Quality Assessment of Agricultural Water Used for Fertigation in the Boland Region of South Africa

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Abstract: Water quality of selected rivers in the Boland region of South Africa was determined by focusing on the concentrations of specific ions and phytotoxic substances as well as the presence of micro-organisms. Additionally the influence of seasonal changes on the water quality was determined (i.e. rainy season vs. dry season). Water samples were collected on the following dates: 9 December 2010 , 6 January 2011, 3 February 2011, 25 February 2011, 10 June 2011, 1 July 2011, 29 July 2011 and 26 August 2011. Klapmuts River recorded the highest levels of chloride and iron, especially in summer. The bigger rivers recorded low levels of micro-organisms. Many sources of nitrate pollution seem to be present in the catchment area of the Berg River. The levels of iron in all the rivers assessed were far above the levels set by the South Africa's Department of Water Affairs and Forestry. The water samples tested for bacteria and fungi density showed Klapmuts and Eerste Rivers positive for *Phytophthora cinnamomi* during winter. *Phytophthora citricola* and *Phytophthora cactorum* were detected in the Klapmuts and Klippies Rivers in summer. Berg, Klapmuts, Krom and Eerste Rivers tested positive for species of the genera *Pythium* and *Fusarium*. Similar organisms were detected in the Eerste River mainly during summer on the fourth sampling date, while Krom River only tested positive for *Pythium spp.* during summer. The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx and efflux and, or moist and aerobic conditions and air temperature. There is an increased need for farmers to sterilize feeding water (chlorination) due to high microbial count.

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1. Introduction

Fertigation is the application of fertilizers, soil amendments, or other water soluble products through an irrigation system. Fertilizer solutions and suspensions are injected into irrigation systems via calibrated injection pumps ensuring precision. Effective fertigation requires knowledge of certain plant characteristics, such as optimum daily nutrient consumption rate and root distribution in the soil (North Carolina Department of Agriculture and Consumer Services, 2009).

Irrigation water vary greatly in quality depending upon the type and quantity of dissolved salts, pH, mineral content and nutrient solubility. Irrigation water salts originates from dissolution or weathered rocks and soil (lime, gypsum and other slowly dissolved soil minerals). The suitability of irrigation water is determined not only by the total amount of salt present but also by the kind of salt. Increased total salt content of the soil may result in the development of various soil and cropping problems. The development of specific management practices may be required to optimize yield (Ayers and Westcot, 1994).

The agricultural sector in South Africa represents about 5% (R22.814 billion) of the gross domestic product. In the Western Cape, agriculture supports about 11 000 farmers with an annual output of about R9 billion, and the provision of about 1.6 million employment opportunities (Department of Water Affairs and Forestry, 2001). Most of the cultivated area in the Boland district of the Western Cape Province is under irrigation. The Department of Water Affairs and Forestry (1999) has reported that the annual average rainfall for the Western Province is 515 mm more than South African annual average of 497 mm. The Western Cape's climate differs considerably from prevailing climatic conditions in the rest of South Africa. Most of the province, especially the extreme southwest, experiences a mediterranean type climate that is characterized by cool, wet winters and warm, dry summer seasons (Department of Water Affairs and Forestry, 1999).

In South Africa, agriculture uses about 50% of our available water (Department of Water Affairs and Forestry, 1996). Increasing water needs claimed for domestic, industrial and mining usages, may decrease agriculture's share to less than the current 50%. Inefficiency in water utilization is becoming a major constraint for the country's vision of sustainable agriculture and rural development (De Villiers e*t al*., 2003). Thus, better utilization of water is imperative since less than 20% of South Africa has a sub-humid climate with a mean annual rainfall higher than 750 mm. In most parts of South Africa, water supplementation through irrigation is essential for economic production of crops (Backeberg et al., 1996).

Irrigated crops depends on adequate supply of water and water quantity is not the only key factor for successful cultivation of crops in a soil-less production system. Water quality concerns have been neglected in the past because good quality water supplies was plentiful and readily available. This situation is now changing in many areas. Water quality has become a crucial factor that is based on specific concentrations of ions, phytotoxic substances and the presence of micro-organisms (Schwarz et al., 2005). Contamination of surface water by micro-organisms is an area of great concern, because hydrological pathways serve as vectors for the transmission of diseases. Only few of these pathogens are transferred to the water source through rain (Oliver et al., 2005). For soil-less production, growers use water sources of different origins (rivers, dams, lakes, boreholes, artificial ponds).

The objectives of this study were to determine the water quality of selected rivers in the Boland region by focusing on the concentrations of specific ions and phytotoxic substances as well as the presence of micro-organisms and also to determine the influence of seasonal changes on the water quality (i.e. rainy season vs. dry season).

2. Material and Methods

This study was conducted in the Boland district, region of the Western Cape Province. The Western Cape Province is one of the nine provinces of South Africa, and is situated between 30°30-34°45'S and 17°50-24°10'E, occupying an area of about 129 370 km^2. It is bound by the cold Atlantic Ocean to the west and the warmer Indian ocean to the south east (Department of Environmental Affairs and Development Planning, 2004). The data was collected in five most important water sources that are used for irrigation purposes in the district, i.e. Klapmuts River, Klippies River, Berg River, Eerste River and Krom River (Figure 1).

There is limited information available on literature and on government documents that describe the Krom and Klippies Rivers in details. This lack of information might be due to the size and the area that these rivers cover. The only Information available is on the three of the five rivers evaluated on this study, and it is listed below:

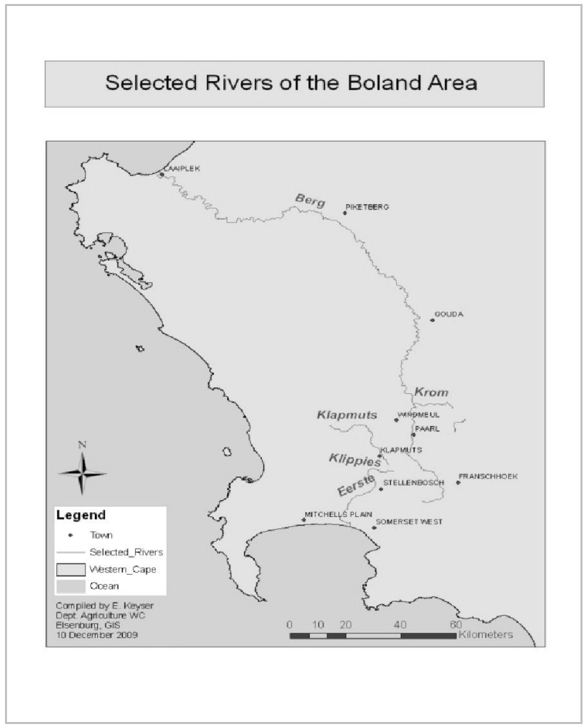


Figure 1. GIS map of selected rivers of the Boland region (Adapted from Keyser, 2009).

The Berg River is located between Franschhoek and Laaiplek in Cape Town in the Western Cape Province (Figure 1). It is approximately 294 km long with a catchment area of 7,715 km^2 and an outlet into the Atlantic Ocean (Department of Environmental Affairs and Development Planning, 2004). It is estimated that approximately 65% of the Berg River catchment area is utilized for agriculture. About 30% of the Berg River catchment area is a natural shrub-land, bush-land, grass-land and water bodies and wetlands. Approximately 4% of the catchment area is degraded, comprising mainly shrub-land and bush-land. Water pollution is caused by residential, commercial and industrial waste (Department of Environmental Affairs and Development Planning, 2004).

The Klapmuts River is located in Klapmuts, north of Cape Town (Figure 1). The water quality of the Klapmuts River is primarily impacted by agricultural-related activities rather than by urban activities, based on SASS4 data. This river is mainly used for irrigation and livestock (Department of Water Affairs and Forestry, 1999). It is reported that the Klapmuts River has lost its summer flow in certain areas due to the construction of in-stream dams directly resulting in the subsequent invasion of the habitat by exotic invasive plants (Boucher, 2009).

The Eerste River is a short river covering a distance of about 40 km (Figure 1). It arises on

Dwarsberg 60 km east of Cape Town at the head of Jonkershoek. The Eerste River catchment area covers the eastern part of the Cape Flats lying to the west of the Hottentots Holland Mountains and south of the Tygerberg. The most important land use in the catchment area is viticulture (River Health Programme, 2005). The Department of Water Affairs and Forestry (1996) reported that the water from the Eerste River is highly polluted. It is believed that this is a biological indication of the severe pollution of the water. Some bacteria and viruses have been found in this river (e.g. *Phytophthora, Pythium, Fusarium* etc.).

Water samples were collected from five rivers in the Boland area. The samples were collected from all sites once every three weeks for a period of six months. The sampling was carried out during specific periods in summer (December to February) and winter (June to August). The sampling dates followed were on the: 9 December 2010, 6 January 2011, 3 February 2011, 25 February 2011, 10 June 2011, 1 July 2011, 29 July 2011 and 26 August 2011. Samples collected were kept in a sterilized 500 ml glass bottles. The sub-samples were collected from 2 horizontal and 2 vertical positions in each river. These samples were collected at 0.5 m below water surface and 0.5 m above the bottom of the river. These sub-samples were combined together and then divided into two samples, for nutrient concentration analysis and microbial species determination (Schwarz et al., 2005). The samples were stored in a cooler-box, before being transported to the laboratory for analyses. The sampling procedure and techniques followed in this study is as described by the Water Research Commission (2000).

The Inductively Coupled Plasma (3120-B) technique was used to measure the levels of Ca, Mg, Na, K, P, S, Cu, Zn, Mn and Fe. Boron and Cl were measured using a 4500-Cl B Argentometric method. Nitrate and NH_4 were measured reflectometrically using the Reflectoquant, Merck® test kit (Clesceri et al., 1989; Manahan, 1979).

Erwinia carotovora and *E. chrysanthemi* from the water samples were cultured in Modified Nutrient Agar (MNA) (yeast extract, glucose and nutrient agar (Difco, Bacteriological)) and Kings Medium B (KMB) (Proteose Peptone (DifCo®)), dipotassium hydrogen phosphate, magnesium sulphate, glycerol, agar (Difco, Bacteriological®) and distilled water, before identifying and purifying these colonies on a MNA plates (Hossain *et al.,* 2005). Conversely, *Phytophthora* spp. were cultured in PARP (Ampicillin, Rifampicin, PCNB, Cornmeal Agar (Difco®), and distilled water); PARPH (PARPH is the same as PARP except for Hymexazol added after sterilization of Hymexazol) and BNPRA (Rhizolex, PCNB, Benomyl, Ampicillin, Rifampicin, Agar (Difco, Bacteriological®) and distilled water)).

Significant results were analyzed using Tukey's least significant difference test (LSD), described by Steel and Torrie (1980), at 5% level of significance to determine statistically significant differences between treatment means using the general linear model (GLM) of the Statistical Analytical System (SAS, 2004) package.

3. Results and Discussion

Chemical composition

The main crops produced in the Boland region are peppers, tomatoes, grapes, cucumbers, cauliflower, sunflower, spinach, cabbage, apricots, apples, etc. Crops such as tomatoes, cucumber, lettuce, pepper, apricots, apples and grapes are normally irrigated by fertigation (River Health Programme, 2005). These crops are grown on open fields and in tunnels and are mostly fertigated by drip irrigation systems.

Farmers in the Boland region use electric pumps and generators to pump water from the river, because it is cheaper than using municipal water. Some of these areas have no water supply infrastructure. Major pollution impacts to the rivers occur in their middle and lower catchment areas and are a consequence of agricultural practices (fertilizers and pesticides).

The cations composition was affected significant (P=0.01) by the interaction between rivers and seasons. Sodium levels were significantly high in the Klapmuts, Klippies and Krom Rivers during dry summer season when compared to the Berg and Eerste Rivers (Figure 2). The greatest change in concentration occurred in the smaller rivers (Klapmuts, Klippies and Krom Rivers) with their relatively high Na concentrations. By far the greatest change between summer and winter was found in the Klapmuts River (Figure 2).

The levels of Na obtained in this study are very low (115-460 mg/L) according to the guidelines of the Department of Water Affairs and Forestry (1996). The water from all five rivers would thus be suitable for fertigation during winter months. Only the Klapmuts River may contain too much Na for saline sensitive crops such as almonds, apricots, citrus and plums. However, 120 mg/L Na obtained in summer can be used for saline tolerant crops such as grape, pepper, potato and tomatoes. Crops vary in foliar absorption rates of Na (Combrink, 2005). The sodium absorption rates of avocados are low while those of citrus, stone fruits and almonds are high (Combrink, 2005). According to Combrink (2005), saline sensitive crops can be grown in soil-less conditions with <70mg/L Na in the solution.

The average measured levels of ammonium are presented in Figure 2. Ammonium levels were influenced significantly (P=0.01) by the interaction between rivers and seasons. Only the Krom River had high levels (4.8 mg/L) of NH_4 in summer (Figure 2). Ammonium levels recorded from other rivers are lower than the maximum level (1 mg/L) allowed for vegetable crops, but it is high enough to satisfy the total NH_4 need of peppers (Combrink, 2005).

There is limited information available on the literature that describe Krom River and crops irrigated from this river. The ammonium levels reported on this study are suitable for most sensitive crops like grapes and fruit trees that are grown on open field and hydroponic production. Modern soil-less growers use small quantities of ammonium in their nutrient solutions for its acidifying effect, preventing rises in pH and the precipitation of Fe and Zn (Combrink, 2005). Care should thus be taken to use NH_4-free fertilizers when using this water in summer to grow peppers. Since the NH_4 level in the Krom River rises substantially during summer, the possibility of pollution by dairy farmers in the catchment area does exist. Growers using this water may note that the pH of drained fertigation water decreases, since only a slight increase in NH_4 concentration may lower the pH of a nutrient solution applied to plant roots (Combrink, 2005).

The average measured levels of potassium are presented in Figure 2. The levels of K were significantly (P=0.05) influenced by the interaction between seasons and rivers. The Klapmuts-, Klippies- and the Krom Rivers had high levels (5-12 mg/L) of K which were especially prevalent during the winter season.

Since salts tend to accumulate in dry seasons, the increased K concentrations during the wet winter months cannot be explained, but as expected, the Berg and Eerste Rivers contained less K. However, most levels were relatively lower than 7 mg/L and would not affect fertigation practices in hydroponic plant production systems.

Calcium levels differed significantly (P=0.01) between the rivers. Klippies-, Klapmuts- and Krom Rivers had higher levels (15-34 mg/L) of Ca than the Berg- and Eerste Rivers (<6 mg/L, Table 1).

Nitrate levels differed significantly (P=0.05) between rivers. The Klapmuts- and Berg Rivers had significantly higher levels of NO_3 than the other three rivers. The nitrate level (7.13 mg/L) of the Berg River is higher than expected for such a big river (Table 1). However, many sources of nitrate pollution seems to be present in its catchment area. This might be caused by leaching of nutrients and water pollution by commercial and industrial waste. During the summer and winter seasons, the manganese levels of the water of the five rivers measured, differed significantly (P=0.01) between rivers. Klapmuts-, Klippies- and Krom Rivers had significantly higher levels of Mn than the two other bigger rivers (Table 1).

Table 1. Calcium, nitrate, manganese and boron levels of different rivers evaluated during summer (9 December 2010, 6 January 2011, 3 February and 25 February2011) and winter (9 June, 1 July, 29 July and 26 August 2011)

	Parameters (mg/L)			
River	**Ca^{2+}**	**NO_3^-**	**Mn**	**B**
Berg	5.75	7.13	0.02	0.018
Eerste	2.38	3.00	0.01	0.011
Klapmuts	30.5	7.75	0.09	0.041
Klippies	15.5	3.25	0.08	0.017
Krom	34.25	4.13	0.08	0.04
P value	0.01^{**}	0.05^{*}	0.01^{**}	0.01^{**}
$LSD_{T(0.05)}$	9.29	2.18	0.06	0.0076
CV%	2.05	2.04	2.04	2.04

ns= not significant at P<0.05, *F-ratio probability of P<0.05, **F-ratio probability of P<0.01
$LSD_{T(0.05)}$=least significant difference, CV%= coefficient of variation

These levels were high enough (15-35 mg/L) to be taken into account when using Klapmuts-, Klippies- or Krom River water for fertigation (Combrink, 2005). Water sources may contain low levels (<5 mg/L) of calcium in low rainfall areas, and relatively high levels calcium (>15 mg/L) may be found in saline water (Combrink, 2005). Calcium deficiency in crops like tomatoes, peppers and cucumbers is usually die-back of the growing tips, fruit failing to ripen properly, restricted growth, scorched leaf margins and dark green, small leaves which later turn yellow or orange or even purple (Niederwieser, 2001).

An interaction between seasons and rivers significantly (P=0.05) affected the levels of magnesium (Figure 2). Only the Klapmuts River had a higher concentration (28 mg/L) of Mg during the dry summer months (Figure 2). This might be due to the low rainfall during summer. The change in Mg content between summer and winter will force growers to change their Mg applications at least twice in a year.

Chloride levels were significantly (P=0.01) influenced by an interaction between rivers and seasons (Figure 2). Only the Klapmuts River had a significantly higher (P=0.01) level of chloride during summer, than during winter (Figure 2). High levels of chloride might limit the uptake of nitrate by plants (Combrink, 2005).

Sulphate levels of the rivers evaluated in summer and winter seasons were influenced by the interaction between season and rivers. The Klapmuts River contained a significantly (*P*=0.05) higher level of sulphate during summer (Figure 2) compared to the Krom River with a sulphate level of 22 mg/L that increased in winter. The increased sulphate level during winter in the Krom River may be due to pollution, but the levels are low enough not to affect any fertigation program. However, the relatively high (43 mg/L) sulphate level during summer in the Klapmuts River should be taken into account for fertigation. This is in line with the study done by Combrink (2005) who reported that, in low rainfall areas, water may contain high levels of essential ions such as sulphate.

The EC levels of the water analysed during the different seasons showed that there was a significant interaction (*P*=0.05) between the rivers and seasons. The EC levels were at 22-99 mS/cm in summer, notably in the three small rivers (Klapmuts-, Klippies- and Krom Rivers; Figure 2). The seasonal difference in (*P*=0.01) EC was significant in the Klapmuts River (Figure 2). The EC levels reflected the trends noted with the macro-nutrients (excluding the unexplainable higher K levels in winter).

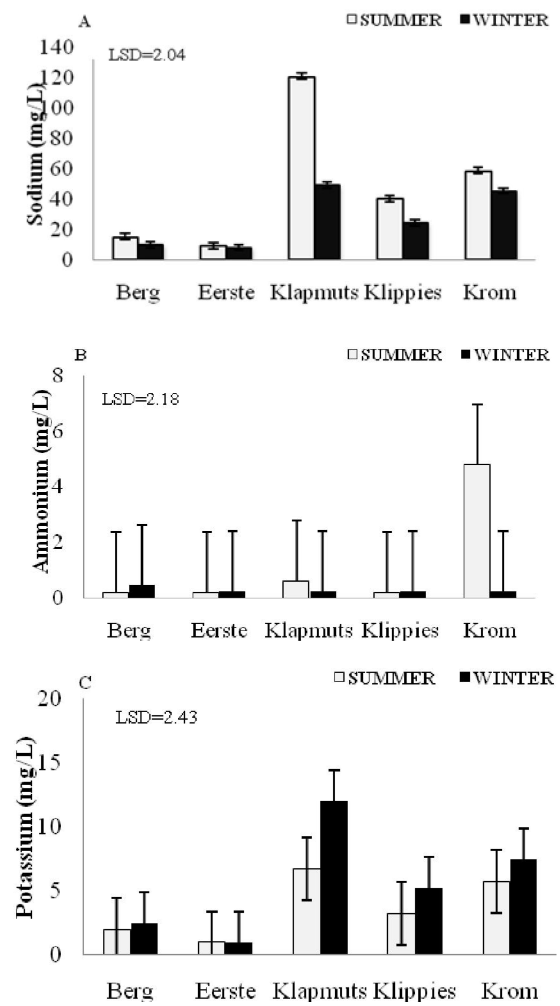
The pH of the water analysed during summer and winter was significantly influenced (*P*=0.01) by an interaction between rivers and season. The Department of Water Affairs and Forestry (1996) has reported that the pH levels of unrefined water lies in the range of 6.5 and 8.5 and this corresponds with the results recorded in this study. The pH levels in the Eerste River were 1.2 higher in winter than in summer (Figure 2). The pH levels obtained on this study will be suitable for grape production. Crops differ in pH sensitivity, most crops that are grown in soil-less production systems tend to grow well with nutrient solutions that has a pH that ranges between 5.3 and 6.3.

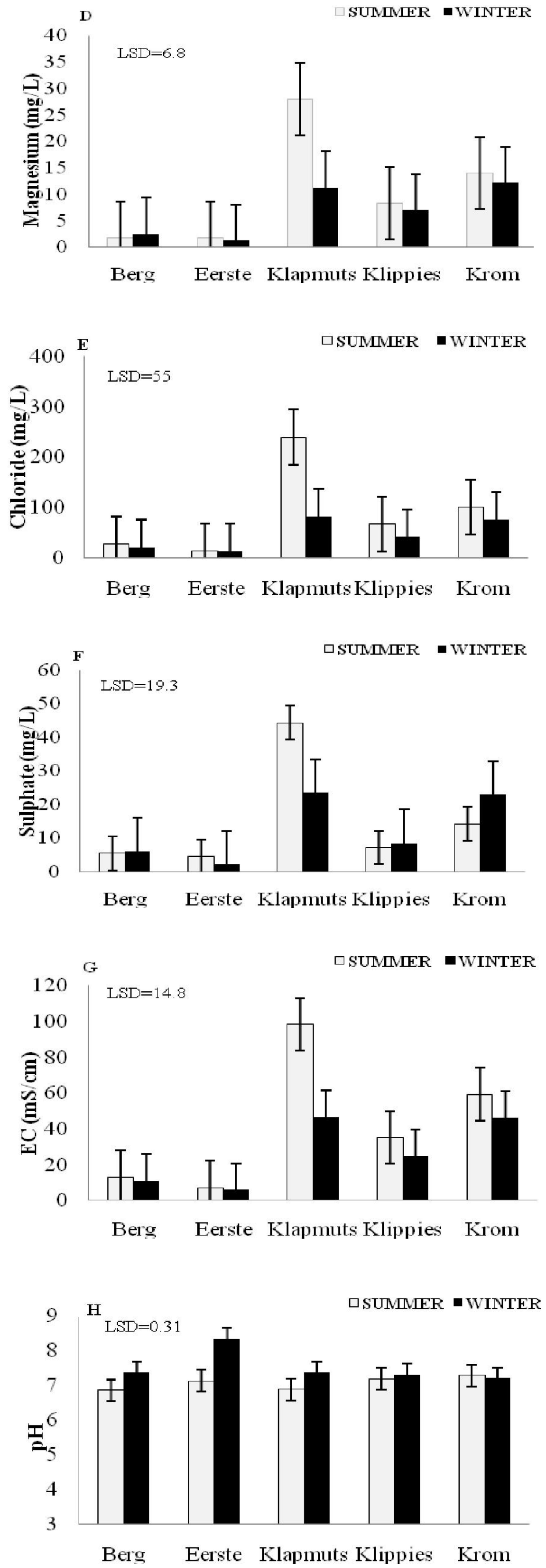
The hardness levels of the analyzed water showed a significant (*P*=0.01) interaction between rivers and seasons. The Department of Water Affairs and Forestry (1996) reported that the standard total hardness of surface water rarely exceeds 100 mg/L. The results of this study showed that high levels (150-210 mg/L) of hardness occurred in the3 Klapmuts- and Krom Rivers during summer and to a lesser extent in the Klippies River (Figure 2), whereas the Berg- and Eerste Rivers showed significantly lower (*P*=0.01) levels when compared to the standard levels reported above.

The levels of Zn was significantly (*P*=0.01) influenced by an interaction between rivers and seasons. The Krom-and Klapmuts Rivers had levels of 0.04 mg/L and 0.02 mg/L respectively, which is the highest level of Zn during winter (Figure 2) with no seasonal differences in the other rivers. Although these levels were comparably higher in the Krom- and Klapmuts Rivers, they were, however, within the range set by the Department of Water Affairs and Forestry (1996).

The concentration of Zn in water is usually low, typically around 0.01 mg/L. Due to the formation of sulphides, zinc has a very low utility under this form (Department of Water Affairs and Forestry, 1996). The higher concentrations of zinc become toxic and as a result, it will induce iron deficiency. Toxicity levels are induced at 0.3-10 mg/L, depending on the plant species (grown in nutrient solution).

The levels of iron were significantly (*P*=0.01) affected by an interaction between rivers and seasons. The Klapmuts River recorded Fe levels as high as 6.5 mg/L in summer, while the Klapmuts, Klippies and Krom Rivers showed the same levels (2 mg/L) of Fe during winter (Figure 2).





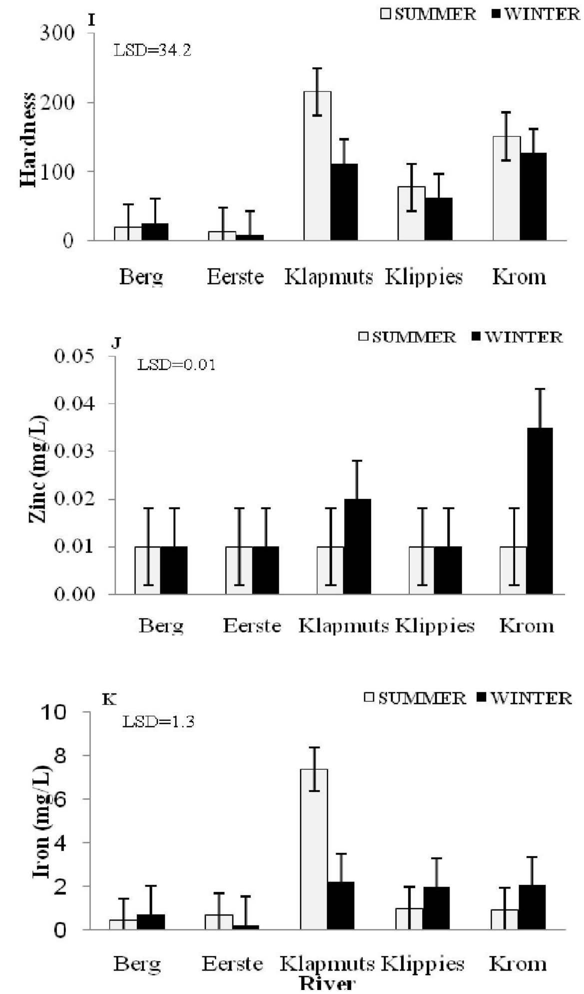


Figure 2. Minerals levels (**A**=sodium, **B**=ammonium, **C**=potassium, **D**=magnesium, **E**=chloride, **F**=sulphate, **G**= electrical conductivity, **H**=pH, **I**= hardness, **J**=zinc, **K**=iron) for different rivers during summer (9 December 2010, 6 January 2011, 3 February and 25 February) and winter (9 June, 1 July, 29 July and 26 August 2011).

The levels of Fe in all the rivers assessed were above the levels (0.001-0.5 mg/L) set by the Department of Water Affairs and Forestry (1996). Water that contains up to 1.0 mg/L of Fe can result in clogging of drip irrigation system (Combrink, 2005). Iron can be present in water in different forms (e.g. soluble, chelated, organic and precipitated) and may not be apparent to the eye (Combrink, 2005).

Deckers (2002) advised growers who make use of drip irrigation to remove iron in the feeding water and it should be replaced with the correct concentration of chelated iron. The Fe levels recorded on this study are not suitable for sensitive crops and precipitated iron can be removed by filtration. Reportedly, the oxidation process is extremely slow in acidic water and therefore this problem can be dealt with by increasing the pH of the water, allowing Fe and Mn to be oxidized and removed much quicker.

Boron levels were significantly influenced by rivers (P=0.01). The Krom- and Klapmuts Rivers had higher levels of B than Berg-, Eerste- and Klippies Rivers (Table 1). Recorded values of B for summer and winter were 0.029 mg/L in the Krom River and 0.023 mg/L in the Klapmuts River (Table 1).

Should concentrations of micronutrients in feeding water exceed prescribed levels for nutrient solutions, the water should be avoided or handled with care (Combrink, 2005). Usually, low concentrations of micronutrients are found in the feeding water of most production areas. In arid regions, feeding water may contain high levels of micronutrients. Guidelines have been compiled which prescribe specific micronutrient levels for different substrate-grown crops (Combrink, 2005). These prescribed micronutrient levels can be used as norms for determining maximum levels in feeding water (Combrink, 2005).

Microbial

The water samples were tested for bacterial and fungal density (Table 2). Only samples collected from Klapmuts and Eerste Rivers during winter in week 27, tested positive for *Phytophthora cinnamomi. Phytophthora citricola* and *P. cactorum* were found in the Klapmuts River in summer and in the Klippies River in summer and winter. None of the samples tested positive for Erwinia carotovora and E. chrysanthemi.

The samples from the Berg-, Klapmuts-, Krom- and Eerste Rivers collected during winter in weeks 23 and 35, tested positive for species of the genera *Pythium* and *Fusarium.* Similar organisms were detected in the Eerste River mainly during summer in week 9. The Krom River tested positive for Pythium spieces during summer and winter in weeks 9, 23 and 35.

The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx, efflux and/ or moist and aerobic conditions and air temperature. Farmers using some of the rivers (e.g. Berg River) in the Boland experience problems with high microbial count. There is an increased need for farmers to sterilize feeding water with From the data examined, it appears that the environmental quality of the Berg River is pristine during summer. The bigger rivers recorded low levels of micro-elements and this might have been affected by winter rainfall.

Table 2. Summary of analysis of biological samples collected in selected rivers (B, Berg; Kl, Klapmuts; Ki, Kliepies; Kr, Krom; Ee, Eerste) Eduring summer (9 December 2006, 6 January 2007, 3 February & 25 February) and winter (9 June, 1 July, 29 July & 26 August 2007) (PC, *Phytophthora cinnamomi*; PC_i, *Phytophthora citricola*; PC_a, *Phytophthora cactorum*; ER_w, *Erwinia carotovora*; ER_c, *Erwinia chrysanthemi*; Pyt, *Pythium* sp.; Fus, *Fusarium* sp.; RI, river; SE, season; WK, weeks;-, Negative; +, Positive; Su, summer; W_i, winter

RI	SE	WK	*MICROBIAL ANALYSIS*						
			PC	PC_i	PC_a	ER_w	ER_c	Pyt	Fus
B	Su	49	-	-	-	-	-	-	-
B	Su	1	-	-	-	-	-	-	-
B	Su	5	-	-	-	-	-	-	-
B	Su	9	-	-	-	-	-	-	-
B	W_i	23	-	-	-	-	-	+	+
B	W_i	27	-	-	-	-	-	-	-
B	W_i	31	-	-	-	-	-	-	-
B	W_i	35	-	-	-	-	-	+	+
Kl	Su	49	-	-	-	-	-	-	-
Kl	Su	1	-	-	-	-	-	-	-
Kl	Su	5	-	-	-	-	-	-	-
Kl	Su	9	-	+	-	-	-	-	-
Kl	W_i	23	-	-	-	-	-	+	+
Kl	W_i	27	+	-	-	-	-	-	-
Kl	W_i	31	-	-	-	-	-	-	-
Kl	W_i	35	-	-	-	-	-	+	+
Ki	Su	49	-	-	-	-	-	-	-
Ki	Su	1	-	-	-	-	-	-	-
Ki	Su	5	-	-	-	-	-	-	-
Ki	Su	9	-	+	-	-	-	-	-
Ki	W_i	23	-	-	+	-	-	-	-
Ki	W_i	27	-	-	-	-	-	-	-
Ki	W_i	31	-	-	-	-	-	-	-
Ki	W_i	35	-	-	-	-	-	-	-
Kr	Su	49	-	-	-	-	-	-	-
Kr	Su	1	-	-	-	-	-	-	-
Kr	Su	5	-	-	-	-	-	-	-
Kr	Su	9	-	-	-	-	-	+	-
Kr	W_i	23	-	-	-	-	-	+	+
Kr	W_i	27	-	-	-	-	-	-	-
Kr	W_i	31	-	-	-	-	-	-	-
Kr	W_i	35	-	-	-	-	-	+	+
Ee	Su	49	-	-	-	-	-	-	-
Ee	Su	1	-	-	-	-	-	-	-
Ee	Su	5	-	-	-	-	-	-	-
Ee	Su	9	-	-	-	-	-	+	+
Ee	W_i	23	-	-	-	-	-	+	+
Ee	W_i	27	+	-	-	-	-	-	-
Ee	W_i	31	-	-	-	-	-	-	-
Ee	W_i	35	-	-	-	-	-	+	+

In the Berg River, many sources of nitrate pollution seem to be present in the catchment area. The levels of iron in all the rivers assessed were far more than the levels set by the Department of Water Affairs and Forestry in all rivers assessed and these might be due to the pH levels and interaction between the rivers and seasons. Iron and manganese levels should be kept low as this may cause production problems by blocking irrigation drippers. An interaction between seasons and rivers showed significantly higher levels of certain elements (e.g. Na, Mg, Cl, EC, and Fe) in the Klapmuts River during summer.

However, it is clear that all the rivers studied are moderately affected by bacteria and algal activities during winter. The water samples tested for bacterial and fungal density showed Klapmuts and Eerste Rivers were positive for *Phytophthora cinnamomi* during winter. *Phytophthora citricola* and *P. cactorum* were detected in the Klapmuts and Klippies Rivers in summer. The Berg-, Klapmuts-, Krom- and Eerste Rivers tested positive for species of the genera *Pythium* and *Fusarium.* Similar organisms were detected in the Eerste River mainly during summer on the fourth sampling date, while Krom River only tested positive for *Pythium* during summer.

The total bacterial and algal density differed significantly between the seasons and was highest in winter. This might be due to high rain water influx and efflux and/or moist and aerobic conditions and air temperature. The presence of abnormally high concentrations of pathogens in some rivers may be the result of leaching from agricultural land, livestock watering or informal settlements in the catchment areas. There is an increased need for farmers to sterilize feeding water (chlorination) due to high microbial count.

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