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Physical and Chemical Characteristics of Thermal Springs in Limpopo Province, South Africa

Olivier J*, Venter JS** and Van Niekerk HJ*

*Dept Environmental Sciences, University of South Africa, PO Box 392 UNISA 0003:

** Council for Geoscience, Private Bag 112, Pretoria 0001.

olivij@unisa.ac.za

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ABSTRACT

South Africa has a relatively large number of thermal springs – especially for a country in which no recent volcanic activity has occurred. A large proportion of the 87 documented springs are located in the northernmost region of the country where they are associated with deep faults in the earth's crust. Some of these hot springs have been developed into successful family tourism resorts, while others remain undeveloped. Thermal springs may have considerable economic potential of developed in a sustainable manner. A research project is being conducted to determine the optimal use of the springs. This paper focuses on the geological and structural features of the thermal springs in Limpopo as well as their thermal and chemical characteristics. The characteristics of 14 thermal springs are given, one of which has not been documented previously.

The research indicates that most thermal springs in Limpopo are associated with major faults in the Waterberg and Soutpansberg regions of the country. All are of meteoric origin and have temperatures ranging from 25°C to 67.5°C. The mineral composition of the thermal waters reflects the geological formations found at the depth of origin. The fluoride and bromine concentrations of waters from the majority of springs do not conform to domestic water quality guidelines and makes the water unfit for human consumption. Unacceptably high values of trace elements such as antimony, mercury, selenium and arsenic were found at some springs.

1. INTRODUCTION

Thermal springs are some of the most under-researched and under-utilised of all natural resources in South Africa. Only around a third of the thermal springs in South Africa have been developed – mainly as family holiday resorts. However, in many other countries, thermal springs are being used for a variety of purposes, ranging from power generation, industrial processing, agriculture, aquaculture, bottling of the mineral waters, the extraction of rare elements (Mock, 1993; Vimmerstedt, 1998; Lund, 2000; Baradács et al., 2001; Lund & Freeston, 2001; Atkinson & Davidson, 2002; Shevenell et al., 2002; Bahati, 2003; Hellman & Ramsey, 2004; Petraccia et al., 2005), as well as for balneology and the burgeoning health and spa industry. A relatively recent development is the identification and use of thermophilic bacteria for possible industrial purposes (Zvauya & Zvidzai, 1995; Mawaza & Zvauyva 1996; Mawadza et al., 2000; Narayan et al., 2008).

The increasing recognition of the value of geothermal resources suggests that there will be a rekindling of interest in SA thermal springs in the near future. The availability of current scientific information on these resources is a prerequisite for sound decision-making regarding their use and development. Unfortunately, most research on South African thermal springs was conducted during the 1910s and 1950s. The last 50 to 100 years have seen considerable changes in land use but it is not known whether they have had an impact on thermal springs of the region.

This article presents current information on 14 thermal springs located in the Limpopo Province. Since the optimal use of a thermal spring is largely dependent on its physical and chemical characteristics, the article focuses on these aspects. Information is provided on the geological features of the study areas in view of their impact on the physical location of the springs and their chemical characteristics. Due to the fact that most developed thermal springs have been sealed off and pumps installed, flow rates could not be measured and are not discussed. Information from previous research findings has been included where possible so as to give an overview of the characteristics of thermal springs in Limpopo and to provide a benchmark for the present research.

2. THERMAL SPRINGS OF LIMPOPO

South Africa is divided into nine provinces, of which Limpopo Province is the most northerly. It occupies an area of 123 910 km^2 and is bordered by Botswana to the west, Zimbabwe to the north and Mozambique to the east. The Province comprises of central highlands, sloping northwards to the Limpopo Valley. Two mountain ranges stretch almost the entire width of the province, the Waterberg being the more southerly and the Soutpansberg lying further to the north. The Eastern Escarpment extends in a N-S direction and separates the highland regions from the eastern lowlands which extend into the coastal plains of Mozambique.

At least 33 thermal springs and boreholes are located in the Limpopo Province. They occur in two main regions or 'belts', namely in the region of the Waterberg in the south (Buffelshoek, Zimthabi, Loubad, Warmbaths, Vischgat, Die Oog, Welgevonden, Libertas, Lekkerrus, Welgevonden, Rhemardo, Badseloop and Constantia) and in the vicinity of the Soutpansberg in the north (Paddysland, Tugela, Evangelina, Icon, Vetfontein, Masecula, Windhoek, Mphefu, Chipise, Gordonia, Klein Chipise, Sulphur Springs, Stindal, Adrianskop, Masequa, Siloam (Sendedzane) and Minwamadi). Isolated springs are found to the east of the escarpment (Souting, Letaba and Makutsi). The location of these springs is shown in figure 1.

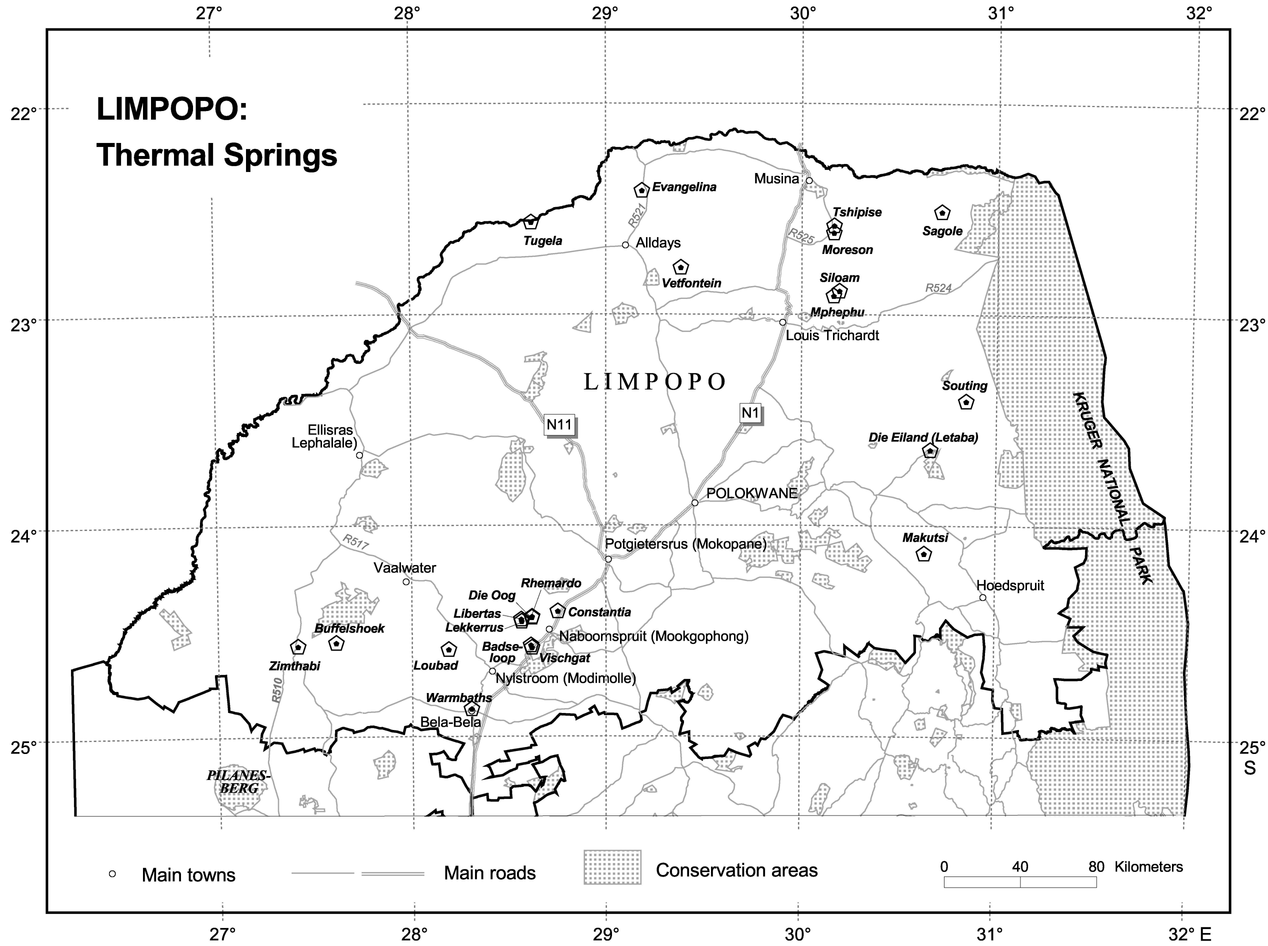

Figure 1 Distribution of thermal springs and boreholes in Limpopo (adapted from Kent, 1949)

Since there is no evidence of recent volcanic activity, it is generally assumed that all thermal springs in South Africa are of a meteoric origin (Rindl, 1916; Kent, 1949; 1969; Hoffmann, 1979; Ashton and Schoeman, 1986; Visser, 1989; Diamond and Harris, 2000). Geological studies have also shown conclusively that the origin of each individual thermal spring can be attributed to the local presence of deep geological structures such as folds, fractures, faults and dykes that provide a means for the circulation to depth and the return of the heated waters to the surface.

3. DATA AND METHODOLOGY

Field trips were undertaken to the study area during the period 2003 to 2005. Unfortunately, not all springs could be visited. Considerable difficulty was encountered since many of the springs that were documented by Kent in the 1940s and 50s, have undergone changes in use, ownership and name during the intervening period. Many of these changes could only be identified by means of comparison of geographical coordinates. It was, for example, found that Klein Chipise (Tshipese) is called now called Sagole; Gordonia seems to coincide geographically with Môreson, and Letaba is now the popular holiday resort of Die Eiland. Other springs were recognisable from their original names, only their spelling having changed; Chipise is currently spelt Tshipise, and Mpefu has changed to Mphephu. The town of Warmbaths has been renamed to Bela-Bela, but the actual resort is still called Warmbaths or Warmbad, and will be referred to as such in this paper. Accurate GPS readings facilitated the identification of these springs. Rhemardo and Welgevonden (Kent, 1949) were found to be the same place and some springs, such as Icon and Constantia subsequently have dried up. Identification was further exacerbated by the number of ‘eyes’ issuing from a spring. Although the majority of thermal springs have only one eye, some have numerous. Loubad, for example, has seven different eyes located within a radius of 500 m from each other (Kent, 1946). According to the resort managers, the ‘springs’ at Libertas and Lekkerrus are similar in all respects and can therefore be regarded as having the same origin. In view of their proximity to each other (< 1 km), the springs at Vischgat guesthouse and Badseloop youth camp could possibly be eyes of the same spring. However, visits to the sites revealed that the thermal water at the youth camp issues from a borehole and not from a spring. Problems encountered with the naming of springs in the Soutpansberg area could also have been due to mistaking different eyes, as separate springs. For instance, Kent (1949) mentions that the spring at Mpefu has two eyes located 1,5 km apart. In Winfield’s (1980) report on the thermal springs of Venda, he lists two springs, namely, Mpefu and Siloam (Sendedzane), in close proximity to each other and having more-or-less the same geographical co-ordinates. It was found that the description of Winfield’s Siloam (Sendedzane) spring coincides with that of Kent’s Mpefu. It is therefore assumed that Mpefu, Siloam and Sendedzane are one and the same.

During field trips undertaken during 2003, data were obtained for six springs in the Waterberg region, namely, Vischgat, Die Oog, Welgevonden/Rhemardo, Libertas, Lekkerrus, Loubad and Warmbaths. Trips to Evangelina, Mphephu, Tshipise, Sagole, Moreson and Die Eiland were undertaken during 2004 and 2005. During the course of discussions with local inhabitants at Mphephu, another, previously undocumented spring was 'discovered'. This will be referred to as Siloam, after the nearest village. This article reports on the thermal and chemical characteristics of 14 thermal springs.

Where possible, the temperature of the water was measured at the source of the springs using a laboratory quality glass mercury thermometer. In some cases, the source of the spring had been enclosed and was not accessible. Water samples were collected at source and stored at low temperatures (around 4°C) in 1-litre sample bottles before being submitted to the Institute of Water, Climate and Soil at the Agricultural Research Council (ARC) in Pretoria for chemical analysis. No gas samples were collected. It was not possible to collect flow rate data, since pumps have been installed at the majority of developed thermal spring resorts. Information obtained from literature was used to augment data which could not be gathered during these field trips so as to provide as comprehensive an overview as possible.

4. RESULTS

4.1 Geology and Geological Controls

Secondary permeability of the rocks are very important for South African hot springs, as it creates the aquifers, as well as preferential flow paths for the hot water to reach the surface again. Table 1 gives a summary of the geological structures associated with the thermal springs in Limpopo.

Table 1: Geological structures associated with the thermal springs in Limpopo (Adapted from Bond, 1947; Kent 1946, 1949, 1952, 1969; Kent and Russell, 1950; Hoffman, 1979; Ashton and Schoeman, 1986)

NAME	GEOLOGICAL STRUCTURE
Warmbaths	Intersection of two post-Permian faults in the Waterberg System
Loubad	Diabase dyke in sandstones of the Waterberg Group
Buffelshoek	Diabase dyke as barrier on artesian slope of Bushveld granite
Vischgat	Post-Karoo fault in Bushveld granite
Die Oog	Diabase dyke along post-Karoo fault on Rooiberg felsites
Welgevonden / Rhemardo	Diabase dyke along post-Karoo fault on Rooiberg felsites
Lekkerrus	Diabase dyke along post-Karoo fault on Rooiberg felsites
Libertas	Diabase dyke along post-Karoo fault on Rooiberg felsites
Die Eiland / Letaba	Dolerite dyke in Archaean gneissic granite
Evangelina	Diabase dyke in Archaean gneiss
Moreson	Fault in Archaean gneiss
Mphephu	Pre-Karoo fault
Sagole	Klein Tshipise fault (1:250000 Messina sheet) in mudstone, shale
Siloam	Siloam fault (1:250000 Messina sheet) in basalt
Souting	Fault in Archaean granite
Tshipise	Intersection of two post-Permian faults in upper Karoo
Tugela	Joint in Archaean gneiss
Vetfontein	Post-Karoo fault

The main geological features underlying the southern thermal springs in the Limpopo Province are felsites of the Rooiberg Group, sandstones of the Waterberg Group and granites of the Bushveld Complex (Kent, 1949). The northern thermal springs are underlain by volcanic and sedimentary rocks of the Soutpansberg Group (e.g. Siloam), as well as volcanic and sedimentary rocks of the Karoo Supergroup (e.g. Sagole and Tshipise).

4.2 Temperature

The classification used for South African thermal springs was proposed by Kent in 1949. In this, temperatures of 25 – 37°C are warm; 38 – 50°C are hot or hyperthermic; and >50°C are scalding. The term 'tepid' is used for thermal waters with temperatures ranging between mean air temperature and 25°C.

Table 1 lists the temperature measured at the source of the thermal springs. The second column indicates temperatures measured during the field trips, whereas the third column gives the corresponding temperatures as obtained from literature.

Until now, it has been assumed that Brandvlei is the hottest thermal spring in South Africa 64°C). However, Siloam is hotter by 3.5°C.

Four of the springs in the northern part of Limpopo can be classified as scalding, ten are hot, and eight are warm. The temperatures of the other springs are not known. Perusal of Figure 1 indicates that there is no spatial correlation between springs with similar thermal characteristics. It is noticeable the temperatures at adjacent springs differ markedly. Warmbaths, for instance, has a temperature of 52°C, whereas at Loubad, its nearest neighbour (43 km apart), the temperature is a mere 300C. A similar discrepancy occurs between Tshipise (58°C) and Môreson (40°C). A difference of 28°C occurs between Mphephu (43°C) and Siloam (67°C), less than 2 km away.

It is also interesting to note that the temperatures of the majority of springs are essentially the same as they were in the 1940s and 50s. It is thus likely that they will remain constant for the foreseeable future.

4.3 Chemical Characteristics

Since minerals are generally more soluble in hot water, thermal springs are often enriched with trace elements. Certain minerals dissolve more readily than others, while some rocks are richer in soluble minerals than others. The pH of the solvent also affects the solubility of minerals. Hence, the specific chemical composition of spring water will depend largely on the composition of the rain water, its temperature and pH, the geology of the aquifer and the rocks through which the water rises to the surface.

There are numerous classifications of thermal springs. A number are based on the origin of springs, and some on physical properties such as flow rate and/or temperature. Others are classified according to geology, chemical composition or a combination of these. The chemical classification of thermal waters that is currently used in South Africa was devised by Bond in 1946. This classification distinguishes five different classes of thermal waters (see Table 2).

4.3.1 Major Elements and Ions

The results of the chemical analyses (by the Agricultural Research Council in Pretoria) of water samples collected from the springs visited are given in Table 3. Information for Warmbaths and Buffelshoek, as extracted from Temperley (1975) and Hoffmann (1979), are included to facilitate comparisons. Standards provided by the South African Bureau of Standards (SABS) 1999 for Class 1 potable water are given to facilitate evaluation of water quality.

Table 2 Thermal characteristics of THERMAL springs in LIMPOPO

NAME	TEMP. (°C)	TEMP. From literature (°C)	CLASS.
Siloam	67.5		scalding
Tshipise	58	57.2 (K)	scalding
Warmbaths	52	52 (K) 60 (H)	scalding
Libertas	52	52 (K); 38 (H)	scalding
Lekkerrus		46 (H)	hot
Sagole	45	45.9 (K); 43.6 (W); 49 (B)	hot
Welgevonden/Rhemardo	44	44 (K)	hot
Mphephu	43	42.8; 43.7 (K)	hot
Souting		43.9 (K)	hot
Tugela		42.8 (K)	hot
Môreson	43	37.7 (K)	hot
Die Eiland	42	40.4; 42 (K)	hot
Die Oog	40	40 (K)	hot
Vischgat	40		hot
Evangelina	34	32.5 (K); 45 (C)	warm
Makutsi		35 (B)	warm
Minwamadi		31.6 (W)	warm
Sulphur Springs		31 (K)	warm
Buffelshoek		31(K)	warm
Loubad	30	30 (K)	warm
Vetfontein		29.5 (K)	warm
Paddysland		26 (R)	warm

Source: B: Boekstein (1998); C: Chidley (1985); ; H: Hoffmann (1979);

K: Kent (1949); R: Rindl (1916); W: Winfield (1980)

Table 3: Classes of Thermal Water in South Africa according to Bond (1946)

Class	Water	Chemical composition
A	Highly mineralised chloride-sulphate water	TDS > 1 000mg/ℓ; Cl- > 270g/kg; SO4= >50g/kg
B	Slightly saline chloride water	TDS 300-500 mg/ℓ; Cl- > 270g/kg; SO4= <3g/kg
C	Temporary hard carbonate water	TDS < 800mg/ℓ; pH >7.6
D	Alkaline sodium carbonate water	TDS < 1000mg/ℓ; Na2CO3 or NaHCO3 > 150mg/ℓ . No permanent hardness
E	'Pure' waters	TDS <150 mg/ℓ; pH <7.1

Water samples from the springs share a number of chemical characteristics. They all have pH ~7; are neutral (neither corrosive nor depositional: pHs – pH = -1 to +1); and have SAR values of more than 1. The latter indicates that they are not suitable for irrigation. Only Loubad's water is suitable for human consumption – the other springs having fluoride levels exceeding the 1 mg/ℓ recommended by the South African Guidelines for Domestic Water Quality (DWAF, 1996).

In the majority of cases, barring Loubad and Libertas, the dominant cation is sodium with calcium being subdominant, usually followed by potassium and then magnesium. With the exception of Mphephu and Evangelina, the ratio of calcium to magnesium is high, ranging from 4 : 1 at Libertas to more than 28 : 1 at Tshipise. Most of the thermal waters are rich in bicarbonates, except for Siloam, Tshipise and Moreson. With the exception of Vischgat, Evangelina and Die Eiland, spring waters are poor in sulphates. The chloride levels of the different springs vary. Unacceptibly high values occur at Evangelina and Die Eiland, but it is virtually absent from Loubad and Libertas. Carbonates, phosphates and nitrates are absent or present in very low concentrations, with the exception of Moreson and Evangelina, where some nitrates are found.

According to Bond's classification (1947), all the southern springs, except Warmbaths and Buffelshoek, can be classified as 'pure' waters, the latter two being alkaline sodium carbonate waters. The northern spring waters are mostly temporary hard carbonate waters with pHs above 7.6, but Evangelina and Die Eiland typically alkaline sodium carbonate water.

A Piper diagram (Figure 3) was used to illustrate the chemical character of the thermal spring waters and to identify the degree of correspondence between the source areas of the springs. The explanation of the Piper diagram is based on that of Johnston (1975) as given in Lloyd and Heathcote (l985).

The top diamond-shaped field provides irrefutable evidence that waters from Die Oog and Rhemardo have identical hydrochemical characteristics and therefore share a common source area. Geographically, they are located only a kilometre or so apart. Waters issuing from the thermal springs at Buffelshoek, Warmbaths, Moreson and Tshipise also appear to share a common origin and are typically sodium chloride brines. Although some similarly is expected in the case of Moreson and Tshipise due to their proximity to each other, Buffelshoek and Warmbaths are some distance apart and are not adjacent to each other. On the other hand, the neighbouring springs at Loubad and Warmbaths have different origins. According to Kent (1949), Warmbaths (Bela-Bela), Buffelshoek and Vischgat arise from the Bushveld granite while the thermal water at Loubad obtains its characteristics from the underlying Waterberg sandstones (Olivier et al., 2008). Separate aquifers, distinct from the others, feed the springs at Loubad, Libertas, Siloam, Vischgat, Evangelina and Die Eiland. The above indicates that there are no clear differences in the chemical characteristics of waters from the springs located in the Waterberg and the Soutpansberg regions of the Limpopo Province and that physical proximity of springs to each other does not necessarily indicate identical physical and chemical characteristics.

The lower LHS triangle in Fig. 3 illustrates the cation concentration of the spring waters. This diagram clearly shows similar high Na+ content of the springs at Moreson, Tshipise, Sagole, Die Eiland, and Buffelshoek. The Na+ content of Siloam and Evangelina are very similar, while that of Rhemardo, Die Oog and Vischgat are almost identical. Libertas has a slightly higher proportion of Ca++ ions. Mphephu has the highest proportion of Mg++. Loubad is clearly richer in Ca++ than the other spring waters, while the anion composition of Vischgat differentiates it from the other thermal springs.

The waters exhibit a gradient of diminishing chloride and increasing bicarbonate concentrations from Die Eiland (being the most saline) through Evangelina, Warmbaths, Buffelshoek, Tshipise, Siloam, Sagole to Mphephu, Die Oog and Rhemardo, to the bicarbonate-rich Libertas and Loubad. None of the springs are rich in magnesium and sulphate ions.

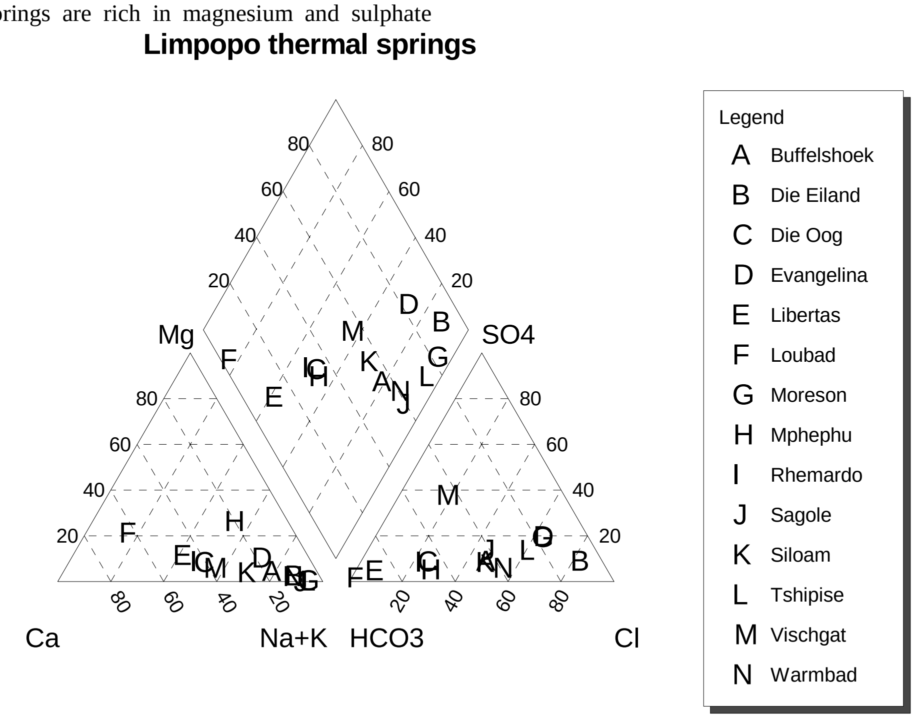

Fig 3 Piper diagram of 14 Limpopo thermal springs

The majority of the thermal springs (except Evangelina, and to a lesser extent, Vischgat and Die Eiland) exhibit typical characteristics of dynamic and coordinated hydrochemical regimes. At Evangelina and Die Eiland, the dominant processes are dissolution and mixing. The latter two springs just fall into the upper half of the diamond-shape figure, which, according to Johnson (1975: In Lloyd & Heathcote 1985: 37) is indicative of “static waters and other unusual waters”. Loubad shows the least signs of dissolution, mixing and ion exchange.

A comparison of present research findings with those given by Kent in 1949 for Tshipise, Evangelina, Loubad, Die Oog and Libertas (Table 3, in brackets), reveals that the mineral composition of the thermal waters have remained remarkably constant over the last 60 years. Minor differences are probably due to advances in analytical techniques, rather than fundamental changes in water chemistry.

<u>4.3.2 Trace Elements</u>

Water samples from 12 thermal springs visited were analysed for 29 trace elements by the Institute of Water, Climate and Soil (ARC, Pretoria).

Target ranges for domestic water quality for some of the trace elements are listed in columns 2, 3 and 4, as given by Mamba et al., 2008. The WHO and EU standards have been included since SA standards are at times less stringent than those used in other countries. WHO and EU standards are important in the event of bottling the water for the international market or for consumption by overseas visitors.

According to local and international standard, none of the thermal springs in Limpopo conform to general health standards with regard to trace elements. All of the springs, except Libertas, have excessively high concentrations of bromine, while Libertas, Die Eiland, Tshipise, Moreson and Evangelina are contaminated with mercury. All of the thermal springs in the Soutpansberg region, barring Tshipise, have extremely high levels of selenium; Siloam has unacceptable amounts of antimony and Evangelina’s waters contain arsenic.

The majority of the springs also have high, although acceptable, levels of some trace elements. For example, Evangelina, Moreson, Sagole, Mphephu, Siloam and Die Eiland are high in iodine. It is interesting to note that most of the southern Limpopo springs contain high levels of strontium and titanium. This also applies to Evangelina that has >1000 ppb strontium. The only spring waters with high amounts of vanadium are Evangelina and Die Eiland.

In general, the thermal springs in the Soutpansberg region of the Limpopo Province have a greater variety and amount of trace elements. Evangelina has the poorest water quality of the seven springs, exceeding recommended levels of bromine, selenium, and arsenic, and has very high levels of mercury, iodine, strontium, boron, titanium and vanadium. Water quality at Die Eiland is almost as bad, exceeding recommended levels of bromine, mercury and selenium. Exceptionally high concentrations of lithium, strontium and vanadium are also present.

It should also be noted that it is immaterial whether the elements in the waters originate from the geological formations or from other sources: the fact remains that the long-term ingestion of water from this source may be hazardous to human health.

5. SUMMARY AND CONCLUSION

This article has expanded current knowledge of the distribution and characteristics of thermal springs in the Limpopo Province of South Africa. It provides current information on the temperature and chemical composition of 14 thermal springs in the area.

The Limpopo Province has more thermal springs and more developed thermal spring resorts than any of the other provinces in South Africa. The springs are all of meteoric origin and range from warm to scalding in temperature. The mineral composition of the thermal waters reflects the geological formations that occur at the depth of origin of the thermal spring water, rather than the surface formations. This indicates that the spatial distribution of thermal springs do not dictate the physical and chemical characteristics of the springs and that two or more springs located in close proximity to each other may differ markedly from one another with respect to their temperatures, flow rates or chemical composition and may not share the same development potential.

To date, only about one third of the thermal springs in Limpopo have been developed as family holiday resorts. A great many of the springs are located in former Homelands and have not been developed at all. The results indicate that waters from the springs are contaminated with fluorine and bromine, making them unfit for human consumption. Some springs also have high levels of other toxic and potentially toxic elements such as mercury, arsenic and selenium. The present use of these waters for swimming and bottling (at some of the resorts) should be closely monitored. Conversely, the extremely high concentrations (measured in ppm.) of elements such as bromine, iodine, strontium and others may make small-scale mineral extraction economically viable.

There is great potential for the use of geothermal resources in Limpopo. Uses such as agriculture, aquaculture, direct heating and possibly small-scale geothermal energy production and mineral extraction should be investigated. To date, no research has been conducted on thermophilic organisms and their potential for use in industry. This aspect needs to receive urgent attention. The information generated in this study will play a pivotal role in decision –making regarding optimal use of these geothermal resources.

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REFERENCES

Atkinson, T.C., and Davidson, Is the water still hot? Sustainability and the thermal springs at Bath, England, Geological Society, London, Special Publications, 193, (2002), 15-40.

Ashton, P.J., and Schoeman, F.R.: Southern African thermal springs, The Naturalist, 30, (1986), 32 - 34.

Bahati, G.: Geothermal energy in Uganda, country update, Proc. International Geothermal Conference, September 2003, Reykjavik, (2003), 48-53.

Baradács, E., Hunyadi, I., Dezs, Z., Csige, I., and Szerbin, P.: 226Ra in geothermal and bottled mineral waters of Hungry, Radiation Measurements, 34, (2001), 385-390.

Boekstein, M.: Hot Springs Holidays: Visitors' Guide to Hot Springs and Mineral Spa Resorts in Southern Africa, Mark Boekstein and Logo Print, Cape Town (1998).

Bond, G.W.: 'n Geochemiese opname van die grondwatervoorrade van die Unie van Suid-Afrika, Memoir Geol. Surv. S. Afr., 41, (1947), 90-94.

Chidley, C.M.: The geology of the country around Evangelina and Pontdrift, CGS Report No. 1985 – 0231, (1985).

Department of Water Affairs and Forestry, South African Water Quality Guidelines, Domestic Water Quality, (1996), http://www.dwaf.gov.za [Accessed 13 December 2006].

Diamond, R.E., and Harris, C.: Oxygen and hydrogen isotope geochemistry of thermal springs of the Western Cape, South Africa: Recharge at high altitude? J. Afr. Earth Sci, 31, (2000), 467-481.

Hellman, M.J., and Ramsey, M.S.: Analysis of hot mineral springs and associated deposits in Yellowstone National Park using ASTER and AVIRIS remote sensing, Journal of Volcanology and Geothermal Research, 134, (2004), 195-219.

Hoffmann, J.R.H.: Die chemiese samestelling van warmwaterbronne in Suid- en Suidwes-Afrika, CSIR Report No. WAT 56A, Pretoria (1979), 21.

Kent, L.E.: The warm springs of Loubad, near Nylstroom, Transvaal, Trans. Royal Soc. South Afr., 31, (1946), 151-168.

Kent, L.E.: The thermal waters of the Union of South Africa and South West Africa, Trans. Geol. Soc. S. Afr., 52, (1949), 231-264.

Kent, L.E.: The Medicinal Springs of South Africa, Publication and Travel Department, South African Railways, Pretoria (1952).

Kent, L.E.: The thermal waters in the Republic of South Africa, In: Proc. Of Symposium II on mineral and thermal waters of the world, B-overseas countries, Vol 19, Report of the 23rd session of the International Geological Conference, Academia, Prague (1969), 143-164.

Kent, L.E., and Russell, H.D.: The warm spring on Buffelshoek, near Thabazimbi, Transvaal, Trans. Royal Soc. South Afr., 32, (1950), 161-175.

Lloyd, J.W., and Heathcote, J.A.: Natural Inorganic Hydrochemistry in Relation to Groundwater, Clarendon Press, Oxford (1985).

Lund, J.W., and Freeston, D.H.: World-wide direct uses of geothermal energy 2000, Geothermics, 30, (2001), 29-68.

Mamba, B.B., Rietveld, L.C., and Verbeck, J.Q.J.C.: SA drinking water standards under the microscope, The Water Wheel, 7(1), (2008), 24-27.

Mawadza, C., and Zvauya, R.: Some factors affecting endo-b-1,4-glucanase production by two Bacillus strains isolated from Zimbabwean hot springs, Journal of Basic Microbiology, 36, (1996), 177-187.

Mawadza, C., Hatti-Kaul, R., Zvauya, R., and Mattiasson, B.: Purification and characterization of cellulases produced by two bacillus strains, Journal of Biotechnology, 83, (2000), 177 – 187.

Mock, J.E.: Geothermal energy – the environmentally responsible energy technology for the 90s: A federal perspective. In: Proceedings: Geothermal Energy: The Environmentally Responsible Energy Technology for the Nineties, Berkeley, California, USA (1993).

Narayan, V.N., Hatha, M.A., Morgan, H.W., And Roa, D.: Isolation and characterization of aerobic thermophilic bacteria from the Savusavu hot spring in Fiji, Microbes Environ, 23, (2008), 350-352.

Olivier, J., Van Niekerk, H.J., and Van Der Walt, I.J.: Physical and Chemical characteristics of thermal springs in the Waterberg area of Limpopo Province, South Africa, Water SA, 34(2), (2008), 163-174.

Petraccia, L., Liberati, G., and Masciullo, S.G.: Water, mineral waters and health, Clinical Nutrition, 25, (2005), 377-385.

Rindl, M.R.: The Medicinal Springs of South Africa, S. Afr. J. Sci, 13, (1916), 528-552.

Shevenell, L., Garside, L., Arehart, G., Van Soest, M., and Kennedy, B.M.: Geothermal sampling of thermal and nonthermal waters in Nevada to evaluate the potential for resource utilization, GRC Transactions, (2002).

South African Bureau of Standards (SABS).: Class 1 Potable Water Standards, SABS 241:1999, Pretoria, South Africa (1999).

Temperley, B.N.: The Welgevonden fault aquifer of the central Transvaal and its thermal water, Groundwater Series no. 2, South African Geological Survey, Pretoria, South Africa (1975).

Vimmerstedt, L.J.: Opportunities for small geothermal projects: Rural power for Latin America, the Caribbean and the Philippines, Natural Renewable Energy Laboratory, Colorado, USA (1998).

Visser, D.J.L.: The Geology of the Republics of South Africa, Transkei, Bophuthatswana, Venda and Ciskei and the Kingdoms of Lesotho and Swaziland. 4th ed, Department of Mineral and Energy Affairs, Pretoria, South Africa (1989).

Winfield, D.: The thermal springs of Venda. Report on desk study and visit to Venda, July 1980, Mining Corporation Limited, RD/OW/1138, (1980).

Zvauya, R., and Zvidzai, C.J.: Constitutive production of endoglucanase by Bacillus sp. Isolated from Zimbabwean hot spring, World Journal of Microbiology and Biotechnology, 11, (1995), 658-660.

Table 4: Chemical Composition of thermal springs in Limpopo

	Southern springs								Northern springs						
	SABS 1999	Warm bad*	Lou-bad	Buffels hoek*	Vischgat	Die Oog	Rhemo.	Libert.	Mph.	Siloam	Tshi-pise	Sagole	More-son	Evan-gelina	Die Eiland
pH	6 - 9	8.3	6.81	Not available	7.07	7.27	7.33	6.98	8.10	8.92	8.30	8.72	8.55	7.49	7.63
pHs			7.79		7.82	8.01	7.96	8.00	8.24	8.50	8.70	8.91	8.93	7.29	7.67
SAR (1)			0.34		2.39	1.72	1.62	1.13	1.99	2.83	15.93	8.11	11.92	8.88	20.58
TDS	<450	340	134.18		302.85	175.48	179.90	137.90	175.90	157.93	422.10	173.98	340.55	1385.00	1937.2
Conduct. (mS/m)	<150	69	25.00		52.00	32.00	34.00	25.00	34.00	29.00	80.00	33.00	57.00	230.00	330.00
CATIONS (mg/ℓ)															
Sodium	<200	132.5	7.87 (8)	151.6	55.95	34.21 (41**)	32.72	21.98 (21)	40.14	41.36	140.19 (140.9)	58.46	99.23	360.90 (343.8)	621.88
Potassium	<50	2.9	2.90 (3)	5.7	6.13	3.62 (4**)	3.58	3.57 (4**)	1.14	2.82	3.51 (2.2)	1.05	3.24	6.15	21.79
Calcium	ns	13.0	30.92 (26)	27.1	36.13	24.80 (19)	25.57	23.02 (23**)	13.35	14.02	5.58 (6.0)	3.93	4.80	79.37 (78.8)	53.61
Magnesium	ns	1.8	6.44 (6)	4.7	3.30	3.14 (2**)	3.28	3.46 (3**)	10.60	1.30	0.17 (1.3)	0.00	0.27	27.60 (29.4)	9.37
ANIONS (mg/ℓ)															
Fluoride	1.5 (1#)	11.0	0.95 (0.5)	6.6	6.54	5.66 (6)	5.39	5.95 (3.5)	2.54	6.08	5.08	0.72	3.69	6.50	2.24
Nitrate	Ns	0	0.59	0	0.68	0.60	0.88	0.41	0.07	0.04	0.39	0.00	23.79	19.97	2.69
Chloride	<200	85.2	2.21	138.5	31.70	28.31	28.64	7.24	32.93	44.35	158.60	44.09	117.31	535.17	982.62

			(4)			(25)		(7)			(139.1)			(443)	
Sulphate	<400	12.1	2.16	35.1	92.82	12.96 (8)	13.68	5.86 (5**)	8.28	10.69	47.58 (27.6)	17.78	48.18	226.01 (215.9)	143.63
Phosphate	ns	< 0.2	0.00	-	0.00	0.00	0.00	<0.2	0.00	2.69	0.00	0.10	0.00	1.26	24.86
Carbonate	ns	-	0.00	-	0.00	0.00	0.00	0.00	0.00	0.00	6.00 (12)	16.50	13.50	0.00	0.00
Bicarb	ns	102.0	161.65 (122)	213.5	140.30	125.05 (110)	134.20	134.2 (110)	134.20	70.15	109.80 (103.5)	64.05	54.90	244.00 (191.3)	149.45
Classific.		D	E	D	E	E	E	E	C	C	C	C	C	A	A

Source: *Kent, 1949; Temperley, 1975 (as reported in Hoffmann, 1979 p8) ; **Hoffmann, 1979 p15 #DWAF, 1996; ns: not stipulated

Values in brackets: Kent 1949

Table 5: Trace elements

Element	WHO*	EU*	SA*	Visch-gat	Die Oog	Rhem.	Libert.	Lou-bad	Tship.	Evang	More-son	Sagol	Mphep.	Siloam	Die Eiland
	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l	ug/l
Antimon	5	5	5	1.03	0.00	2.49	0.05	0.00	1.11	1.39	1.14	1.16	1.31	14.99	0.48
Arsenic	10	10	10	1.35	3.25	4.48	6.63	4.23	5.02	24.32	6.04	4.25	4.08	0	5.77
Barium				9.47	13.26	13.27	29.00	42.26	6.85	14.18	25.76	1.17	39.03	5.22	78.74
Beryll.				0.60	0.63	0.68	1.07	0.44	0.07	0.09	0.05	0.03	0.05	0.14	0.15
Bismuth				3.80	3.85	3.70	3.60	3.62	0.28	0.60	0	0	0.37	5.03	0.71
Boron			1500	47.63	49.38	47.96	43.78	33.07	106.26	303.75	67.15	29.85	37.10	58.84	267.60
Bromine		10	10	39.64	60.93	31.36	0.00	20.73	235.12	1032.13	153.83	72.61	49.34	154.47	4111.00
Cadm.			5	1.79	0.47	1.20	0.03	0.93	0.08	1.13	1.31	0.09	0.27	0	0.17
Chrom.	50	50	100	2.84	3.31	3.56	3.39	5.52	10.94	23.51	8.00	6.01	9.24	0.85	2.25
Cobalt			150	2.13	1.13	1.56	2.15	3.50	0.12	1.22	0.11	0.02	0.20	0	2.07
Copper	2000	2000	1000	6.07	1.14	4.97	5.77	5.54	2.65	11.75	2.11	0.69	0.56	0.37	3.61
Iodine				15.90	6.96	7.75	20.08	0.00	49.68	215.41-2248.96	549.93	340.79	284.36	7.09	234.30
Lanthan.				0.00	0.00	0.00	0.00	0.00	0.01	0.12	0.00	0.01	0.00	0.00	0.18
Lead	10	10	20	3.73	5.69	6.96	5.70	5.64	4.71	2.66	2.94	2.51	3.25	0	1.64
Lithium				79.54	45.42	47.14	37.21	16.43	48.49	73.44	40.77	16.31	8.77	9.25	176.70
Mangan.	500	50	100	9.63	3.13	3.52	14.22	20.14	5.39	6.06	6.40	4.26	4.82	0.37	3.13
Mercury	1	1	1	0.00	0.00	0.00	1.77	0.00	0.94	0.94	1.88	0	2.24	0	2.54
Molybde				9.67	11.63	11.07	12.49	6.30	1.79	16.30	1.59	1.64	2.14	2.66	3.74
Nickel	20	20	150	8.80	4.43	7.07	10.18	17.33	0	1.05	0	0	0	0	2.83

Platinum				0.00	0.00	0.00	0.00	0.00	0.88	0.81– 1.03	0.10	0.11	1.03	0	0.20
Selen.	10	10	20	0.00	0.00	0.00	0.00	1.66	5.37	29.41	11.46	6.66	6.00	2.03	15.29
Stront				227.27	125.11	127.36	202.39	104.34	227.04	704.18	74.95	59.01	44.13	17.41	1018.00
Tellur.				0.00	3.46	0.00	2.11	4.92	3.52	1.10 – 2.53	0.99	0.56	0	0	0.46
Thallium				0.77	0.64	0.66	0.39	0.37	0	0.32	0.31	0	0	0	0.41
Titanium				228.59	134.50	144.68	141.64	178.96	42.57	299.20	30.24	14.80	39.00	30.06	8.44
Tungstn				1.10	0.00	3.21	0.00	0.00	5.10	2.99	3.28	1.42	0.13	0.45	
Uranium			70	0.00	1.37	4.12	2.98	1.28	0.33	26.05	1.12	1.03	1.74	3.68	8.53
Vanad.			100	3.78	4.18	4.30	3.17	3.71	27.86	98.10	21.99	10.75	20.86	47.36	60.86
Zinc	3000		5000	37.54	9.93	19.53	14.63	8.65	0	24.50	6.17	0	0	8.92	1738.00

*(Mamba et al., 2008) ***Tentative water quality guideline for Uranium (Kempster et al., 1996) DWAF 1996 *

SABS 1999** Standards