View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by Uniswa e-Journals (University of Swaziland)

UNISWA Research Journal of Agriculture, Science and Technology [Online] | 15: 1-8, 2014
© Published by University of Swaziland ISSN: 1029-9645 | Varkey and Dlamini

Design, construction and use of solar stills for water purification: A study of their performance in two geographical regions in Swaziland

A. J. Varkey and M. D. Dlamini

Department of Physics, Faculty of Science and Engineering, University of Swaziland,
Private Bag 4, Kwaluseni M201, Swaziland.

ABSTRACT

Clean water for drinking and other domestic purposes is becoming a scarce resource the world over. The presence of pathogens such as *Escherichia coli* [*E. coli*] in contaminated water often leads to health complications and at times death, particularly when they originate from human or animal waste, and may give rise to gastro-intestinal diseases such as diarrhoea and cholera. Simple and affordable water purification devices are therefore essential in rural and peri-urban areas without municipal water supply. Two locally built solar stills, sometimes called solar distillers, were designed and constructed at the workshop of the Physics Department of the Faculty of Science and Engineering, University of Swaziland. They were installed at two locations in Swaziland with different climatic conditions, one at Dvokolwako in the Lowveld and the other, at Etimpisini in the Middleveld. Data on monthly variation of the amount of distilled water collected at each of the two locations were recorded over a period of one year. The effect of the ambient temperature on the water collection efficiency was also evaluated. The amount of distilled water collected at each of the two locations was found to increase with ambient temperature. The collection efficiency was found to be higher in the Middleveld in spring and summer [September to February], whereas it was lowest in winter [June and July]. The percentage increase in the amount of water collected in the Middleveld between July and September was approximately 75%. In the Lowveld, however, the variation in the collection efficiency was only about 19%. On average, a still can produce about 2.75 litres of water per day in the Middleveld, compared to 2.6 litres in the Lowveld, using a still with a base area of 1 m^2. The raw and distilled water were tested at the Swaziland Water Services Corporation [SWSC], Mbabane for the presence of *E. coli* and total coliform, as well as the levels of pH and total hardness. Tests on cations and anions were carried out by the Department of Geological Survey and Mines, Mbabane. Results of the water quality tests showed that the solar stills had the capacity to eliminate *E. coli* and total coliform completely from the raw water and reduce the levels of pH, total hardness, anions and cations significantly. The anions were reduced by 22 % to 100 % and there was a 53% to 100% reduction in cations. All the parameters were found to be within the South African [SA] and SWSC standards for water quality. Improvements for future work have also been highlighted.

Keywords:, *E. coli*, distilled water, raw water, solar still, water purification

Corresponding Author: M. D. Dlamini Department of Physics, Faculty of Science and Engineering, University of Swaziland, Private Bag 4, Kwaluseni M201, Swaziland. Email: mgidi@uniswa.sz

INTRODUCTION

Clean water for drinking and other domestic purposes is of great importance to the global community, where 1.1 billion people lack clean water [McCarthy, 2010]; nearly all of them are in the developing countries. The majority of countries in Africa, large areas in central Asia, and countries such as China, India, Peru and Bolivia, are having difficulties with establishing basic water services like clean drinking water [Anon., 2010a; Curry, 2010]. It is estimated that in Africa only 46 per cent of people have access to clean water and most of them reside in rural areas, where the water supply is usually contaminated [Anon., 2010b; Chissano, 2010]. Over 2 million people die each year from drinking contaminated water and 9,500 children alone die every day [Sciperio, 2009]. In 2008, for instance, water contamination in the Eastern Cape in South Africa led to the death of nearly 80 children from diarrhoea and other complications [Anon., 2008; Department of Health, 2008]. Even though water is the most common resource on earth, only 2.53 per cent of it is fresh, whilst the rest is salty [McCarthy, 2010]. Water quality is expected to get worse as the population increases and pollution levels from industry, agriculture and human waste rise.

According to the United Nations [UN], more people die from unsafe water every year than from all forms of violence, including war [Anon., 2010c]. Due to the seriousness of the problem, the UN launched an annual event dubbed 'International World Water Day' so as to focus attention on sustainable management of fresh water resources. In support of the global effort, Japan hosted a World Water Forum in Kyoto, Japan in 2003 [Anon., 2003]. It has been observed that humans can live for several weeks without food, but for only a few days without water [Anon., 2010b].

Swaziland is a small landlocked country in Southern Africa which covers just over 17,000 square metres. It shares the northern, western and southern sides of its border with South Africa and the eastern side with Mozambique, at a latitude of 31°31'east of Greenwich and a longitude of 26°30' south of the equator [Thompson, 2009]. It consists of four distinct geographical regions, the Highveld, the Middleveld, the Lowveld and the Lubombo plateau. The hub of Swaziland is Manzini, an area located in the Middleveld at a latitude of -26.49 [26°31'24''S] and a longitude of +31.38 [31°22'48''E]. On average, the insolation in Manzini is 5.57 kWh/m^2/day in summer and 3.76 kWh/m^2/day in winter whilst the temperatures are 23.34°C in summer and 17.73°C in winter [Anon., 2010d].

The Swaziland Water Services Corporation [SWSC] provides safe water to urban and rural communities. This service is available to only 60% of the population; the remaining 40% are forced to use rivers and streams [Poverty Reduction Strategy and Action Programme, 2006]. In 2007, only 54% of the total population in rural areas had access to clean water [Magongo, 2007]. Communities in some locations in the rural areas continue to draw water for consumption from muddy dams which are intended to serve as sources of drinking water for livestock [Mabuza, 2007]. The presence of coliform bacteria in contaminated water is one of the major causes of water-borne illnesses such as gastric infections. These bacteria are present in the environment and in the faeces of all warm-blooded animals, including human beings. Escherichia coli [*E. coli*] is a common bacterium that lives in large numbers in the intestines of animals and human beings. It is extremely harmful and can cause severe illness such as diarrhoea, kidney damage and, occasionally, death.

A possible solution to the water crisis is to provide the affected communities with appropriate technology for water purification [Varkey and Dlamini, 2010]. Since solar energy is available throughout the year in Swaziland, the use of solar stills is an ideal solution. On average, insolation in the Middleveld is 4.77 kWh/m^2/day [Anon., 2010d]. A solar still utilises solar energy to evaporate water which, on condensation, is purified. This leads to the separation of clean water from unwanted salts, minerals and other impurities from the otherwise contaminated water [Anon., 2010e; Tenthani *et al.*, 2012]. The technique is simple and suitable for use in rural and peri-urban areas where clean, potable water is a scarce resource. According to H. Shongwe, Director of the Energy Department, Ministry of Natural Resources, Government of Swaziland, Mbabane, there has been no report on the use of solar stills in Swaziland [Personal Communication, 31 January 2011]. Therefore, solar stills were designed and constructed by the authors using locally available materials. A study on their performance over a period of one year was then undertaken.

MATERIALS AND METHODS

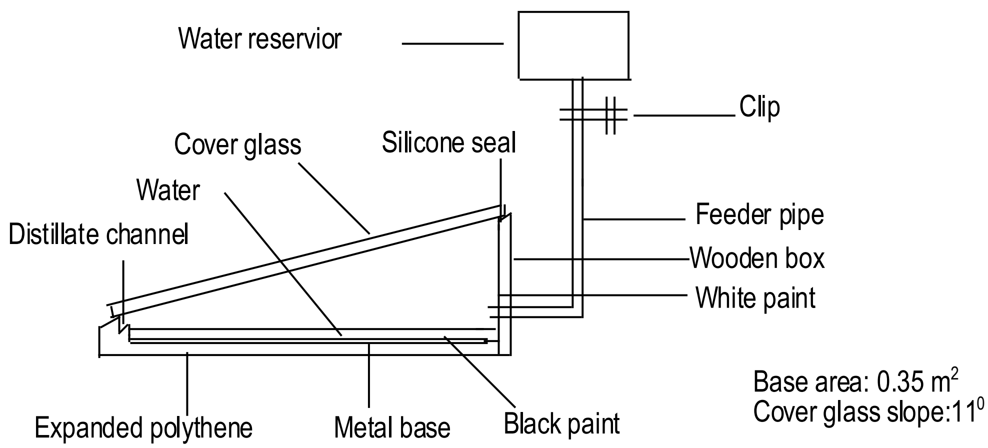

Figure 1: *Cross-section of the solar still.*

Two solar stills were designed and then constructed in the Physics Department of the University of Swaziland. Figure 1 shows the cross-sectional view of the still.

The metal base is made of aluminium, as it does not corrode or rust compared to metals such as iron; it also absorbs heat faster. The disadvantages of aluminium are that it is expensive and requires special equipment for welding. Furthermore, its expansivity is high, hence the base tends to warp on getting hot. The paint used for the base is black pigmented silicone; however, it is not available in the country. For this reason, three types of locally available black paints were tried on the metal base, namely, bitumen black, acrylic paint and stone-chip filler. Bitumen black is normally used in water tanks. Its disadvantage is that it melted when hot and contaminated the water. On the other hand, the colour of acrylic paint changed to grey within a week of use, thus reducing its heat absorptance. Stone-chip filler paint, commercially known as “rubberiser”, does not melt when hot and absorbs heat strongly. Furthermore, it does not fade much with time and does not contaminate water. The “rubberiser” was therefore adopted as a suitable paint. The best known paint for the inner walls of the still is white gloss paint. The cover glass can be made of perspex or glass. Even though perspex is mechanically strong, tests showed that it has low wettability and hence is not suitable for stills. Glass was therefore found to be a better cover plate due to its high wettability. However, it has the disadvantage that it breaks easily. A 3 mm ordinary [soda] glass was used in this work. A silicone sealant was found to be suitable for the joints as it does not contaminate water and its properties are resistant to weather changes. Expanded polythene was used for the base insulation as it is a sufficiently good heat insulator.

The stills were installed at two locations, one in the Middleveld and another one in the Lowveld. Water samples were collected from rivers in the two regions. The amount of distilled water obtained from the stills and the average temperature of the day were recorded throughout the year using a maximum and minimum thermometer. Exceptional changes in climatic conditions were also noted. The quality of the distilled water was tested for the presence of coliforms, as well as the levels of pH, total hardness and ions, using colisure, a pH meter, titrimetry and atomic absorption spectroscopy, respectively. The amount of distilled water was analysed in relation to ambient temperature and other climatic conditions. The seasonal variation in the quantity of distilled water was used to determine the minimum still size for a family of five [average family size in Swaziland]. On the basis of the results, recommendations were made on ways to improve the efficiency of the stills.

RESULTS AND DISCUSSION

The data collected from Etimpisini in the Middleveld and Dvokolwako in the Lowveld are shown graphically in Figures 2, 3 and 4. Figure 2 shows that in the Middleveld the amount of water distilled and collected increased with ambient temperature. The same applies to the Lowveld, with the exception that the increase is comparatively slower in the Lowveld, as shown in Figure 3. Since the ambient temperature is a measure of insolation in a location [Anon., 2010d, Anon., 2010f], the amount of water distilled is proportional to insolation. Figure 4 shows monthly variation of the amount of distilled water collected in the course of the year at the two locations. In the Middleveld, the collection efficiency changes drastically; it is lowest in winter [June and July] and highest in spring and summer [September to February]. The percentage increase in the amount of water collected between July and September is approximately 75%. In the Lowveld, however, the variation in the collection efficiency is only about 19%. In spite of the difference in variation between the Middleveld and Lowveld, it was noted that, on average, the amount of water collected per day per square metre over a period of one year in the Middleveld and Lowveld was 2.75 litres and 2.60 litres, respectively.

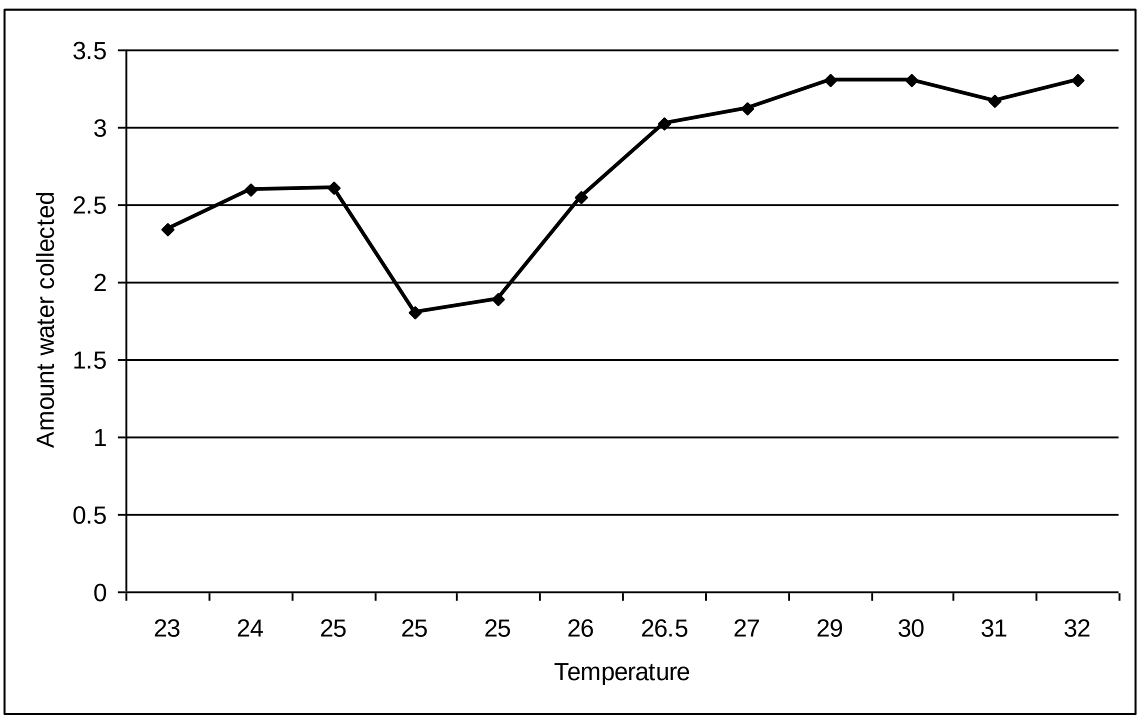

Figure 2. Amount of water [L/m^2/day] collected in the Middleveld at different ambient temperatures [^{0}C]

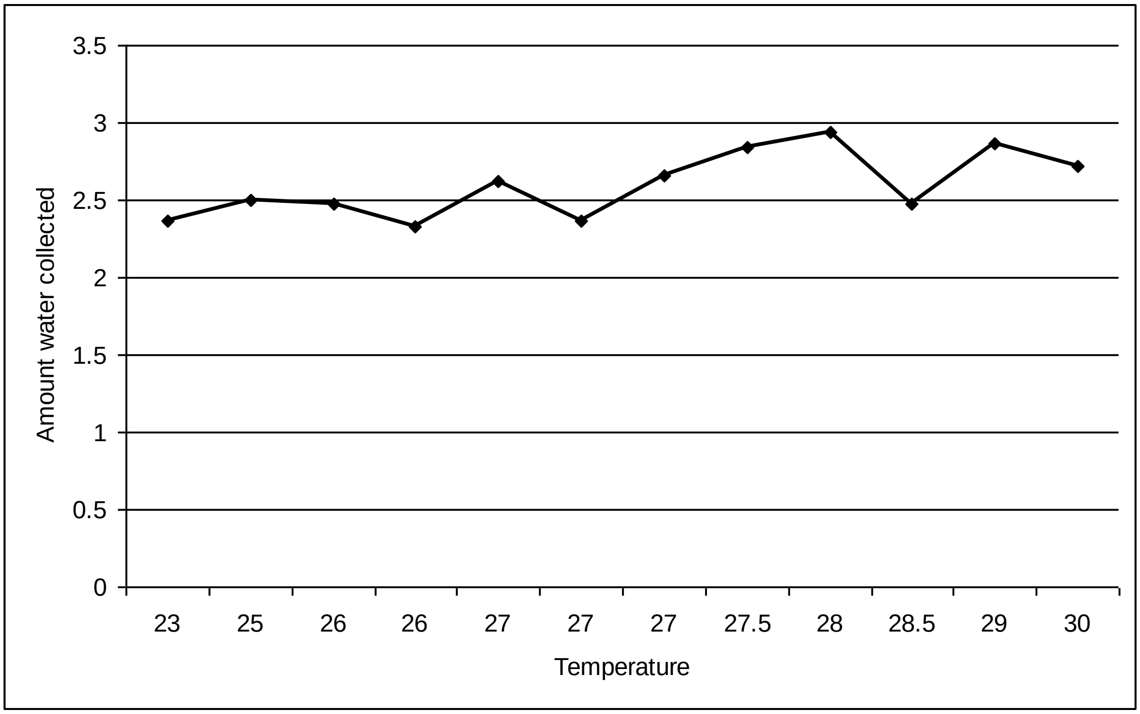

Figure 3. Amount of water [L/m²/day] collected in the Lowveld at different ambient temperatures [^{0}C]

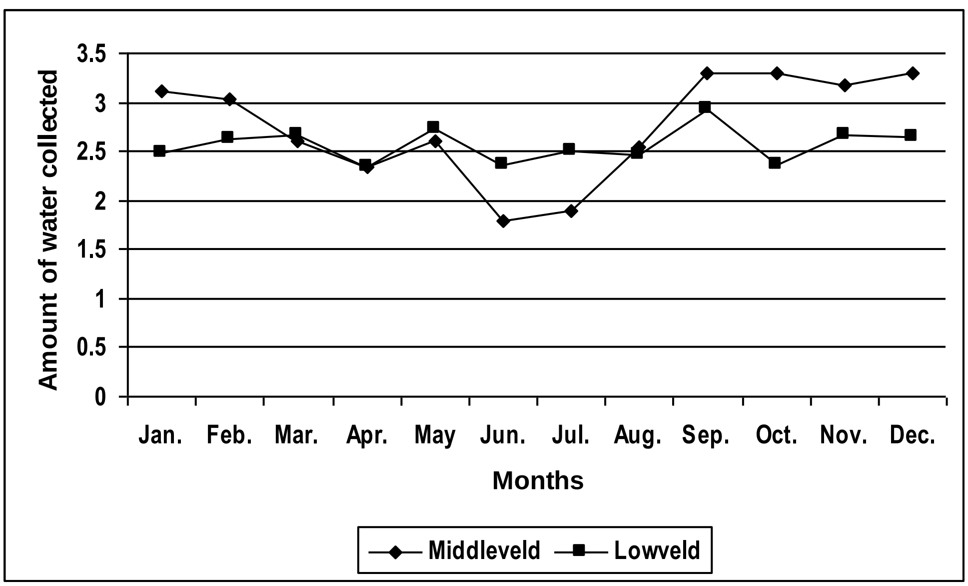

Figure 4. Comparison of the average amount of distilled water [L/m²/day] collected in the Middleveld and the Lowveld from January to December.

Table 1 provides information on the presence of *E. coli*, total coliform and the levels of pH and total hardness. The results show that the distilled water is free from coliforms, in spite of their high levels in the raw samples. Although the pH and total hardness of the raw water samples were within the South African [SA] standards, it was noted that the solar still had the capacity to reduce the levels of these parameters further. The distillation process reduced the total hardness by 53%.

Table 1. Analysis of raw and distilled water samples for *E. coli*, total coliform, pH and total hardness.

Type of water sample	*E. coli* [CFU per 100ml] SA Standard: Zero	Total coliform [CFU per 100 ml] SA Standard: Zero	pH [at 25 °C] SA Standard: 6– 9	Total hardness [mg/L $CaCO_3$] SA Standard: 0-150
Raw water	435	4352	8.01	40.00
Distilled water	0	0	7.79	18.97

Table 2. Analysis of raw and distilled water samples for levels of anions, cations and pH

Parameters		Cations [mg/L]						Anions [mg/L]				pH
Water sample	№	Ca	Mg	Na	K	Fe	Mn	HCO_3	Cl	SO_4	NO_3	
Raw [MV]	1	15	42	40	1	Nd	Nd	55	50	9	6	8
Distilled [MV]	2	7	4	0	0	0	Nd	6	14	7	Nd	8
% Decrease [MV]		53	91	100	90	---	---	89	72	22	100	0
Raw [LV]	3	43	124	64	41	Nd	Nd	110	95	13	9	8
Distilled [LV]	4	7	96	54	38	Nd	0.1	67	84	12	9	9
% Decrease [LV]		84	22	16	7	---	---	39	12	8	---	---

Key: MV= Middleveld; LV= Lowveld; Nd= Not detected

Table 2 shows the analysis of the levels of anions, cations and pH in raw and distilled water samples. The anions and cations were reduced by 8 to 100% and 7 to 100%, respectively, depending on the type of the ions. The anions and the cations were within the SA standards for water quality.

A number of observations were also made with regard to the maintenance of the stills. On a few occasions, the cover glass broke and had to be replaced. Hence, if ordinary soda glass is used for the cover, extra care must be given to make sure that the still is not within the reach of children and animals. A possible solution to this problem is to use perspex glass in place of ordinary soda glass. However, the drawback of perspex glass is that it is more expensive and the angle of tilt needs to be increased in order to facilitate an easy flow of distilled water into the distillate channel. This is likely to reduce the efficiency of the stills.

Occasional cleaning of the base is necessary to remove the dirt and other sediments left over from the raw water during distillation. To remove dirt, physical cleaning is enough. But in case of chemical residues, a dilute solution of sulphuric acid can be used. For better performance, occasional repainting of the base is recommended. It was found that when kept for a long time in the sun, the wooden frame would buckle, hence leading to leakage of the distilled water.

Given that the base of the stills constructed was relatively smooth and the fact that a rough surface absorbs solar energy more efficiently due to its anti-reflecting property, their performance can be improved by making the still base rough or corrugating. A permanent structure could also be constructed by utilizing a concrete frame in place of wood.

CONCLUSION AND RECOMMENDATIONS

A solar still is a viable source of clean water for drinking and domestic use. The amount of distilled water depends on the ambient temperature. On average, a still can produce about 2.6 litres of distilled water per day per square metre of base area in the Lowveld and about 2.75 litres in the Middleveld regions in Swaziland. Solar stills with appropriate base areas can be made for use by a household depending on the family size. Thus for a family of five, for example, a solar still, with a base area of 4 m^2 is sufficient for domestic use, assuming an average consumption of 2 litres per person.

In both the Lowveld and the Middleveld areas in Swaziland, a reasonable amount of clean water can be distilled easily using solar stills, with the exception of rainy days. No distilled water could be collected from the still on rainy days. Bright and sunny conditions or clear sky are most favourable conditions for the performance of the still. Cloud cover is another factor responsible for low output of the distilled water. Harnessing rain water for domestic use is therefore recommended as a supplement to water from the stills.

Solar stills can be made locally and installed in houses in rural areas where pipe water supply is not available. Depending upon the family size and hence the amount of water needed, a still can be fabricated with an appropriate base area. The approximate cost of a locally made still with a base area of 1 m^2 is US$70.00.

ACKNOWLEDGEMENTS

The authors are grateful to the Physics Department for material and technical support as well as the Swaziland Water Services Corporation and the Department of Geological Survey and Mines for undertaking the water quality tests.

REFERENCES

Anonymous. [2008]. Probe under way into E Cape child death http://www.mg.co.za/articlePage.aspz?articleid=337696&area=/breaking_news/. 30/4/2008.

Anonymous [2010a]. 'River crisis' worsens threat of water scarcity – study. http://www.canada.com/news/world/River+crisis+worsens+threat+water+scarcity. 17/11/2010.

Anonymous. [2010b]. Drinking water. http://cc.bingj.com/cache.aspx?q=Scarcity+potable+water+Africa&d=459704538267. 29/11/2010.

Anonymous. [2010c]. Water quality. http://www.un.org/waterforlifedecade/quality.html. 17/11/2010.

Anonymous. [2010d]. Manzini, Swaziland – Sunrise, sunset, dawn and dusk times for the whole year – Gaisma. http://www.gaisma.com/en/location/manzini.html. 26/11/2010.

Anonymous. [2010e]. Solar still basics. http://www.solaqua.com/solstilbas.html. 7/12/2010.

Anonymous. [2010f]. Daily and annual cycles of temperature. http://www.physicalgeography.net/fundamentals/71.html. 5/12/2010.

Anonymous. [2003]. Summary of the 3rd world water forum and ministerial conference. http://www.iisd.ca/crs/3wwf/sdvol82num8.html. 22/10/2014.

Chissano, J. [2010]. Africa: Access to clean water still a problem in Africa. New Vision. http://allafrica.com/stories/201003221269.html. 30/10/2013.

Curry, E. [2010]. Water scarcity and the recognition of the human right to safe freshwater. *Northwestern Journal of International Human Rights* 9[1]: 1-20.

Department of Health. [2008]. National Health Council discusses report of death of children In Eastern Cape. The National Department of Health Website. http://www.doh.gov.za/show.php?id=1866. 30/10/2013.

Mabuza, N. [2007]. Government to spend more money on clean water. *Times of Swaziland,* 8 November, p. 12.

Magongo, M. [2007]. 54% Swazis in rural areas have access to clean water. *Times of Swaziland,* 29 March, p. 13.

McCarthy, M. [2010]. Water scarcity could affect billions: Is this the biggest crisis of all? http://www.commondreams.org/headlines03/0305-05.html. 17/11/2010.

Poverty Reduction Strategy and Action Programme. [2006]. *Towards Shared Growth & Empowerment*, Volumes 1 and 2. Mbabane, Swaziland: Ministry of Economic Planning and Development.

Sciperio Incorporated. [2009]. The water problem. http://www.sciperio.com/watertech/water-problem. asp. 22/2/2009.

Tenthani, C. Madhlopa, A. and Kimambo, C.Z. [2012]. Improved solar still for water purification. *Journal of Sustainable Energy and Environment* 3: 111-113.

Thompson, C.F. [2009]. *The Country, Geography and Climate*. Swaziland Business Year Book, 16th Edition 12th Electronic Edition. Mbabane, Swaziland: Christina Forsyth Thompson.

Varkey, A.J. and Dlamini, M.D. [2010]. Indigenous porous pot water filter for rural communities in Swaziland. *UNISWA Research Journal of Agriculture, Science and Technology* 13[1]: 61-68.