporation [kg/h];
A = Pond surface area [m^2];
v = Air velocity [m/s];
p_w = Saturation vapour pressure of pond water [bar – absolute];
p_a = Saturation pressure of air at dew point [bar – absolute];
or saturation pressure at air temperature × relative humidity;
T_s = Water surface temperature [°C].

Evaporative heat loss is therefore given by Equation 27:

$$q_{ev} = W_p[\tfrac{kg}{h}] \times h_{ev}\left[\frac{kJ}{kg}\right] \tag{27}$$

where W_p = Rate of evaporation [kg/h];
q_{ev} = Evaporative heat loss [kJ h^{-1}];
h_{ev} = Specific heat of evaporation for water at temperature,T_s [kJ/kg].

Convective heat loss
Convective heat loss is the heat loss associated with the passing of cold air over the surface of pond water. This is basically influenced by the temperature difference between the cold air and the warm water surface and the velocity of the cold air. Convective heat loss is computed by Equation 28:

$$q_{cv} = 9.045v \times A \times (T_w - T_a) \tag{28}$$

where q_{cv} = Convective heat loss [kJ/h];
v = wind velocity [m/s];
A = Pond area [m^2];
T_w = Pond water temperature [°C]
T_a = Ambient air temperature [°C].

Conductive heat loss
Conductive heat loss is basically the heat lost due to conduction through all the wall area. Since it is usually very small compared to other heat losses, it is usually omitted in most design cases. However conductive heat loss is calculated by Equation 29:

$$q_{cd} = \{[(L + W) \times 12.45] + (L \times W \times 0.4084)\} \times [(T_w - T_a) - 8.33] \tag{29}$$

where q_{cd} = Conductive heat loss [kJ/h];
L = Length of the pond [m];
W = Pond width [m].

Radiative heat loss
Radiative heat loss is due to the heat transfer from the water to the air due to their temperature difference and is given by Equation 30:

$$q_{rd} = 1.836 \times 10^{-8} \times [(492 + 1.8T_w)^4 - (492 + 1.8T_a)^4] \times A \tag{30}$$

where q_{rd} = Radiative heat loss [kJ/h].

To maintain the hatchery ponds at 29°C and the rearing ponds at 28°C, the thermal power requirement and hot water requirement are summarized in Table 12. The greatest energy requirement is in August amounting to 4,154 kW.

TABLE 12: Maximum hot water requirement for the fish farm at different source temperatures

Power (kW)	**Hot water requirement (l/s)**			
	55°C	**65°C**	**78°C**	**95°C**
4,154	36.83	26.87	14.89	14.84

4. ECONOMIC ANALYSIS OF THE SELCTED DIRECT USES

Economic feasibility of any project can be measured using different financial management tools. In this report the Payback Period, Net Present Value (NPV) and the Internal Rate of Return (IRR) are considered.

Simple Payback Period
Payback Period is the duration the project´s cash inflows are expected to repay the investment cost. It is recommended that the Payback period is kept as low as possible for the project to be profitable. This is determined by dividing the investment cost by the annual cash inflow.

Net Present Value (NPV)
This is an analysis tool in which all cash inflows and outflows are discounted to their present value. If the Net Present Value is positive, the project should be accepted. This is basically dependent on the discounting rate. Lower discounting rates, as low as 4%, are commonly used for government projects to be considered viable. A discounting rate of 10% has also been greatly applied (Freeston and Browne, 1994). NPV is computed using Equation 31 (Schmidt, 2014-2015):

$$\mathrm{NPV} = \sum_{n=1}^{n} (\mathrm{FV_n}) \times (1/(1 + r)^n) \tag{31}$$

where NPV = Net Present Value [monetary units];
FV = Future value [monetary units];
n = Number of years;
r = Discount rate [%].

Internal Rate of Return (IRR)
Internal rate of return is the value of the discount rate (r) at which the net discounted cash flows exactly equals the investment cost. It is thus the value of the discount rate that makes Equation 31 equal to zero. A higher IRR is recommended for viability of the project; it should be greater than the desired discount rate.

Based on (ACCA, 2015), IRR is computed by using Equation 32. A discount rate r_a is chosen and NPV is calculated using Equation 31. A second rate r_b is chosen such that NPV is either negative if the first one is positive or positive if the first one is negative. With the two values of r and the two NPV's, IRR is computed as follows:

$$\mathrm{IRR} = r_a + \frac{\mathrm{NPV_a}(r_b - r_a)}{\mathrm{NPV}_a - \mathrm{NPV_b}} \tag{32}$$

where IRR = Internal Rate of Return [%];
r_a = Lower discounting rate [%];
r_b = Upper discounting rate [%];
$\mathrm{NPV_a}$ = NPV at r_a [monetary units].

However, with the use of MS Excel, IRR is easily found by using Goal Seek function to determine the discount rate by setting the value of the NPV equal to Zero.

4.1 Feasibility of swimming pools and spas

4.1.1 Swimming pools

In swimming pools, the major costs are the investment cost, cost related to chemicals, labour, advertising, maintenance and other supplies. Apart from the initial investment cost, chemicals for water purification and PH control and energy for pumps in the recirculation system are the main contributors to the variable cost. The cost and revenues have been listed in Table 13 and the NPVs for a 10-year period and a discounting rate of 10% have been plotted in Figure 8 as an example for the other technologies. Construction cost estimates are based on Clean Pool and Spa (2015) while road works are costed based on Ministry of Transport and Public Infrastructure (2010). Fees were based on prevailing hotel charges in Malawi.

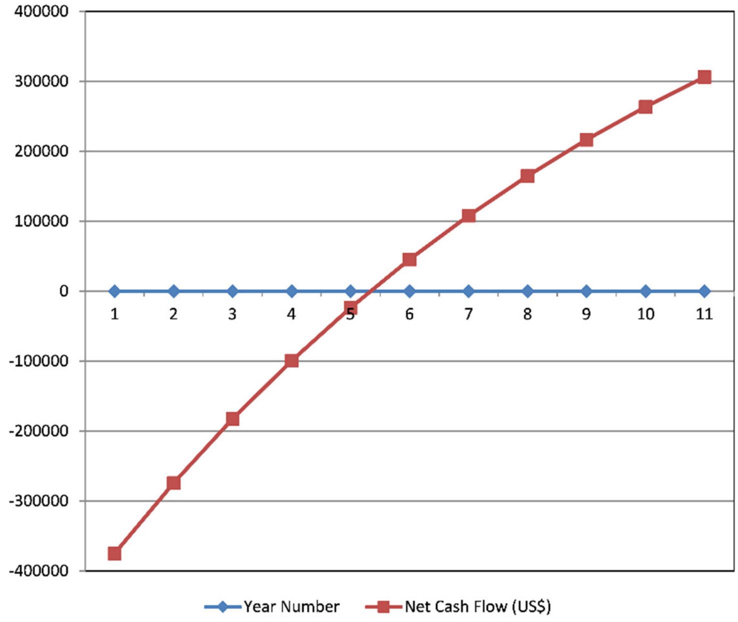

FIGURE 8: Discounted cash flows for computing NPV for swimming pools

With net annual revenue of US$ 110,880 against an initial investment cost of US$ 375,000, we get the values as follows:

IRR = 27%
NPV = US$ 306,292
Discounted Payback period (breakeven point) = 4.21 yrs.
Simple Payback period = 3.4 yrs.

TABLE 13: Estimated cash inflows and outflows for swimming pools

Description	Item	Quantity	Unit Price (US$)	Cash flow (US$)
Investment cost	Pool construction	1	25,000	(25,000)
	Building and access road	1	350,000	(350,000)
Total investment cost				**(375,000)**
Variable cost	Collective cost	12 months	2,500/month	(30,000)
Revenue	Fee collection	12 months	11,740/month	140,880
Net cash flow				**110,880**

4.1.2 Feasibility of a spa

Unlike in swimming pools, in geothermal nature baths, there are no circulation, filtering and PH control systems. The major cost is the investment cost, labour, advertising, maintenance, and other supplies. These are far much lower as compared to those of swimming pools. The cash flows are shown in Table 14.

TABLE 14: Estimated cash inflows and outflows for hot spas

Description	Item	Quantity	Unit Price (US$)	Cash flow (US$)
Investment cost	Pool construction	1	10,000	(10,000)
	Building and access road	1	250,000	(250,000)
Total investment cost				**(265,000)**
Variable cost	Collective cost	12 months	1,000/month	(12,000)
Revenue	Fee collection	12 months	11,740/month	128, 070
Net cash flow		**1 yr.**		**116, 070**

With net annual revenue of US$ 116,070 against an initial investment cost of US$ 265,000, we get the values as follows:

IRR = 43%
NPV = US$ 453,200
Discounted Payback period (breakeven point) = 2.5 yrs.
Simple Payback period = 2.2 yrs

4.2 Feasibility of greenhouse tomato production

In geothermal greenhouse tomato production, major costs are those related with the structure, irrigation and heating network, packaging, storage and labour. For tomato production to be profitable, it is recommended that the product be sold before planting, thus the market should be established before planning to grow the crop. The cash flows are shown in Table 15. Current open field tomato production in Malawi yields on average 950 kg/ha with one cycle per year (Mango et al., 2015). It is anticipated that with proper management the greenhouse tomato yield will reach an average 10 kg per plant giving a total of 6.1 tonnes per cycle. This is an equivalent of 48.4 tonnes per hectare per year.

Greenhouse and tomato production cost and selling prices were based on Pena (2005) and Smith et al. (2015) and some prevailing market prices in Malawi.

TABLE 15: Estimated cash inflows and outflows for greenhouse tomato production

Description	Item	Quantity	Unit price (US$)	Cash flow (US$)
Investment cost	Greenhouse structure	1	65/m^2	(32,760)
	Buildings	1	15,000	(15,000)
	Irrigation	1	25,000	(25,000)
	Packaging and Storage	1	20,000	(20,000)
Total investment cost				**(92,760)**
Variable cost	Collective cost	1	30/m^2	(15,120)
Revenue	Sales	25 tonnes	1.5/kg	36,900
Net cash flow				**21,780**

With net annual revenue of US$ 21,780 against an initial investment cost of US$92,760, we get the values as follows:

IRR = 20%
NPV = US$ 41,069
Discounted Payback period (Breakeven point) = 5.5 yrs.
Simple Payback period = 4.3yrs

4.3 Feasibility of intensive aquaculture facility

The main cost associated with intensive raceway aquaculture is investment cost, pumping cost if water is not supplied by gravity, cost of seed (fingerlings) if there is no on farm hatchery and fish feed if it is not produced on farm. Other costs include labour for harvesting, processing and transport. In this project it is proposed that feed and hatching will be on the farm, purchase will be done in the first year only. The cash flows are shown in Table 16. Expected yield and cost are based on personal information collected from Chambo fisheries in Malawi.

TABLE 16: Estimated cash inflows and outflows for fish farming

Description	Item	Quantity	Unit Price (US$)	Cash flow US$)
Investment cost	Raceway construction	1	6,000,000	(6,000,000)
	Building and access road	1	650,000	(650,000)
Total investment cost				**(6,650,000)**
Variable cost	Collective cost	1 yr.	250,000	(250,000)
Revenue	Fish sales	420 tones	4	1,680,000
Net cash flow				**1,430,000**

With net annual revenue of US$ 1,430,000 against an initial investment cost of US$6,650,000 we get the values as follows:

IRR = 17%
NPV = US$ 2,136,731
Discounted Payback period (breakeven point) = 6.3 yrs.
Simple Payback period = 4.7 yrs.

4.4 Feasibility of indoor fish drying

The major challenge in computing profitability of the fish drying process is that the final product for sale is about 22% in mass as compared to the fresh fish bought. This leads to the processed fish having very high market price per kg – much higher than the fresh fish. The major costs are the investment cost, the equipment and labour and the actual buying of the raw material (fresh fish) while the income is through sales. The cash flows are shown in Table 17.

TABLE 17: Estimated cash inflows and outflows for indoor fish drying

Description	Item	Quantity	Unit Price (US$)	Cash flow (US$)
Investment cost	Structure and equipment	1	2,600,000	(2,600,000)
	Other cost	1	200,000	(200,000)
Total investment cost				**(2,800,000)**
Variable Cost	Fresh fish purchase	500 tones	1.5 / kg	(750,000)
Revenue	Dried fish sales	106 tones	13 / kg	1,376,471
Net cash flow				**626,471**

With net annual revenue of US$ 626,471 against an initial investment cost of US$2,800,000, we get the values as follows:

IRR = 18%
NPV = US$ 1,049,391
Discounted Payback period (breakeven point) = 6.1 yrs.
Simple Payback period = 4.5yrs

5. CONCLUSIONS AND RECOMMENDATIONS

From the energy and hot water requirement calculations, it has been shown that it is possible for Malawi to develop the existing geothermal fields in Nkhotakota for economic activities like commercial swimming pools, spas, greenhouse tomato production and fish drying. Intensive aquaculture would however require at least some minimal drilling of within 400 m to have enough hot water supply. The economic analysis of all the technologies yielded high Internal Rate of Return and positive Net Present Value though the greenhouse requires a minimum of double the design area to achieve a positive NPV.

I would like to recommend that a detailed social economic status and market analysis be done to come up with a more realistic estimates of the sales of both products and services from the geothermal field development. I would also like to recommend that shallow slim wells of the size of borehole for portable water be drilled and their yield be tested to ascertain sustainable availability of the hot water supply. However, with the existing flows, swimming pools, spas and greenhouses can be developed.

There is need to have similar evaluations done for all geothermal fields in Malawi and determine potential direct utilization technologies which could be implemented while waiting for advanced exploration and deep drilling activities.

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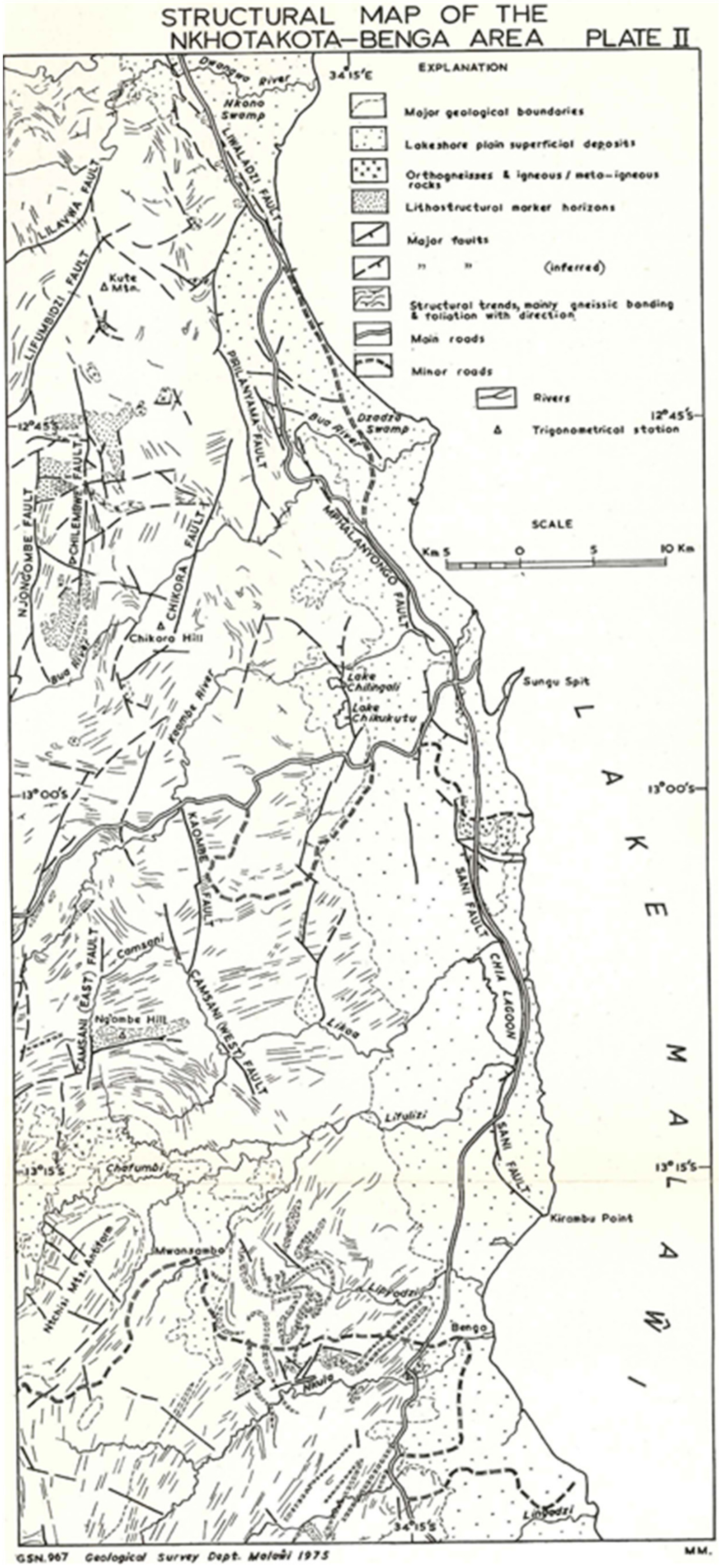
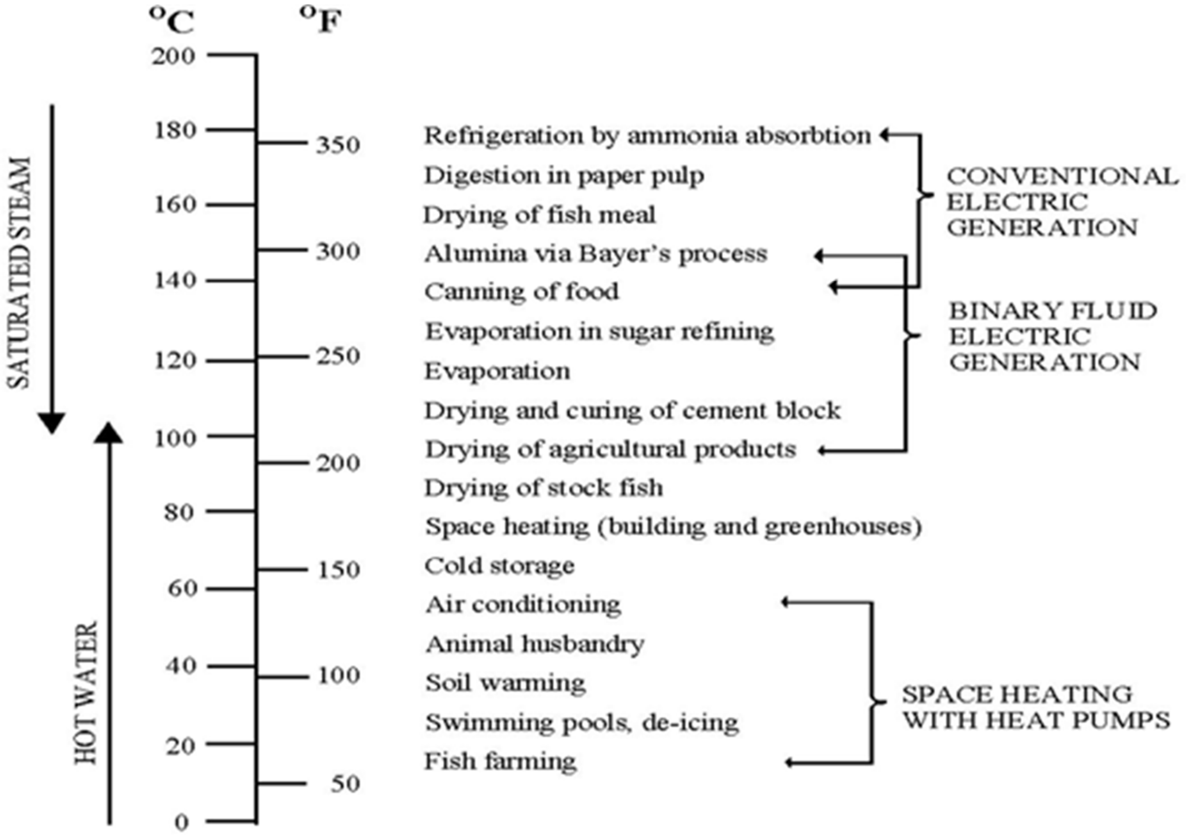
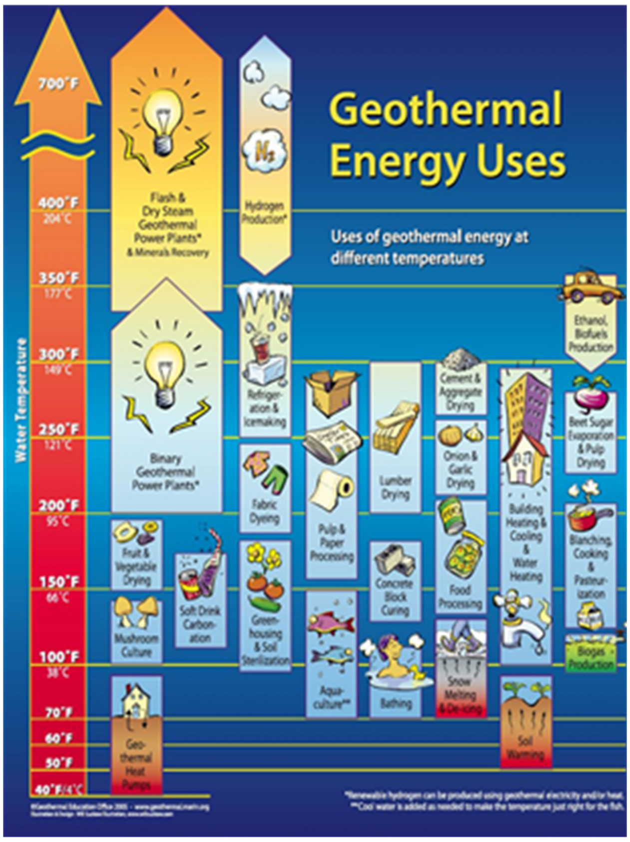
APPENDIX I: Structural map of Nkhotakota – Benga Area (Harrison and Chapusa, 1975)



APPENDIX II: Lindal diagram and pictorial modified Lindal diagram

(Kiruja, 2011; Geothermal Education Office, 2005)





APPENDIX III: Swimming pool, spa and aquaculture ponds water to air temperature differences and their corresponding partial pressures

Month	Mean monthly min. temperat. (°C)	Wind velocity (m/s)	RH (%)	Vapour saturation pressure (mbar)	Partial pressure of air (mbar)	pw - pa (28°C)	pw - pa (29°C)	pw - pa (38°C)	pw - pa (40°C)	pw - pa (42°C)	pw - pa (45°C)	pw - pa (47°C)
Jan	21.1	2.81	80	35.03	28.13	9.70	11.96	38.19	45.71	53.96	67.81	78.13
Feb	21.1	2.63	79	35.03	27.74	10.09	12.35	38.58	46.10	54.35	68.20	78.52
Mar	20.7	2.72	77	24.43	18.88	Q	a.21	47.44	54.96	63.21	77.06	87.38
Apr	20.1	2.98	68	23.54	15.98	21.85	24.11	50.34	57.86	66.11	79.96	90.28
May	17.7	3.33	58	20.26	11.73	26.10	28.36	54.59	62.11	70.36	84.21	94.53
Jun	15.6	3.68	56	17.73	9.96	27.87	30.13	56.36	63.88	72.13	85.98	96.30
Jul	15.1	3.86	54	17.17	9.19	28.64	30.90	57.13	64.65	72.90	86.75	97.07
Aug	15.7	4.12	48	17.84	8.58	29.25	31.51	57.74	65.26	73.51	87.36	97.68
Sep	17.7	4.21	44	20.26	8.93	28.90	31.16	57.39	64.91	73.16	87.01	97.33
Oct	20.5	4.30	47	24.13	11.24	26.59	28.85	55.08	62.60	70.85	84.70	95.02
Nov	22.1	3.77	57	26.61	15.03	22.80	25.06	51.29	58.81	67.06	80.91	91.23
Dec	21.6	3.07	73	25.81	18.82	19.01	21.27	47.50	55.02	63.27	77.12	87.44

Month	Mean monthly min. temperat. (°C)	ΔT(28)	ΔT(29)	ΔT(38)	ΔT(40)	ΔT(42)	ΔT(45)	ΔT(47)
Jan	21.1	6.9	7.9	16.9	18.9	20.9	23.9	25.9
Feb	21.1	6.9	7.9	16.9	18.9	20.9	23.9	25.9
Mar	20.7	7.3	8.3	17.3	19.3	21.3	24.3	26.3
Apr	20.1	7.9	8.9	17.9	19.9	21.9	24.9	26.9
May	17.7	10.3	11.3	20.3	22.3	24.3	27.3	29.3
Jun	15.6	12.4	13.4	22.4	24.4	26.4	29.4	31.4
Jul	15.1	12.9	13.9	22.9	24.9	26.9	29.9	31.9
Aug	15.7	12.3	13.3	22.3	24.3	26.3	29.3	31.3
Sep	17.7	10.3	11.3	20.3	22.3	24.3	27.3	29.3
Oct	20.5	7.5	8.5	17.5	19.5	21.5	24.5	26.5
Nov	22.1	5.9	6.9	15.9	17.9	19.9	22.9	24.9
Dec	21.6	6.4	7.4	16.4	18.4	20.4	23.4	25.4

Partial pressure at water surface (RH =100%)	
T(°C)	**Ps (mbar)**
28	37.83
29	40.09
38	66.32
40	73.84
42	82.09
45	95.94
47	106.26