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Possible Linkages Between Algae Toxins in Drinking Water and Related illnesses in Windhoek, Namibia

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Minor Field Study in Namibia, 2001

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Eventuella samband mellan algtoxiner i dricksvattnet och relaterade sjukdomar i Windhoek, Namibia

Abstract: The sub-tropical climate in Namibia, together with nutrients in the water, creates a good environment for phytoplankton, especially cyanobacteria. Many of these produce toxins that can be harmful to people and animals. One of the algal toxins is microcystin. This toxin is hepatotoxic, i.e. the primary toxic effect is on the liver. Cases of gastro-enteritis, nausea, vomiting, diarrhoea, muscle weakness and paralysis have been associated with the consumption of water containing high numbers of blue-green algae all over the world.
The aim of this study was to chart the possible linkages between algae toxins in drinking water and related illnesses in Windhoek. The results showed an annual seasonal variation in gastrointestinal problems and high levels of liver-enzymes. It also showed a relationship between the concentration of chlorophyll-a in the drinking water and the cases of people suffering from diarrhoea.

Keywords: Namibia, blue-green algae, algal toxins, microcystin, drinking water and health effects

Approved by/Godkänd av:

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Preface

For many years Sida has been giving scholarships to Swedish university students. The aim of these scholarships was to raise the level of knowledge of interest in Swedish international cooperation and to give students opportunity to learn about other countries, thus promoting international understanding and forming a basis for the recruitment of future international workers.

The students use the scholarship to carry out an in depth study as part of their university programme. Representatives of the institution concerned in your country and a supervisor representing a Swedish university would have agreed upon the layout and plan of the study. The scholarships were intended to cover a study-visit abroad of approximately two months.

One of the objectives of the visit was to give the institution in the host country information in the form of a report by the students on the findings of the study. Another objective was to promote contact between students in Sweden and in Namibia. It is hoped that the Minor Field Study Programme was of benefit to both countries.

Sida
Minor Field Study Programme

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Something to think about:

When I was a boy, the ponds and waterholes used to last the whole year through. Now they are dry and empty. When the rains came and filled the Oshanas, we used to take our baskets and go fishing. Now the fish baskets hang from the roof poles as ornaments. They are never used. We walked to school through long grass as high as our armpits, as far as you could see. Now the grass has all gone and there is nothing for the cattle to eat."

Witness to the changing water landscape in the Cuveali basin Oshakati, October 1999. (National water policy – Republic of Namibia, 2000)

Sage words from Dr. Lucas van Vuuren, one of the pioneers of the Windhoek reclamation system: *"Water should not be judged by its history, but by its quality"*.

Summary

During the past 20 years there has been an increased interest in harmful algae, but algal blooms is not a new phenomenon and have been known about for several hundreds of years.
The increased occurrence and attention during the last few decades are mostly due to the eutrophication, which has increased the numbers of algal blooms.
It is mainly the cynaobacteria that produces toxins and one of the most important cyanobacteria is *Microcystis* sp., which produces the toxin microcystin. If the toxins reach the drinking water, they can cause different kinds of health problems and even promote liver cancer.

This study was conducted in Windhoek, Namibia during two months and the aim was to investigate possible linkages between algae toxins in drinking water and related illnesses. Since Namibia is a very dry country, water is scarce and the need for safe quality of drinking water is very important. Different kind of data was collected from the Municipality of Windhoek, Ministry of Health and Social Services, Namwater, several pharmacies and Namibia Meteorological Service. The data were compared with each other to find possible relationships between them.

The results showed that there is an annual seasonal variation on cases of diarrhoea, chlorophyll-*a* in the drinking water, rainfall, levels of liver enzymes and sold anti-diarrhoeal medicine. Known results on microcystin in drinking water in Windhoek never exceed the TDI (tolerable daily intake) but despite this, our results show an important relationship between the cases of diarrhoea and chlorophyll-*a*. We suspect that another algae toxin, lipopolysacharid endotoxin (LPS), might be one of the reasons to this problem.

Contents

1. Introduction

This Minor Field Study on possible linkages between algae toxins in drinking water and related illnesses was carried out between the 22nd of March and 20th of May 2001.The study was conducted in Windhoek, Namibia (see fig 1.) in association with the Desert Research Foundation of Namibia.

Fig. 1 Namibia is situated on the West Coast of southern Africa (source Sidas' website)

The aim of our study was to investigate and chart the health aspects of algal toxins in drinking water in Windhoek. Our expectation was to be able to collect existing and available data, which would make it possible for us to draw any conclusions in our study. We wanted to compare the level of algal toxins recorded in drinking water with medical records obtained from the Windhoek hospitals with emphasis on known symptoms of algal poisoning. The driving force behind this study is the fact that Namibia is one of the driest countries in the world and water is scarce. The need for safe quality of drinking water and sustainable water treatment in countries with water-shortages is crucial.

2. Presentation of problem

Drinkable water is one of the basic requirements for any society. Water is needed for domestic, livestock and agricultural purposes. Where towns, cities and large settlements of people occur, a constant reliable source of water is essential. Water is often seen as the source of all life, but polluted water kills approximately 25 million people a year in developing countries. Nearly half of the world's major diseases are linked to water, many of them to water that is unclean due to water-borne and water-related diseases. Unhygienic practices and poor sanitation in rural areas often result in water being contaminated, while in the cities, industrial activities and waste disposal result in rivers and dams being polluted (du Toit and Squazzin, 1995).

Every country has its problems when it comes to supplying drinkable water for its people, but in Namibia the problems are often very difficult to overcome because of the critical shortage of rainfall which makes water very precious. Namibia is one of the driest countries in the world. Therefore, it is not difficult to understand why increasing demands for freshwater means that all Namibians need to work towards conserving this precious resource. This also demands high quality tap water so that it does not cause health problems.

The nutrients and the sub-tropical climate in Namibia create a good environment for phytoplankton, especially blue-green algae, to grow. The blue-green algae are well known for their production of toxins and these toxins have been proven to have a negative effect on the physical status of both animals and humans (Chorus and Bartram, 1999).

2.1.Objective

The objective of this study was to chart the possible linkages between algae toxins in drinking water and related illnesses in Windhoek. We wanted to investigate whether there is a relationship between chlorophyll a in drinking water and health problems. Chlorophyll indicates presence of algal material in the water. We hoped to come to some conclusions regarding whether algal toxin in drinking water is related to health problems or not.

Our counterparts in this project have been the Desert Research Foundation of Namibia, the Municipality of Windhoek, University of Namibia (UNAM) and the Department of Wateraffairs (DWA).

3.Background

In October 2000, some students from the University of Kristianstad did a study trip to Windhoek, Namibia. Water samples of the drinking water in Windhoek were taken and were analyzed afterwards in Sweden. The samples showed a content of algal toxins, i.e. microcystin, with a concentration of 0,12 μg/l. (analyses were made by Helené Annadotter, the University of Kristianstad, Nov. 2000). ELISA (Enzyme Linked Immuno Sorbent Assay) was used for the analyses. After experiments on growing pigs, concentration of microcystin in drinking water was proposed at 1,0 μg/l for short-term exposure (Falconer et al., 1994) and in another study, 0,1 μg/l for long-term exposure (Ueno et al. 1996). Tolerable Daily Intake (TDI) is 1,0 μg microcystin/l, according to World Health Organization (WHO) standards. The algal toxin microcystin is probably only partially removed by conventional water treatment as indicated by its presence in drinking water. (Burger et al, 1989).

A further reason for our study is the fact that an investigation made in 1989, showed that another type of toxin produced by blue-green algae, endotoxins, was found in the drinking water in Windhoek (Burger et al., 1989).

3.1 Sustainable development in Namibia

3.1.1 The water situation in Namibia

Namibia, situated on the southwest Atlantic coast of Africa, has a total area of 824 290 km^2. It is the driest country in sub-Saharan Africa and the country's water resources are extremely fragile. Almost 90% of Namibia’s area consists of desert, arid and sub-arid land. Namibia’s high temperatures, clear skies and low humidity intensify conditions for high evaporation rates. Over most of the country, potential evaporation is at least five times greater than the average rainfall.

Water is an economic resource of high value and as such requires wise decisions and good management to provide for present and future needs. Efficient and effective use of water today will assure a sustainable water supply well into the future. Efficient use means using less water while keeping up the same output (Heyns et al, 1998). Namibia’s only perennial rivers, or rivers that flow throughout the year, are those on its northern and southern borders (Heyns et al., 1998). These rivers originate in the neighboring countries (Angola, Botswana and South Africa) and there is already conflict over which country may or may not utilize the water and how much for a specific purpose. It is known that the water resources in Namibia will not be able to sustain economic development from the year 2015 onwards. The demand for water is increasing in Namibia, but it is not only the quantity that is threatened. Because of unwanted compounds and other matter, such as organic and inorganic material, finding their way into the water, the water quality is also threatened (Menge and König, 1999).

Water shortages are not necessarily caused by insufficient sources, but may be caused by poor water management. Every Namibian has the right to have reasonable access to clean water.
Agenda 21, the document that was a result of the United Nations conference on the environment, which the president of Namibia, Dr Sam Nujoma attended, pointed out the importance of placing an economic value on water. Water should not be provided free, but should be treated as a scarce and valuable resource (Heyns et al., 1998).

The annual rainfall of 284 mm ranges from less than 50 mm in the western region along the coastline to 700 mm/year in the northeastern Caprivi. Internally produced surface water resources are estimated at 4.1 km^3/year. Of the total rainfall, 83% evaporates shortly after precipitation, 17% is available as surface runoff, of which 1% recharges groundwater sources and 14% is lost through evapotranspiration. (www.fao.org/waicent/Faoinfo, Namibia–geography, population and water resources, 010329).

3.1.2 Water policy in Namibia

Water gives life to Namibia's people and is essential to the country's social, economic and environmental security. Because of that, a national water policy was created for efficient and sustainable water resources management. Namibian groundwater is heavily saline over large areas of the north where the majority of the population lives.

The perennial rivers to which Namibia has access lie on its northern and southern borders and are shared with neighbouring countries. This means that international agreements are required regarding their use and management. Beside the perennial rivers there are also some ephemeral rivers, which only flow for a short periods of time following heavy rainfall. In 1971, groundwater was brought under state control and the Government, which restricted use of groundwater from boreholes, established ”water control areas”. No one may sink, deepen or alter these without a permit. This was intended to replace the Water Act of 1956, which was a framework that distinguished between “public” and “private” water and this act benefited only some parts of society. But unfortunately there are various gaps and shortcomings in the framework from 1971. For example, water quality standards have not been established and there are no regulations to prevent adverse environmental impacts or health hazards.

Water-related activities have been positioned within specific Ministries such as the Ministry of Agriculture, Water and Rural Development, the Ministry of Health and Social Services etc. Most of the responsibilities for developing and managing the resource, for example, water quality and pollution control, have been located in the Department of Water Affairs. There is also a need to review the low penalties for polluting water, since polluters rarely reach the courts. (Ministry of Agriculture, Water and Rural Development, 2000)

3.1.3 Water in Windhoek

Three different water sources supply Windhoek with drinking water: water from state dams (Von Bach, Swakopport, Omatako), boreholes and the Goreangab Dam together with the reclamation plant. (Menge J., 1995)

The population is increasing by three percent a year and in the city of Windhoek the population is increasing with six to eight percent a year, which has an effect on the balance of resources (van der Merwe and Menge, 1996). The Municipality of Windhoek has to supply potable water at a reasonable cost to the citizens of Windhoek. Ground- and surface water sources in the surroundings of the city had been used up. The average annual rainfall in Windhoek is 366 mm while the average evaporation is 3 396 mm per year. Since the early sixties Windhoek has faced several problems concerning its water supply, such as limited water resources, continuing drought and the high cost involved in augmenting water. In 1968 the city was forced to implement a system of direct reclamation from domestic wastewater for reuse as potable water (Van der Merwe and Menge, 1996). During the period from 1968 to 1995 the average production from the reclamation plant was 4% of the total water supply. With an extension of the plant the reclaimed water would increase to 28 % of the total water supply, and this was planned to start at the end of 2000, but this has been delayed. The reclamation of water is based on the premise that reclamation can only succeed if all important elements can be controlled. A multi-barrier treatment sequence was required as safeguard against pathogens (Haarhoff and Van der Merwe, 1995).

The experience of Windhoek with reclamation of domestic wastewater to a potable standard over 27 years is important in view of water shortages in certain parts of the world. The risks of using reclaimed water, if any, are lowered through the blending of reclaimed water with water from other sources. Since reclamation was started in 1968 no known water-related outbreak of disease has been experienced (Van der Merwe et al.; 1995).

3.2 The cyanobacteria

Blue-green algae (cyanobacteria) have survived on earth over 3 ½ billion years and inhabit virtually all fresh water bodies. Eutrophication, which means artificial enrichment of nutrients in lakes, is a worldwide phenomenon (Marshall, 1991) and the problem is likely to get worse as human populations increase. One of the earliest and most obvious consequences of eutrophication is an increase in the population of cyanobacteria (blue-green algae). The bloom can result in very large stock of cyanobacteria that discolour the water or result in a surface scum. Blue-green algae, also known as cyanobacteria, are primitive autotrophy prokaryotes. (www.madsci.org, 010415) They have something in common with both plants and bacteria. Like algae, they are photosynthetic. Like other bacteria, they do not have internal organelles bound by membranes. Also like bacteria, they produce a variety of toxins. Toxicity is a function of exposure and dose, meaning that the more toxins one contacts, or the longer the contact, the sicker one will become. Just how sick depends on which specific toxin is contacted. Many species of cyanobacteria, which dominate eutrophic waters, produce toxins, which pose a potentially serious health hazard to consumers. There are lots of different kinds of cyanobacteria, but only a few of them dominate in algae blooms, for example; *Anabaena, Oscillatoria, Microcystis, Nodularia* (Annadotter et al, 2000).

Fig.2 *Microcystis aeruginosa(Culture...)*

The main toxins of freshwater cyanobacteria are hepatotoxic heptapeptides, microcystin (fig.4) that have been identified in *Microcystis*, *Anabaena*, *Planktothrix* (*Oscillatoria*) and *Nostoc*. Related pentapeptide nodularin (fig.4) occurs in the brackish water cyanobacterium *Nodularia*. These cyanobacterial liver toxins have been characterized as protein phosphatase 1 and 2A inhibitors and tumour promoters. Microcystins in drinking water are known to be harmful even at low concentrations (Lawton and Robertson, 1999).

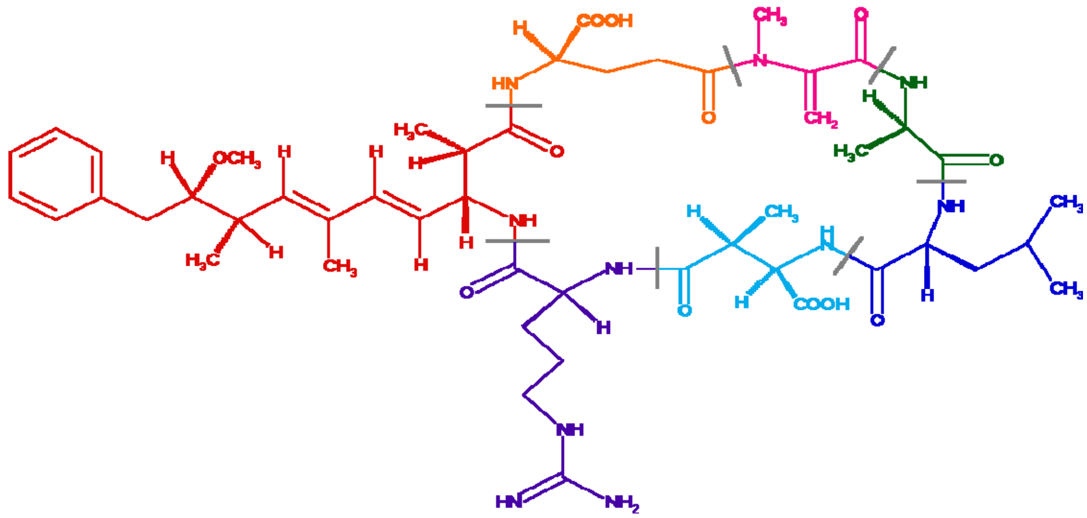

Fig.3 The structure of Microcystin (http://lurac.latrobe.edu.au/~botbml/mictox.html, 2001-04-06)

The growth of cyanobacteria and the formation of blooms are influenced by physical, chemical, and biological factors such as light intensity, temperature, water-turbulence, presence of inorganic nitrogen and phosphorus nutrients, and pH. The optimum temperature for toxin production in cyanobacteria is between 20° and 25° C, which suggests that cyanobacteria are most toxic during periods with warm weather and in areas with warm climates (WHO, 1998). An excess of nitrogen and phosphorus triggers the blooms and when the bacteria die, the toxin (present in about 1/4 the blooms) is released into the water. According to the US EPA, "essentially an ambient total phosphorus concentration of greater than about 0.01 mg/L and or a total nitrogen of about 0.15 mg/L is likely to predict blue-green algal bloom problems during the growing season (Pflugmacher et al., 1994).

Some cyanobacteria cause unpleasant tastes and odours in the water and result in increased costs of water purification (Marshall, 1991) The odor is often described as muddy, and the two organic compounds which have been implicated in causing these problems are geosmin and 2-methylisoborneol (2MIB). The compounds are produced by cyanobacteria.

Both compounds are cyclic tertiary alcohols, and are thus resistant to oxidation by conventional water treatment. Geosmin and MIB have extremely low threshold odour concentration, 10 and 29 ng/liter, respectively. These are average values, and many people are able to detect the compounds at lower concentration levels (Izaguirre et al, 1981). Guideline level for geosmin is 30 ng/l, but there is no guideline value for 2MIB, although Rand Water in South Africa (Scientific services, who cooperate with the City of Windhoek in analyzing water samples) also uses 30 ng/l as a guideline.

3.2.1 Microcystin

One of the most important cyanobacteria in eutrophic systems is *Microcystis* sp. and they produce polypeptides known as microcystins (Marshall, 1991) The microcystin toxins are produced and contained inside the *Microcystis* cells, and are released in to the water when the cells die and disintegrate (www.ohd.hr.state.or.us, 010430).

Toxin levels in a water body tend to be higher near shorelines and at the surface of the water where animal and human contact is most likely. There are many reports of livestock being killed after drinking water with heavy blooms of cyanobacteria.

Microcystin are hepatotoxins, i.e. the primary toxic effect is on the liver (Johansson and Olsson, 1999). Studies on animals have shown that long-term effects of microcystin can cause chronic lever damage and may promote the formation of liver tumours (www.ohd.hr.state.or.us, 010430). Cases of gastro-enteritis, nausea, vomiting, diarrhoea, muscle weakness and paralysis have been associated with the consumption of water containing high numbers of blue-green algae all over the world (Marshall, 1991).

WHO has suggested TDI of 1,0 μg microcystin/L. Some would argue this concentration is too high. Even smaller doses have been shown to cause health problems such as primary liver cancer, and a study performed in China recommended that the limit should be a hundred times less, that is 0,01 μg microcystin/L (Ueno et al, 1996). Studies have shown that *Microcystis* is not removed by conventional water treatment processes and can only fully be removed by a combination of active carbon and ozone. Exposure of *Microcystis* cells to chlorine before filtration can cause the cells to die and release their toxins (www.ohd.hr.state.or.us, 010430).

Toxins from cyanobacteria are among the most lethal substances known. There is no known antidote for blue-green algal toxins once a lethal dose has been ingested. The only way to tell if the bloom water is toxic is by injecting it into a lab animal. The conventional treatment and disinfections, afforded most public drinking water supplies, are not effective in removing or deactivating blue-green algae toxins. Boiling is similarly ineffective. Water that is free of blue-green algae following a bloom may not be free of the toxin. The time to control a toxic algae bloom is before the bloom develops (www.madsci.org, 010418).

Algal toxins form a threat to human health and compromise water-related activities like the drinking water industry, fishery, aquaculture and tourism. Reliable and easy-to-perform analytical methods enable identification of exposure routes to man and assessment of toxin levels. This makes human health risk evaluation and minimization feasible.

3.2.2 Health effects

In February 1996 the world of water science received a wake-up call when 65 dialysis patients in Caruaru, Brazil died after exposure to a liver toxin. The source of the toxin was traced to the use of treated water contaminated with the blue-green algae, *Microcystis aeruginosa.* The clinic allowed toxins into the patients' dialysis process by using poorly filtered reservoir water treated with chlorine. The World Health Organization additionally reports that, "Elsewhere in South America, in 1988, more than 80 deaths and 2,000 illnesses due to severe gastroenteritis have also been directly linked with toxic cyanobacteria in a newly constructed dam." In China, a high incidence of primary liver cancer has been linked to the presence of cyanobacterial toxins in drinking water (Chorus and Bartram, 1999).

Since the 1996 incident, a survey of 1,000 water samples from reservoirs in the US and Canada found that 80% contained measurable amounts of algal toxins and 20% exceeded the World Health Organization standard for microcystin. Freshwater blue-green algae produce both nerve toxins and liver toxins that account for some of an estimated 900,000 illnesses and 900 deaths every year due to contaminated water. According to Dr. Wayne Carmichael of Wright State University, "A large amount of liver disease, that is attributed to alcoholism, may actually be due to the water."

Recorded cases of blue-green algae poisoning have mostly been the effects of blooms in combination with inadequate water treatment. Treatment with active carbon removes only the cell itself, not the poison dissolved in water. One example of this is the yearly problem in Harare, Zimbabwe. (Annadotter, 1995).

Children living in one part of the city and got drinking water from Lake Chivero, developed gastro-enteritis each year at the same time, as there was a blooms of blue-green algae in the reservoir. In different parts of the city, supplied by other water reservoirs without the blooms, there were no problems with the drinking water at that same time of year. These problems were thus of an acute nature, and were detected as they occured (Marshall, 1991). Children are more vulnerable for several reasons, because they drink more water per unit body weight.

Even in Sweden there have been some problems with acute toxicity from blooms of blue-green algae. In Örtofta, Sweden, water contaminated with microcystin accidentally came into contact with drinking water. This resulted in numerous recorded problems from those who came into contact with the water (Annadotter et al., 2001).

An epidemiological survey of the causes of a high incidence of primary liver cancer in Haimen city, China, found a close correlation between the incidence of liver cancer and the drinking of pond and ditch water containing microcystin (Ueno et al., 1996). People who already have major illness, for example, people with hepatitis, alcoholism, and toxic injury form other sources, or kidney damage, will be more susceptible to toxic injury from blue green algal toxins than healthy individuals (Falconer, 1998).

The levels of patients' liver-enzymes, at the hospital in Armidale, Australia, were investigated by Falconer et al. (1983). They did that during a period of heavy algal blooms with *Microcystis aeruginosa* in the city's drinking water reservoir. An earlier investigation into this subject had been made on mice and they were given non-lethal doses of microcystin during several weeks, and this resulted in damage to the liver cells. Falconer et al. (1983) came to the conclusion that low doses of microcystin could cause liver damages even in humans. Liver damage could be discovered by determination of the different liver enzymes, ASAT, ALAT, and GGT. Another indicator is high level of the pigment bilirubin, which is formed when haemoglobin is destroyed. Falconer et al. assumed that the Microcystis cell had been destroyed and that the algal toxin microcystin had probably been dissolved in the drinking water. They based this conclusion on the assumption that *Microcystis aeruginosa* is not removed by conventional water treatment, and since either flocculation or filtration eliminates dissolved microcystin, the algae toxins would be present in the drinking water. By treating raw water with chlorine, a cell lysis of the toxic cyanobacteria occurs, with the consequence that the toxins are dissolved in the water without being eliminated (Annadotter et al.2000). When they examined the liver enzymes from patients in Armidale, and compared it with those of patients from the neighbouring countryside who drank water from another source, they saw a significant higher amount of the liver enzyme GGT in the Armidale patients. These high levels of GGT were not found in the patients before and after the algal blooms. The conclusion was that the toxic algae had caused the increased levels of GGT (Annadotter et al.,2000).

The reference ranges used in Namibia for these substances are:

- ASAT: 10 – 42 units/l
- ALAT: 10 – 62 units/l
- GGT: 7 – 64 units/l
- Bilirubin: 0 – 21 units/l

4.Methods

Our method was to collect from different departments in Windhoek recorded data that could help us to draw some conclusions about the drinking water quality regarding the possible content of algal toxins.

4.1 Data collecting

With help from the DRFN and Jürgen Menge and Erich König at the Municipality of Windhoek we were able to get started with our project. They provided us with:

- Names of people to contact
- Analytical data from several occasions on algal toxins in the drinking water in Windhoek.
- Data on the water-treatment process, the drinking water reservoirs and the reclamation plant in Windhoek.

Nicolaas de Plessis at Namwater provided us with:

- Information on different nutrients in the water, like nitrate and sulphate, and also the content of chlorophyll. Data was both on the water reservoirs and the final water (drinking water
- The content of different kind of bacteria in the water.

Ben Hochobeb, professor at the University of Namibia:

- Helped us to establish further connections with people of interest, especially the important contact with The Ministry of Health and Social Services. He also helped us to get permission to use data gathered by the Ministry of Health regarding the number of reported cases of different kinds of illnesses of the period between 1995-2000. These illnesses were divided into two categories, children under the age of five years old and everyone over the age of five.
- He provided us with a letter of recommendation to Mrs. Angula, which was necessary to collect data on the levels of liver-enzymes, for the year 2000, from the Namibia Institute of Pathology at the State Hospital.

The pharmacist Carol Molloy, from Autosterile Namibia (supplier of medical and pharmaceutical products to hospitals):

- Gave us the idea to draw up a questionnaire to send out to all the pharmacies in Windhoek (more than 30 pharmacies). This form was for the pharmacies to fill in with regard to different kinds of medicine sold for illnesses that could be related to algal toxin poisoning over a period of one month. We were also interested in the patients' sex, age and which part of Windhoek they were from. We wanted to compare that to collected levels of algal toxins during the same period.
- Recommended we contact Maria Costa-Tré at the pharmacy Essential health, who provided us with data on medicine sold for the period May 2000 to May 2001.
- Recommended us to contact the medical suppliers Geka Pharm and Nampharm, where we got access to medicine that they supplied the pharmacies with, over a period of one year back in time and half a year back in time, respectively.

Namibia Meteorological Service:

- Rain statistics for Windhoek

4.2 A review of collected data

All the collected data were compared with each other to see if there was any correlation between them. We wanted to investigate if there were any possible linkages between algae toxins in drinking water and related illnesses. Since only a few analyses on algal toxins have been done in Windhoek, we had to look at other possible indicators showing a possible presence of algal toxins in the drinking water.

We decided to put some limitations regarding the collected data on the liver-enzymes. We have used only the data on liver-enzymes for children under five years old. The reason for this is due to the fact that high levels of the ASAT can also indicate myocardial infarction and damage to the skeleton. High levels of ALAT can be an indicator of long-term alcohol consumption. Children probably do not suffer from these problems during their first five years of life. If the children have high levels of the liver-enzymes, this is probably due to some kind of toxic exposure through either food or liquid. The temporal relationships were analysed descriptively by interpreting graphs.

5. Results

5.1 Analytical results on water

The tables below show both quantitative and qualitative data on cyanobacteria and the concentrations of geosmin and 2-methylisoborneol (2-MIB) in raw water and in final water (drinking water), (table 1-6). The water samples were taken on occasions when many consumers complained of bad smell and taste. These parameters were not analysed on a regular basis. Rand Water in South Africa did all analyses by request of the Municipality of Windhoek.

Table 1. Analytical results on water samples' concentration of microcystin from the Von Bach dam on the 23rd of September 1999.

Raw water	*Microcystis aeruginosa* (cells/ml)
Von Bach 5 metres	5742
Von Bach 11 metres	3659

Table 2. Analytical results on water samples' concentration of geosmin and 2-MIB from the Von Bach dam on the 27th of September 1999.

Raw water	Geosmin ng/l	2-MIB ng/l
Von Bach 5 metres	51	<26
Von Bach 11 metres	39	< 26

Table 3. Analytical results on water samples' concentration of microcystin from the Avis dam on the 6th of July 2000.

Avis dam	Concentration of microcystin (μg/l)
Sample 1	0,83
Sample 2	0,30

Table 4. Analytical results on water samples' concentration of geosmin , 2-MIB and cyanobacteria from the several different sampling points and final water on the 8th of March 2001.

Sample point	Geosmin (ng/l)	2-MIB (ng/l)	Cyanobacteria	(Cells/ml)
Von Bach 5 m	34	130	Microcystis sp Oscillatoria sp Anabaena sp	331 2067 1365
Von Bach 10 m	104	90	Anabaena sp	2033
Von Bach 15 m	62	60	Anabaena sp Microcystis sp Merismopedia sp	413 345 1654
Von Bach filter outlet	66	94		
Goreagab Final-WG7	68	44	Microcystis	3653
Scientific Services tap water	83	101	Not done	
Jordan st., tap water	105	118	Not done	

Table 5. Analytical results on water samples' concentration of microcystin and abundance of cyanobacterial cells from the Goreangab dam on the 14th of March 2001.

Goreangab dam	Total concentration of microcystin (ug/l)	Cyanobacteria	(Cells/ml)
Raw water	0,44	Microcystis sp Merismopedia sp	4365 2022
After sand filter)	0,43	Microcystis sp Merismopedia sp	4383 8601
Tap water from lab	<0,16	Microcystis sp	34

Table 6. Analytical results on water samples' concentration of geosmin and 2-MIB from the Goreangab dam, 15th of March 2001.

Goreangab dam	Raw water	After sand filtration	Tap water from lab	Tap water from Windhoek
Geosmin (ng/l)	<14	14	<14	<14
2-MIB (ng/l)	17	21	33	12

5.2 Relationship between different parameters

The diagrams below (fig.5-21) show different relationships between different parameters, such as chlorophyll-*a*, cases of diarrhoea, rainfall, concentration of nitrate, sold medicine for gastro-intestinal disorders and levels of liver-enzymes on a yearly basis.

1995

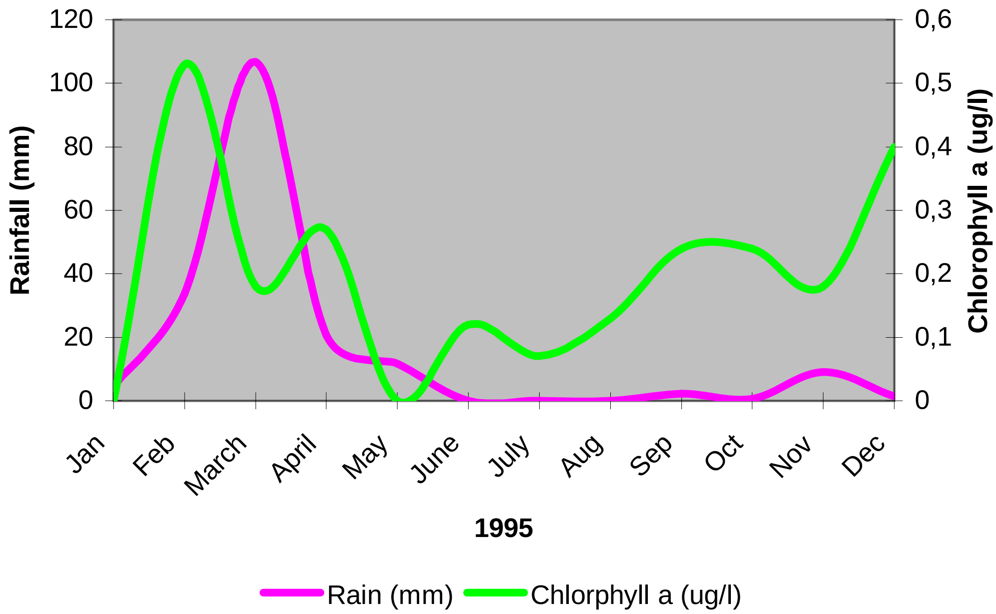

Fig. 4. The relationship between rainfall and concentration of chlorophyll-*a* in drinking water in Windhoek, 1995.

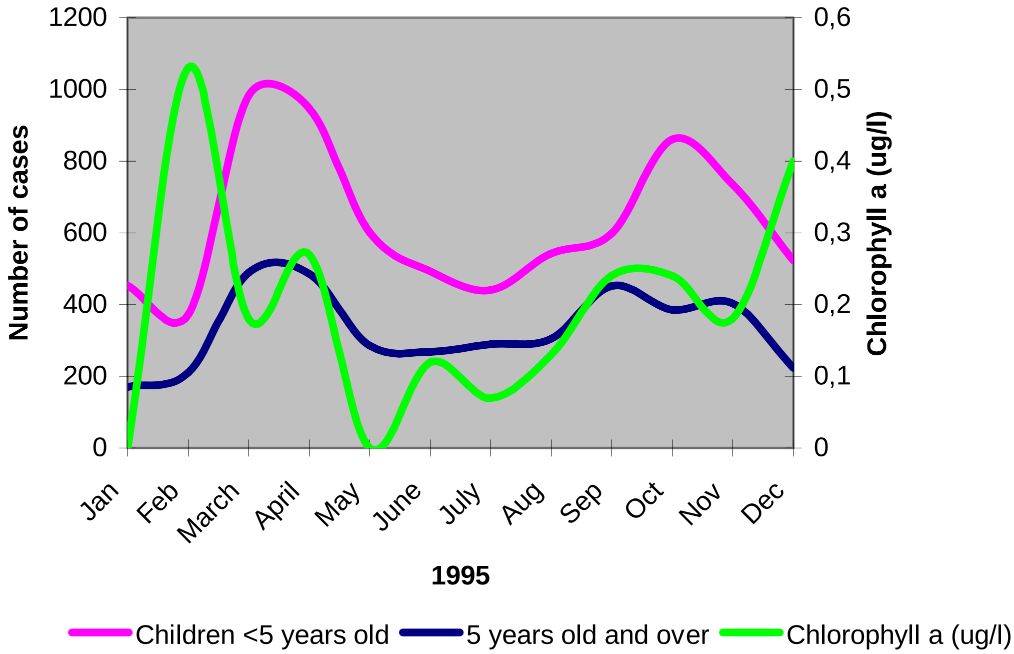

Fig. 5. The relationship between cases of diarrhoea and the concentration of chlorophyll a in drinking water in Windhoek, 1995.

In 1995, the peak of chlorophyll-*a* in the beginning of the year is explained by the fact that the rainy season always begins at the end of the year, transporting nutrients into the water. At the end of the rainy season the temperature increase which promotes algal blooms. Peaks of diarrhoea cases, with some delay, follow the peaks of chlorophyll-*a* (fig. 4 and 5). (No data available on concentration of nitrate in the drinking water for 1995).

1996

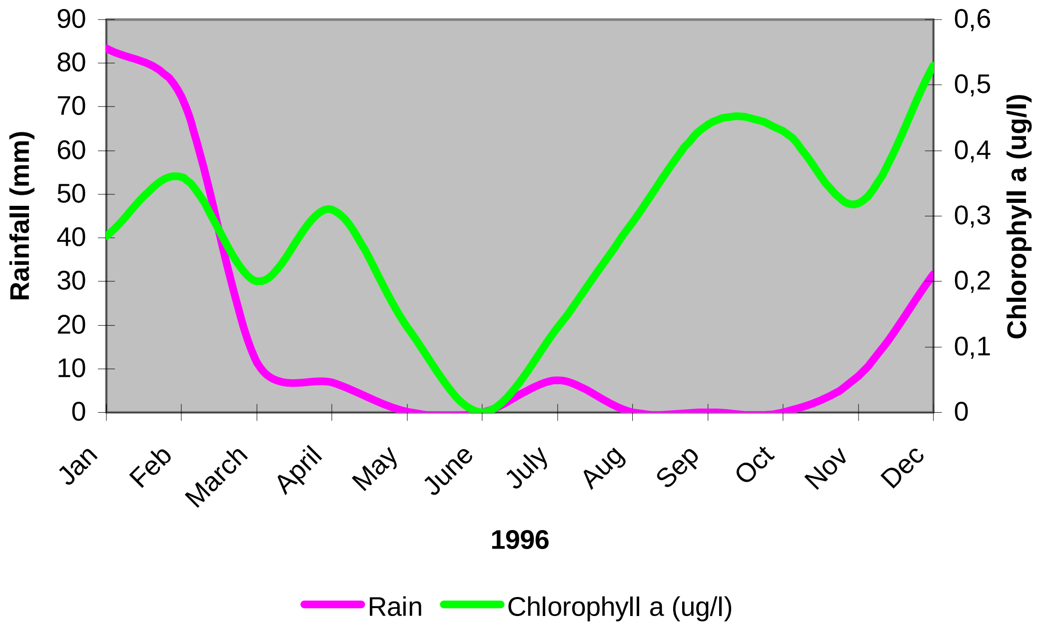

Fig. 6 The relationship between rainfall and concentration of chlorophyll a in drinking water in Windhoek, 1996.

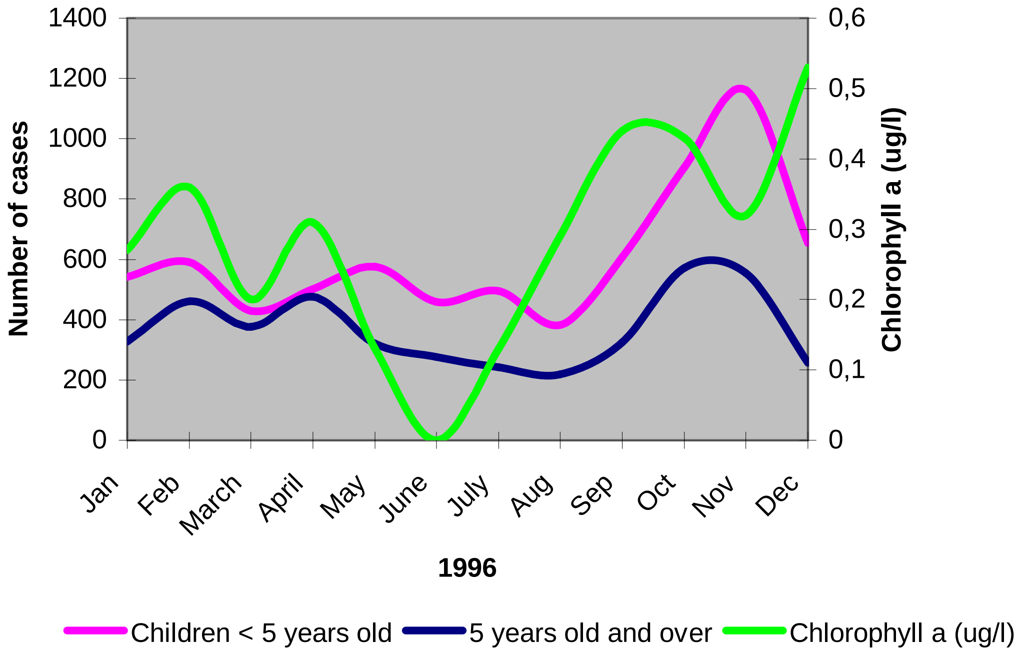

Fig. 7. The relationship between cases of diarrhoea and the concentration of chlorophyll a in drinking water in Windhoek, 1996.

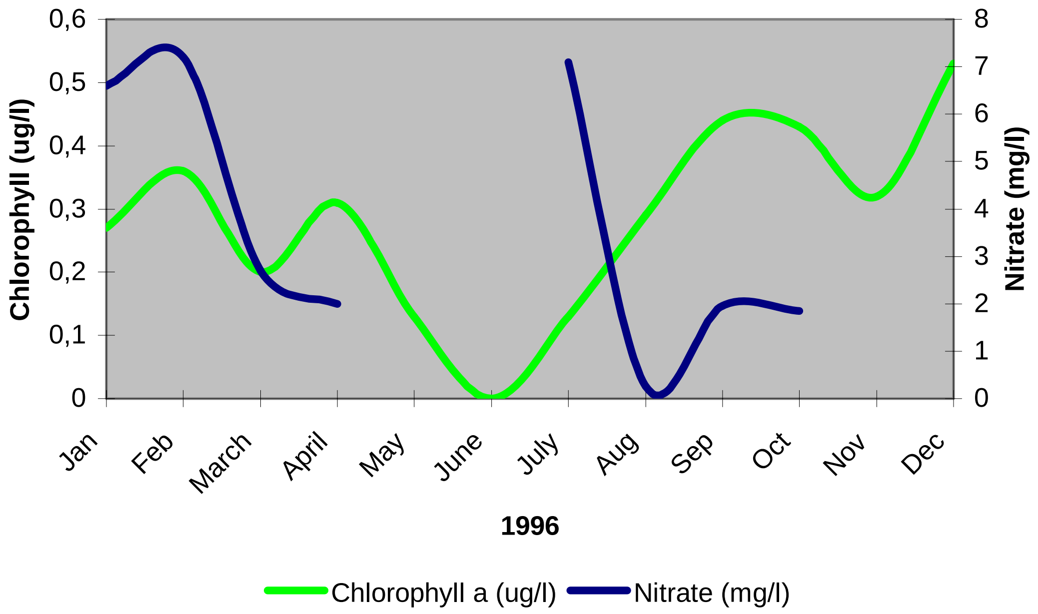

Fig. 8. The relationship between chlorophyll-*a* and nitrate in drinking water in Windhoek, 1996. (No data available for nitrate in May, June, July, Nov and Dec.).

In 1996,there is an obvious relationship between the peaks of chlorophyll a and rain and also the cases of diarrhoea. In June, there is hardly any chlorophyll a in the drinking water, but only a little amount of rain is needed for the levels of chlorophyll a to increase again. This rain, together with the high temperature during the following months, is the probable cause of the high peak of chlorophyll-*a*. There is a delay between the peaks of chlorophyll-*a* and the cases of diarrhoea. The highest peaks of both chlorophyll-*a* and cases of diarrhoea are observed in the last three months of the year. We have do observed that the levels of nitrate decrease with increasing levels of chlorophyll-*a* (fig.6-8).

1997

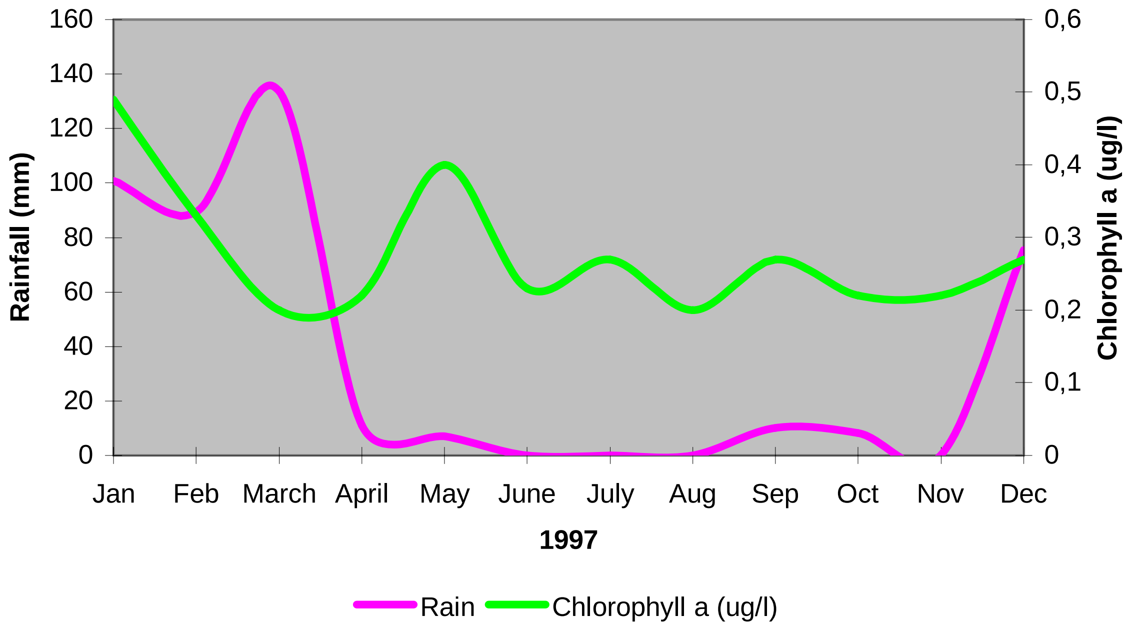

Fig. 9. The relationship between rainfall and concentration of chlorophyll-*a* in drinking water in Windhoek, 1997.

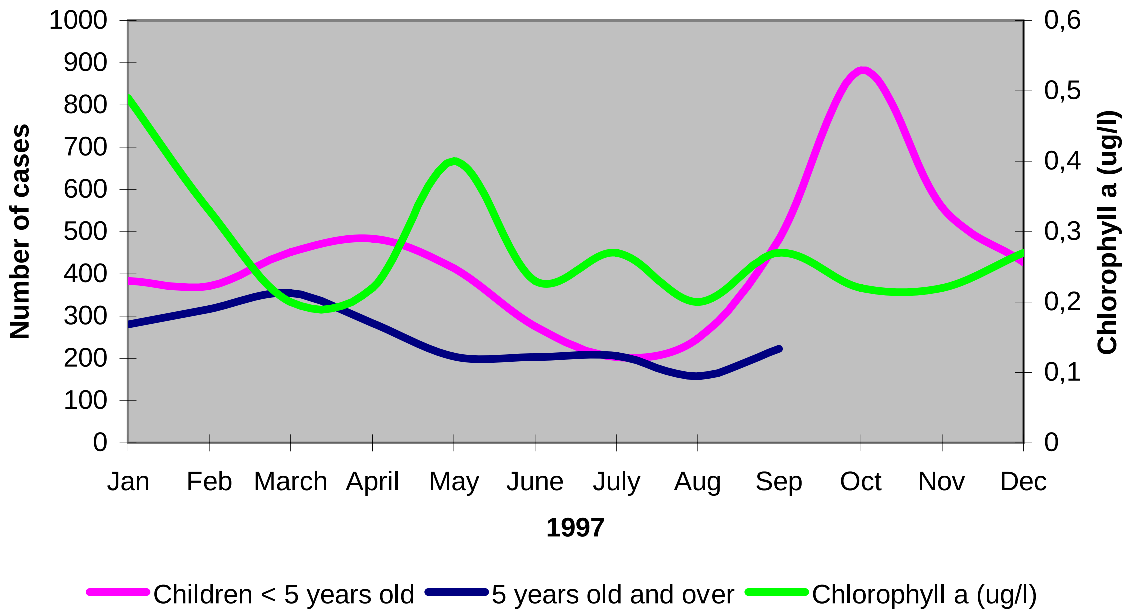

Fig. 10. The relationship between cases of diarrhoea and chlorophyll-*a* in drinking water in Windhoek, 1997. (No data available for cases of diarrhoea, 5 years old and over, Sep-Dec)

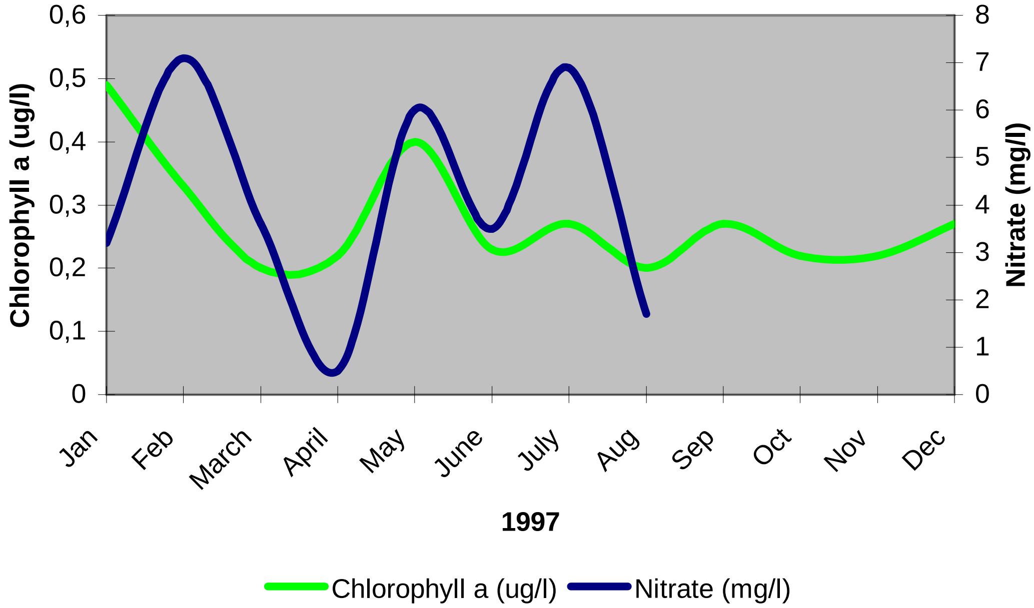

Fig. 11. The relationship between chlorophyll-*a* and nitrate in drinking water in Windhoek, 1997. (no data available for nitrate Sep-Dec).

In 1997, the peak of chlorophyll-*a* at the beginning of the year is explained by the fact that the rainy season always begins at the end of the year. It is also obvious that only small amounts of rain are needed for the levels of chlorophyll-*a* to increase. At the end of the rainy season the temperature increases which promotes algal bloom. Peaks of diarrhoea cases, with some delay, follow the peaks of chlorophyll-a. The highest peak of cases of diarrhoea is observed at the end of the year. An observation is that there is an indication that nitrate is consumed by something in the water (Fig.9-11).

1998

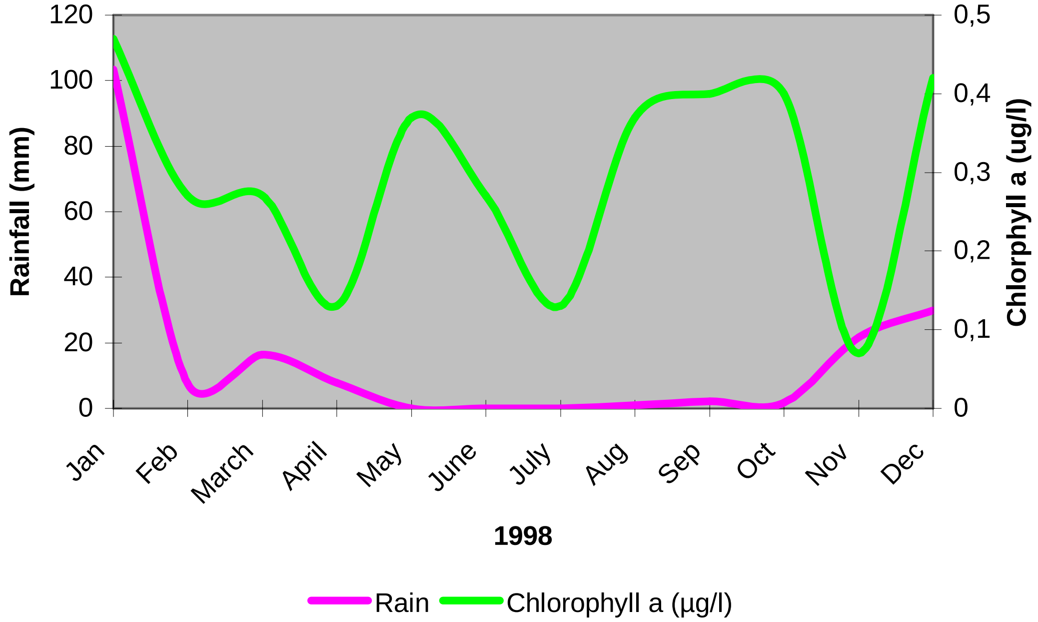

Fig. 12. The relationship between rainfall and chlorophyll-*a* in drinking water in Windhoek, 1998.

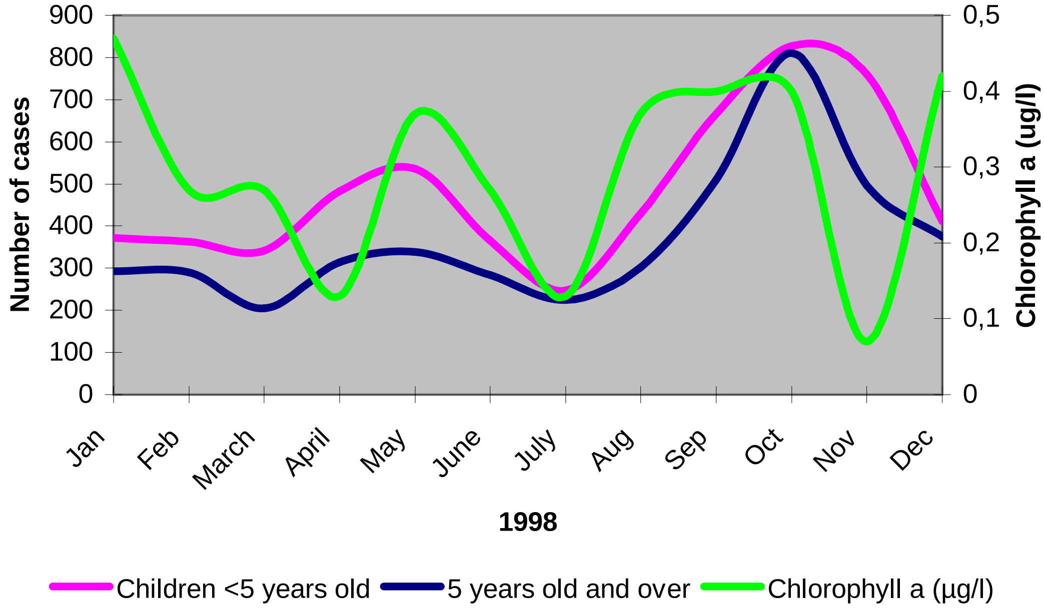

Fig. 13. The relationship between cases of diarrhoea and chlorophyll-*a* in drinking water in Windhoek, 1998.

In 1998, there is an obvious relationship between the peaks of chlorophyll-*a* and rain and also the cases of diarrhoea. In July, it starts raining a little bit and this small amount of rain is needed for the levels of chlorophyll-*a* to increase rapidly again. This rain, together with the high temperature during the following months gives the high peak of chlorophyll-*a*. The highest peaks of both chlorophyll-a and cases of diarrhoea are observed in the last three months of the year. There is a delay between the peaks of chlorophyll-*a* and the cases of diarrhoea. (No data is available on the concentration of nitrate in the drinking water) (fig.12 and 13).

1999

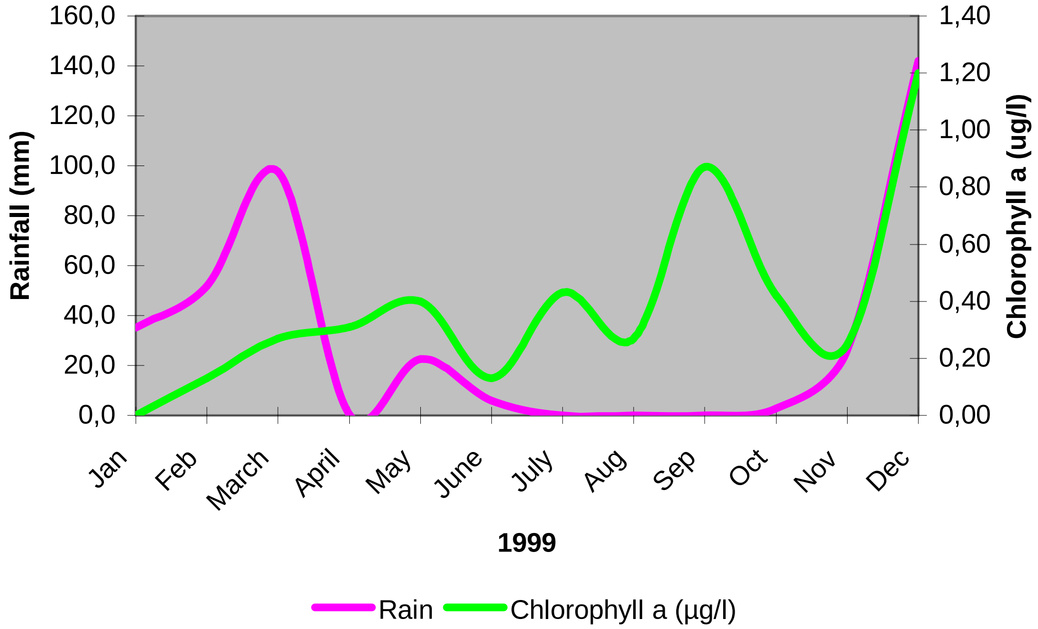

Fig. 14. The relationship between rainfall and chlorophyll-*a* in drinking water in Windhoek, 1999.

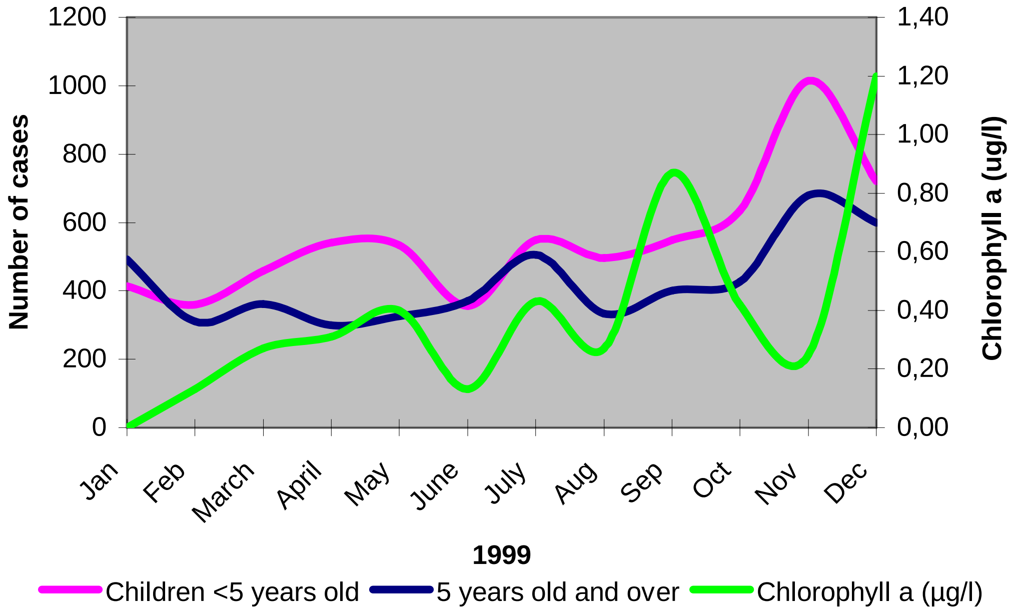

Fig. 15. The relationship between cases of diarrhoea and chlorophyll-*a* in drinking water in Windhoek, 1999.

In 1999, the relationship between rainfall and chlorophyll-*a* shows again that an only very small amount of rain is needed for the levels of chlorophyll-a to increase rapidly. There is once again a relationship between the peaks of chlorophyll-a and the cases of diarrhoea, with some delay.

2000

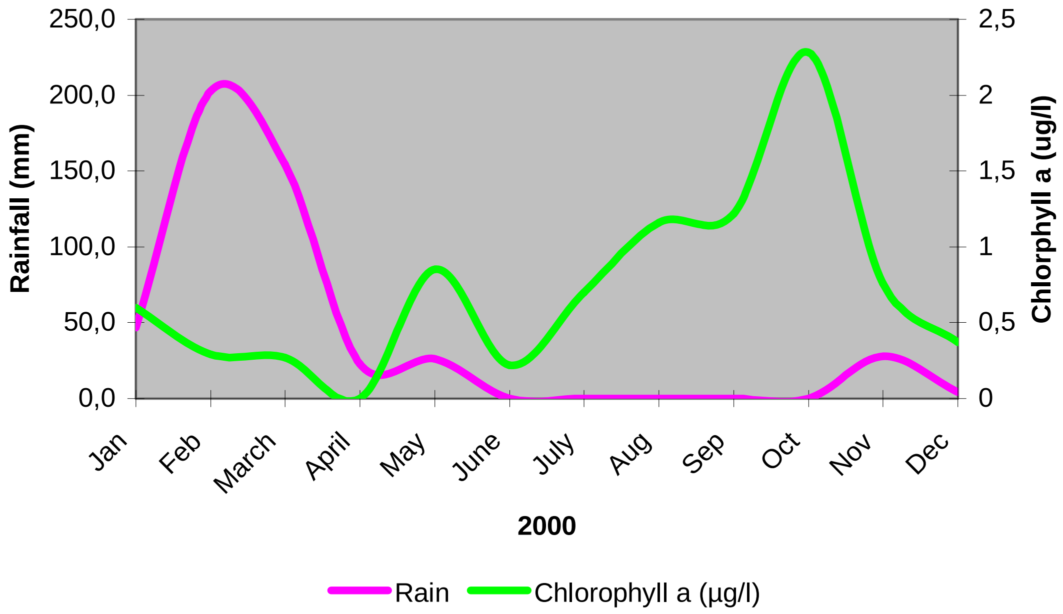

Fig. 16. The relationship between rainfall and chlorophyll-*a* in drinking water in Windhoek, 2000.

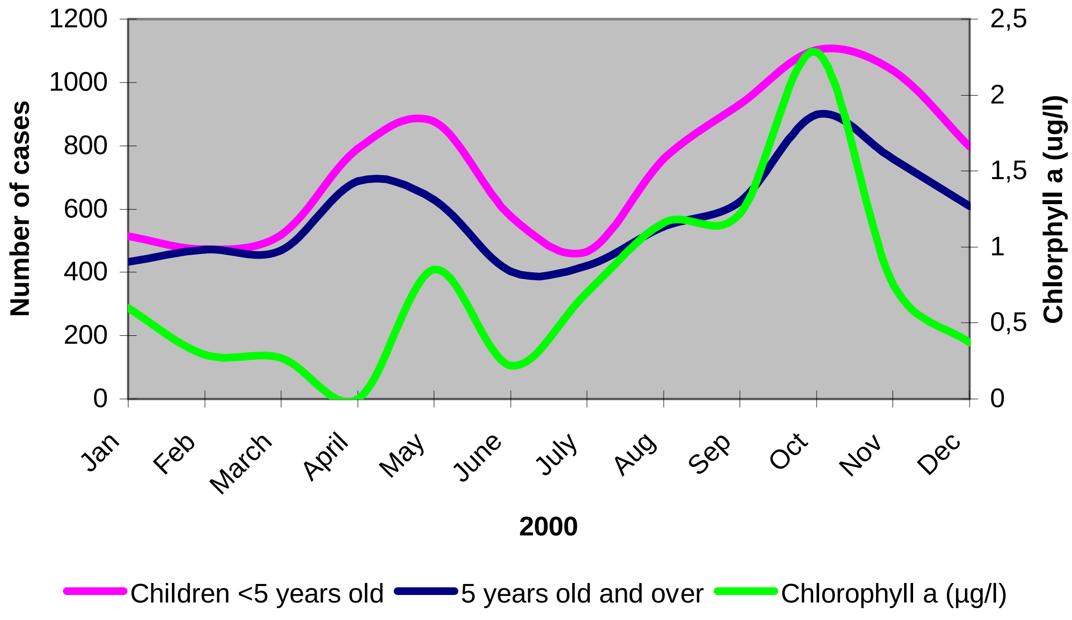

Fig. 17. The relationship between cases of diarrhoea and the chlorophyll-*a* in drinking water in Windhoek, 2000.

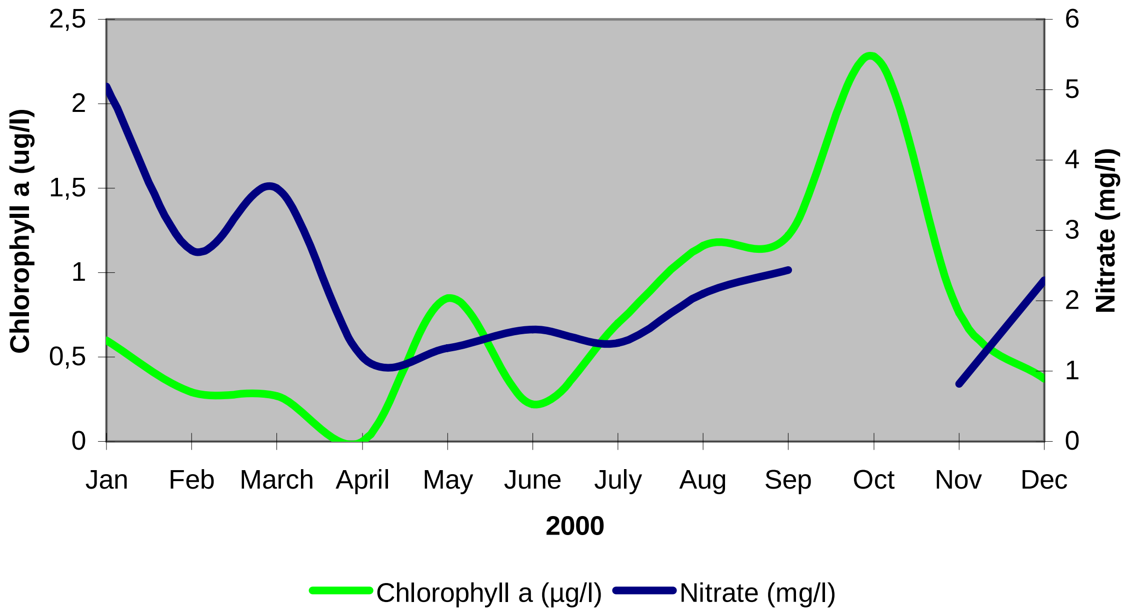

Fig. 18. The relationship between chlorophyll-*a* and nitrate in drinking water in Windhoek, 2000. (no data available for nitrate in Oct and Nov.)

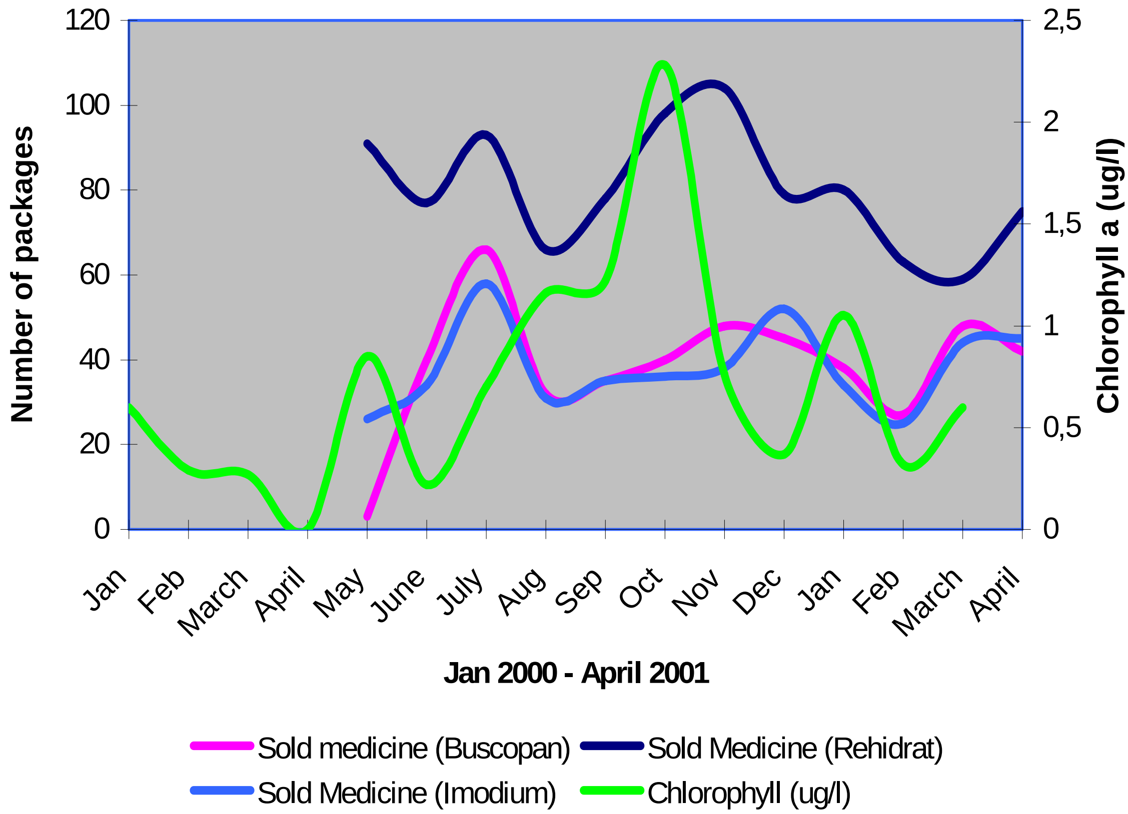

Fig. 19. The relationship between sold anti-diarrhoea medicine, dehydration medicine and anti-spasmodic medicine and the concentration of chlorophyll-*a* in drinking water, January 2000 – April 2001.

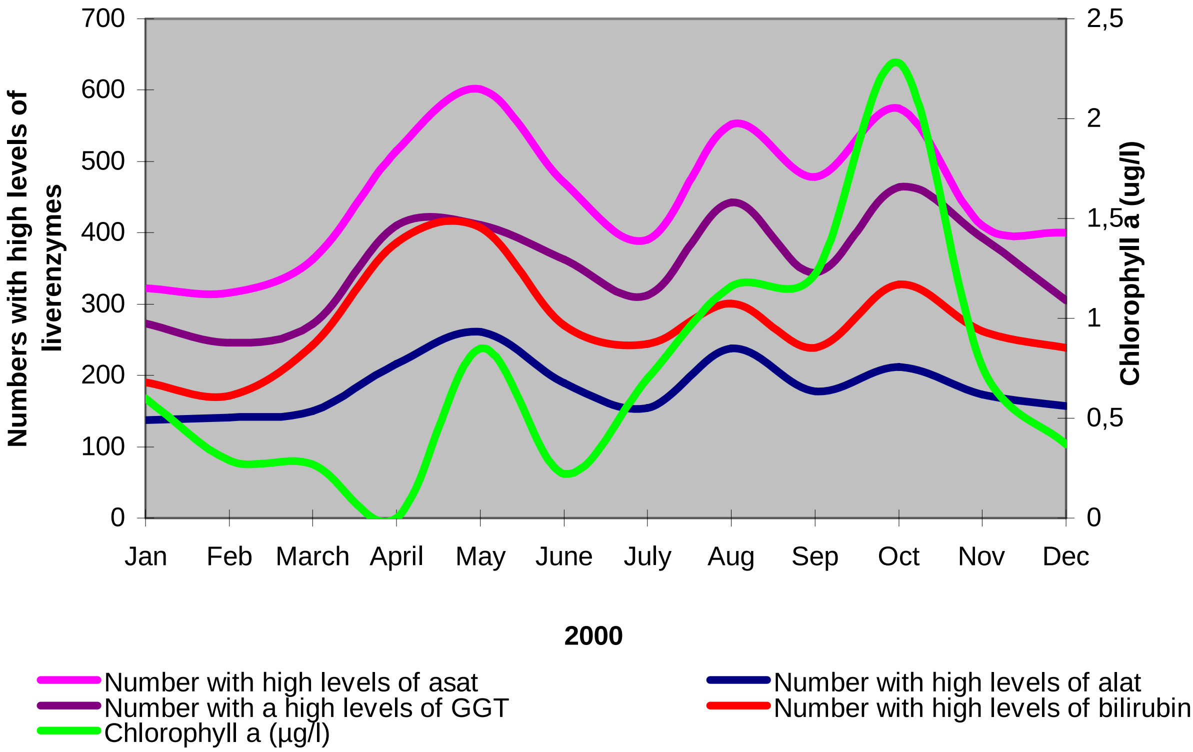

Fig 20. The relationship between numbers of patients (children <5 years old) with high levels of the liverenzymes asat, alat, GGT and bilirubin and the concentration of chlorophyll-*a* in drinking water, 2000.

In 2000, the levels of chlorophyll-*a* were very high, but the pattern is the same as the years before. These high levels may be the reason that there is no delay between the peaks of chlorophyll-*a* and the peaks of diarrhoea. They almost coincide with each other at the end of the year. The levels of nitrate decrease slowly at the beginning of the year. The most interesting observation was in September and November, when the levels of chlorophyll-*a* reached their highest peak. There is also a correlation between the changes of levels of chlorophyll-a and the number of sold medicines (Buscopan, Imodium and Rehidrat). The trend is the same as with the cases of diarrhoea, but with a delay. Another important relationship was observed between the numbers of patients, under the age of five, with high levels of liver-enzymes (alat, asat, GGT and bilirubin) and the levels of chlorophyll-a in the drinking water. These peaks coincide throughout the whole year (fig.14-20).

5.3 Bacteria analyses of the drinking water

All data, collected and available, since 1995, showed no content of different pathogenic bacteria, with a very few exceptions. This was probably due to leakage into the drinking water distribution system, of some kind of pollution. The following parameters have been analysed regularly (1-2 times a week, 1995-2001): Total coliforms, faecal coliforms, somatic colihage, male-specific phage, bacteroides fragilis phage, giardia, crypto sporidium, faecal streptococci, clostridium spores and clostridium viable cells.

5.4 Complaints on the water quality

The table below shows complaints from the citizens of Windhoek regarding the drinking water quality. The complaints were received from the Municipality of Windhoek and they provided them further to us.

Tab 7. Some complaints from citizens to Municipality, 99-01

Date	Complaint
990101	Turbid particles in the drinking water
990121	Complaints about the quality of the water
990215	Oily, muddy smell and taste.9 people in house, all with stomach problems
990218	Water is very bad, sick for two days, diarrhoea, very strong smell and taste in drinking water
990315	Water taste like paraffin
990326	Water taste like petrol/oil
990823	Taste problems
990902*	Fish are dying in Van Ryn dam
000512	Undrinkable water
000228	Family with diarrhoea
010109	Water smells and taste like petrol
010124	Whole family have severe stomach problems
010208	Soil taste, though drinking water is clear
010228	Odour problems in drinking water, water taste muddy
010302	Awful smell and taste
010305*	Taste and odour problems
010306	Taste and odour, family sick with stomach problems
010307	Taste and odour

*Due to the complaints in September 1999 and March 2001, analyses on relevant parameters were done. The results showed that the distributed water conforming to guidelines from WHO, was bacteriologically safe and fit to drink.

6. Discussion

Our study showed annual seasonal variations in gastrointestinal problems and liver enzymes. In the year 2000, three peaks on liver enzymes coincided with peaks on chlorophyll-*a*. In the same year, incidences of diarrhoea also correlated well with occurrence of chlorophyll-*a*. In the other years, the peaks of diarrhoea were usually observed some weeks after the chlorophyll a peaks. The discrepancy can be explained by the fact that chlorophyll-*a* in drinking water was much higher in the year 2000 than in the other years.

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Cyanobacterial blooms have evidently developed in the raw water. For example, in September 1999, the maximum concentration of chlorophyll-*a* coincided with taste problems. On that occasion, 3.6 millions cells/l of *Microcystis* were detected in the final water. Thus, the water treatment in Windhoek did not efficiently remove the cyanobacterial cells from the raw water. The fact that chlorophyll-*a* has been detected weekly in Windhoek's final water indicates that a considerable amount of algae were present all the time in the drinking water. The numbers of reported cases of diarrhoea in Windhoek were not likely caused by bacteria. The records from the Municipality show that the levels of bacteria in drinking water after purification were non-detectable.

Unfortunately, analysis of microcystin was not done on a regular basis and has been done on only few occasions, after complaints from drinking water consumers. The level of microcystin in raw and final water has never exceeded the WHO's TDI (tolerable daily intake) level. However our study shows that there is a relationship between cases of diarrhoea and chlorophyll-*a* in drinking water on seasonal basis. A likely increased level of lipopolysacharid endotoxins, LPS, may instead explain the seasonal variation in liver enzymes among children with liver problems. These substances, which are produced by cyanobacteria and gram-negative bacteria, were present in the final water in Windhoek when studied by Burger et al. (1989). The phytoplankton content in the distributed water will probably promote a bacterial growth in the tap water. The endotoxins are heat-stable and will not be eliminated by boiling. A flu-like syndrome with fever, muscle pains, chest tightness and respiratory-tract symptoms has been observed two to five hours after taking a shower. During an outbreak of algal blooms of cyanobacteria in Zimbabwe, LPS endotoxins were measured in a water reservoir and tap water (Annadotter et al., 2002)

Other indicators of the presence of cyanobacteria are the organic compounds geosmin and 2-methylisoborneol, which have also been detected in the water samples. Both geosmin and 2-MIB gives an unpleasant taste and smell. The Municipality of Windhoek has received all complaints the citizens have had regarding the drinking water (see tab.7). In March 2001 there was an article in the local paper (The Namibian) about the detection of odours and an earthy taste in the drinking water. " City authorities have assured residents that this phenomenon occurs seasonally and normally lasts about 10 days before it is flushed out of the system."

According to fig. 19, there were detectable levels of chlorophyll-*a*, and at the same time, sales of anti-diarrhoeal medication increased. We talked to Mr Baines, a vet from Windhoek. He told us that more than three times a day he gives treatment to animals with diarrhoea and vomiting problems. He can also see a clear increase in this immediately after the rainy season. People generally believe that when cattle die, it is because of some disease or snakebite, but he is convinced that these are not the only reasons. His theory is that during times with algae blooms there is also algal toxin in the water that the animals are drinking. Depending on the amount of algal toxin, it can cause the death of the animal within thirty minutes.

Our attempt to collect data from all the pharmacies in Windhoek regarding the sold medicine during one month, failed because of a poor interest in the project.

We hope our study will be followed up, because we believe that there is something in the drinking water, causing health problems. We base this on the fact that in the drinking water there is chlorophyll-*a*, which should not be there, and according to our graphs there are several correlations, which gives cause for continued work. The results of this study indicate the need to monitor cyanobacteria and its toxins in raw water and drinking water, and to promote methods for the reduction of blooms and toxins.

7. Conclusion

Even though that the found levels of microcystin never exceeded the TDI, our conclusion is that there is a relationship between the cases of diarrhoea and the chlorophyll-*a* in drinking water. Instead, a likely increased level of lipopolysacharid endotoxins may explain this seasonal variation. There is also a seasonal variation in liver enzymes among children with liver problems, which probably is due to the presence of chlorophyll-*a* in drinking water.

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