Water Pollution

AND SOUTH AFRICA'S POOR

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WATER POLLUTION AND SOUTH AFRICA'S POOR

Anthony Turton

Table of Contents

1. Introduction

South Africa is a water-scarce nation, among the 30th driest countries on earth. Its diversified economy is the result of more than a century of sophisticated planning, forecasting and the development of science, engineering and technology.

South Africa's economic performance can be benchmarked against countries with similar semi-arid grassland ecosystems: Argentina's Pampas, Russia's Steppes and the Great Plains of Canada and the United States. Water management is fundamental to this nation's wellbeing: as the hydraulic foundation of all economic and social activities, South Africa's destiny as a nation can be measured in the management of this life-giving resource.

Sadly, South Africa has a high level of income disparity, massive unemployment and deep-seated poverty. This means that the consequences of water pollution are not evenly distributed across society.

This paper will interrogate this country's current trajectory, contextualising its historic, geographic and socio-economic reality. It argues that poverty is an invisible casualty of water quality and suggests policy and technological solutions to reverse this outcome.

2. A short history of South Africa's water management

2.1. South Africa's first environmental law: *Plakkaat 12*

South Africa's history of water management began in 1652 when the Dutch East India Company (DEIC) established a settlement at Camissa (or "place of sweet waters" in the Khoi language) in the shadow of Table Mountain. Here the merchants found a reliable series of rivers arising from multiple springs beneath the mountain. Jan van Riebeeck, leader of this expedition, noted 36 springs in this system which stretches 6.7km to its final discharge into the Atlantic Ocean.

The Camissa system was valuable to the Khoi and their cattle herds, but also to the DEIC who used its waters to irrigate their extensive vegetable gardens. To protect this valuable resource, the Dutch passed this country's first environmental law, known as *Plakkaat 12*. Promulgated in 1655, the law prohibited any activities that caused "trouble" to the quality and flow[1] of the Camissa system. This included the washing of laundry and defecation by humans and animals.

Camissa is the genesis of South Africa's national economic growth. It is also the origin of the link between water and prosperity, between water and privilege, and between water and the custodial role needed to protect this vital resource.

Today the Camissa system lies abandoned, trapped in the Mother City's sewers and discharging as polluted waste into Cape Town harbour's Duncan Dock. Of the original 36 springs listed by van Riebeeck, the City of Cape Town has 13 on its official register of assets, with a total of 32 known to researchers.

The Camissa system has been abused by political elites in their pursuit of power, fought over by those who sought financial benefit, and eventually abandoned in the city's cesspools. The wisdom enshrined in *Plakkaat 12*, the foundation of this country's modern environmental and water legislation, is forgotten and trivialised as archaic and irrelevant.

1 The exact wording in original Dutch is as follows: "Niet boven de stroom van de spruitjie daer de schepen haer water halen te wassen en deselve troubel te maken".

2.2. Fast forward to the 1960s

On March 21st 1960, the police opened fire and killed or wounded about 250 protesters in the township of Sharpeville near Vereeniging. This turning point in South Africa's history, shocked the nation, led to a massive loss of investor confidence, the rapid outflow of capital, and the birth of the armed struggle.

The state response to this uprising was significant because two new dynamics unfolded. The first was the need to restore investor confidence and rapidly grow and diversify the economy, which was based mainly on agriculture and mining. The goal was to create sufficient jobs and wellbeing to counter the recently-unleashed revolutionary forces. The second was the creation of a Commission of Enquiry into Water Matters, tasked with developing a hydraulic foundation for this economic plan to expand the country's range of goods and services.

Created in 1965, the water commission issued a report five years later that warned of "serious shortages" before the end of the 20th century. It made water management a strategic priority and mandated the creation of a cohort of science, engineering and technology specialists. This commission established the Hydraulic Mission of the State, centred on the construction of large dams, the inter-basin transfer of water designed specifically to drive economic development, the negotiation of a range of water sharing agreements in transboundary river systems, and the creation of the Water Research Commission funded by taxes levied on the bulk sale of water (Turton *et al*., 2004).

2.3. Shift to the democratic transition in 1994

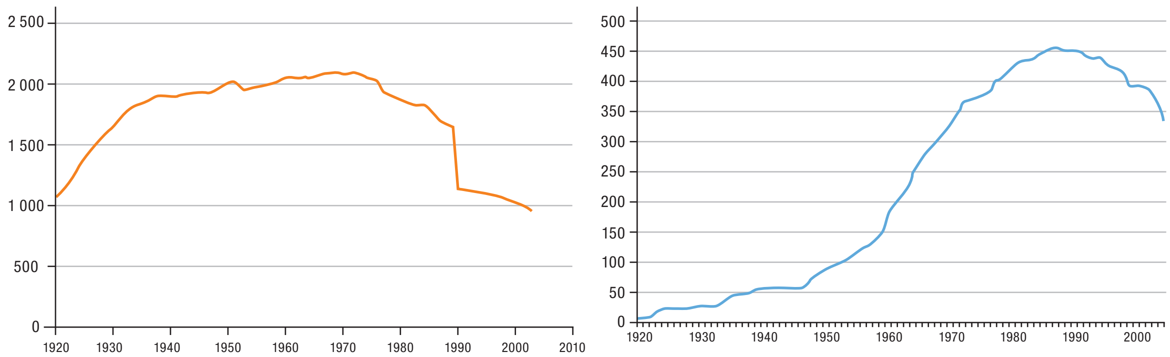
After the euphoria of the country's first democratic elections settled, the new government discarded the wisdom embedded in the Commission of Enquiry into Water Matters claiming that it was tainted by Apartheid. This move doomed the country to forget what it had learned from past experiences.

This institutional loss of memory is demonstrated in the precipitous decline after 1994 in the number of instruments used to record water flow in South Africa. The decrease in the number of functional rainfall gauging stations is shown in Figure 1 (left). The Department of Environmental Affairs manages this system, which is central to measuring, monitoring and predicting rainfall over time. Fewer gauging stations exist today than in 1920 when record keeping began.

Figure 1 (right) shows the number of streamflow gauging stations over time. The Department of Water and Sanitation (DWS or the department) manages this system which is central to measuring, monitoring and predicting flows of water in rivers over time. Today South Africa has the same level of capacity that it had in the 1960s when the Commission of Enquiry into Water Matters was mandated to develop the national water management strategy.

This information illustrates the collapse of the systems that measure, monitor and predict water resources. The blame for this failure should be placed squarely on the government's shoulders because it has prioritised political and economic transformation over the retention of technocratic skills. This fiasco exposes the government's ignorance that water management is a critical element in the successful economic growth needed to meet those aspirational transformation imperatives.

Figure 1: ***Number and timeline of functioning rainfall gauging stations (left) and streamflow gauging stations (right).***



Source: W.V. Pitman, 2011.

2.4. Nationalising water

The new ANC government ignored this country's early history and the essence of *Plakkaat 12*: to prevent "trouble" upstream of the Camissa source. One of its first actions was to nationalise water.

The logic behind this action sheds light on South Africa's current state of water affairs and can be traced back to the 1913 Native Land Act, one of the most contentious pieces of legislation in this country's history. This law gave control over the majority of the land to an ethnically defined minority. It has also played a leading role in water resource management.

Shortly after South Africa's democratic transition, the Zimbabwe government expropriated private farmland. This triggered massive inflation because land that had been used as collateral for bank loans lost its value.

The drafters of the 1998 National Water Act recognised that land redistribution is core to any sustainable peace in South Africa. But realising the risk inherent to this process, they separated land rights from water rights and nationalised this country's water resources. This action converted water resources from an inalienable right into a discretionary authorisation, and made land redistribution subordinate to the granting of water permits. This sent powerful signals to the market as water gives land much of its economic value.

The upside to this approach was that government believed it had firm control over the land issue by controlling the allocation of water permits that gave land its commercial value.

The downside is twofold. First the alienation of rights is a complex legal issue, based on substantial jurisprudence and subject to the final test of constitutionality. For this reason farmers have fought doggedly to either retain their original rights, or to be paid adequate financial compensation for the losses arising from a change to those rights.

Second, the administration of water authorisations has placed a significant bureaucratic burden on the state. This must be interpreted in light of the data shown in Figure 1, which clearly shows that the state's technical capacity is under severe pressure.

For example, a recent study of the Tshwane Metropolitan Municipality's wastewater treatment works blamed failure of the instrumentation systems on inadequately trained staff and budget constraints (Turton, 2015c). Instrumentation failure is characteristic of the entire water system. This is the most important factor to understand when analysing this nation's water quality issues.

3. Understanding South Africa's water

3.1. Quantity and quality

This instrumentation failure is a direct reflection of the competence of the minister of water affairs. As the national custodian of this precious resource, the minister is responsible for overseeing its management in the best interests of all South African citizens, privileged and poor. It is the government's duty to ensure that all South Africans, individuals, groups and companies, have access to enough water that is of good quality.

But South Africa's water resources are overstretched, a condition that was revealed officially in the 2004 National Water Resource Strategy (NWRS). This official plan indicated that the government had already allocated 98% of the country's national water resources to legitimate users and had over-allocated as much as 120% to some water management areas (WMAs).

This official government document, based on technical data available from 1998, is an accurate reflection of reality at that time. More importantly, the 2004 NWRS clearly warned that by 2025 the national water deficit would be 2,044 million m^3 (MCM).

While some water management areas showed a surplus, three serving South Africa's major industrial zones had a projected deficit: 764 MCM in Gauteng's Upper Vaal WMA; 508 MCM in Cape Town's Berg WMA; and 788 MCM in Durban's Mvoti-Umzimkulu WMA.

Clearly government has been aware of the country's national water deficit since at least 2004. This makes its hard to believe the government's claim that it was oblivious to the El Niño drought. But the government could have been caught off guard given the information in Figure 1: the instrumentation system on which daily decisions are made is in an advanced stage of dysfunction, so approaching drought would remain invisible.

Water quality is also dependent on the government's custodial role. South Africa has 1,085 water treatment plants (WTPs) for potable water. They are designed to precipitate and clean river water, which typically carries a heavy load of suspended solids, basically fine clay. The plants then filter the water through gravel beds and disinfect it with chlorine before reticulating it to the consumer. Nearly one-fourth of the country's WTPs, 250, are in poor condition and unable to deliver safe drinking water.

South Africa has 824 wastewater treatment works for processing sewage effluent. This liquid waste is discharged back into rivers and then drawn by the 1,085 water treatment plants and processed into drinking water.

The total volume of effluent treated daily is 5.13 billion litres. Of this total volume of sewage, only 16%, or 836m litres per day (ml/d) is treated to a standard safe for discharge back into rivers and dams. The rest, the staggering sum of 4.3 billion litres daily, or 84%, is discharged in untreated, or at best, partially-treated form.

Sewage return flows have increased dramatically since influx control was abolished in the 1990s. The unplanned arrival of migrants was not accompanied by a planned upgrade of sewage and other water services. An additional problem has been the unlawful discharge of rainwater from gutters into sewers, which has perilously increased peak flows during storms.

The uncontrolled nature of this sewage effluent is the single biggest source of water pollution in South Africa. Other sources of contamination pale into absolute insignificance when compared to the sheer volume of this effluent stream.

When combined with another huge problem, the rising saline levels in the country's rivers, this relentless discharge of sewage poses a widespread plethora of risks which affect all citizens, but mostly the poor and vulnerable.

3.2. Quality and health

3.2.1. Sewage

Sewage effluent is complex consisting of concentrated nutrients, pathogens (virus and bacteria) and many other elements.

It contains over 100 known viruses that range from adenovirus, the sort that causes colds, to rotavirus, which is directly associated with diarrheal risk to infants below the age of five, and is a known risk to the poor.

Table 1:* *Viruses in sewage and health implications

VIRUS	RISK
Adenovirus	Causes colds, but poses a specific risk to children and adults with compromised immune systems.
Astrovirus	Typically manifests as viral gastroenteritis. All persons are at risk, but children, the elderly and those with compromised immune systems are the typical targets. This has particular relevance to the poor who carry a disproportionally high burden of disease.
Coxsackievirus	May cause mumps, aseptic meningitis and hand, foot and mouth disease, which usually occurs in children. A more dangerous subset damages the heart, pancreas and liver, with some evidence that insulin-dependent diabetes is associated with Coxsackievirus B pancreatitis.
Enterovirus	Spread through the faecal-oral pathway, includes polio, currently under control in all but a few undeveloped countries. Infections include conjunctivitis, aseptic meningitis, myocarditis, neonatal sepsis and flaccid paralysis.
Norovirus	Causes gastroenteritis.
Rotavirus	Directly associated with diarrheal risk to infants below the age of five, and is a known risk to the poor.
Cyclovirus	Not yet fully understood by scientists, but currently manifesting as a neurological disease among children in Asia. This includes a form of non-trauma related paraplegia, manifesting mostly among the poor that rely on untreated water for survival.

Sources: https://en.wikipedia.org/wiki/Adenoviridae; https://en.wikipedia.org/wiki/Astrovirus; https://en.wikipedia.org/wiki/Coxsackievirus; https://en.wikipedia.org/wiki/Enterovirus; https://en.wikipedia.org/wiki/Norovirus; https://en.wikipedia.org/wiki/Rotavirus; https://en.wikipedia.org/wiki/Cyclovirus

Along with these viral loads, sewage effluent also includes pathogens such as cryptosporidium[2], which manifests as either diarrhea or a persistent cough in the respiratory tract.

Europeans are already investigating the relationship between sewerage and health. The German Federal Ministry of Education and Research has recently launched a research program[3] to track the movement of antibiotic-resistant pathogens from hospital sewers.

A study by the Irish Environmental Protection Agency, published in January 2016[4], found that high levels of resistant bacteria existed in hospital sewer drains, where typically one in three patients are on the "newer" types of antibiotics. This study concluded that effective wastewater treatment greatly reduced the load of drug-resistant bacteria. Still, even well-managed plants did not eliminate all forms of the mutated pathogen.

This is an important finding for South Africa because wastewater treatment works are failing nationwide. In addition, the country is already grappling with antibiotic resistant forms of tuberculosis and other debilitating diseases, unevenly distributed across society with the highest burden on the poor. This raises several questions:

- What is the status of drug-resistant pathogens in South Africa's rivers and dams?
- Which of these pathogens are passing through South Africa's potable WTPs? (The South African National Standard (SANS) 241 specifies the quality of acceptable drinking water, but only screens for coliform, bacteria found in human waste, and does not test specifically for most of the viruses noted above.)
- Will drug-resistant pathogens emerge, unlike cholera and other illnesses that until now have been easily treated?
- Will polio re-emerge as a result of sewage mismanagement?
- Are the smaller, less well-resourced WTPs, typically found in rural areas, at greater risk than the larger plants managed by the parastatal water boards in Johannesburg (Rand Water), Durban (Umgeni Water) and Bloemfontein (Bloem Water)? Or is the risk identical since the larger plants were never designed to convert sewage effluent into safe potable water?
- What is the impact of incompetent wastewater management on the poor and vulnerable?
- What needs to be done at policy and practical levels?

3.2.2. Eutrophication and algae

Sewage effluent becomes even more complex when water receives an excess of nutrients. This leads to algae blooms and eutrophication, the ecosystem's response to the addition of artificial or natural nutrients, such as nitrogen and phosphate. Excess nitrogen typically comes from industrial effluent and phosphate comes from detergents. Both also come from fertilisers used in agriculture. Both are fundamental building blocks of normal ecosystems, mostly manifest as animal urine and excrement. These nutrients sustain complex aquatic ecosystems, with the N:P ratio significant to the proliferation of cyanobacteria[5], a primitive life form.

Neither plant nor animal, this family of living organisms occupies every ecosystem on the planet. As Earth's oldest life form, cyanobacteria has had billions of years to evolve and produce a complex array of chemical compounds, some useful, but most, highly toxic. The useful compounds include sunblock, which evolved to protect creatures from extremely hazardous sun rays before the atmosphere filtered out incoming solar radiation. The hazardous compounds include a group of chemicals known as cyanotoxins which include the following poisons:

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2 https://en.wikipedia.org/wiki/Cryptosporidium
3 http://m.medicalxpress.com/news/2016-04-multidrug-resistant-bacteria-sewage.html
4 http://www.wateronline.com/doc/sewage-treatment-seen-as-barrier-to-rising-antibiotic-resistance-0001
5 https://en.wikipedia.org/wiki/Cyanobacteria

- **Neurotoxins**[6] act on the central nervous system, typically by blocking the transmission of a signal. They are fast-acting, typically paralyse the diaphragm and induce asphyxia. Some are related to the genesis of motor neuron disease[7] (MND), but more research is needed before hard conclusions can be drawn. Species of cyanobacteria that generate this specific form of toxin include *Anabaena*[8] that produce a potent toxin called Anatoxin-a[9]. It functions like sarin[10] nerve gas when produced by *Anabaena filos aquae*.
- **Cytotoxins**[11] cause necrosis (death of living tissue) at cellular level. These are usually slow-acting toxins, not necessarily leading to death of the individual. They are typically associated with significant localised tissue damage.
- **Endotoxins**[12] are potent toxins released by bacteria when distressed. There is insufficient understanding about the nature of *lipopolysaccharides*, a type of endotoxin associated with a fatty sugar.
- **Hepatotoxins**[13] are specific to the liver and are usually associated with damage caused by chronic exposure to a range of substances including cyanotoxins. They are slow-acting and immune-compromised individuals are more vulnerable than their healthier counterparts. If one accepts that the HIV burden is higher among poor people by virtue of the cost of treatment, then it follows that hepatotoxins will disproportionately affect the poor.

Two specific cyanobacteria, *anabaena* and *microcystis*, are relevant to South Africa and produce specific toxins. *Anabaena* generates anatoxin, which has three different permutations, all fast-acting nerve poisons (Calteau *et al*., 2014).

Microcystis produces microcystin, which is more prevalent than anatoxin. Its molecular structure is also much more complex. This means that when it is altered or denatured, its component parts can be more toxic than the entire molecule.

The World Health Organisation (WHO) has set a safety level of 1.0 microgram per litre[14] for microcystin because of its toxicity. But levels in South African rivers tower above the WHO safety levels, measuring between 10,000 and 18,000 micrograms per litre (Oberholster *et al*., 2004), with two-thirds of the country's large dams now affected by eutrophication[15] (Matthews and Barnard, 2015).

Microcystin levels in South Africa's tap water are much lower, about 10 micrograms per litre, according to scientists. These levels are still ten times more dangerous than the WHO safety standards. These results have never been published because government denies this information and funding is either withheld from scientists and/or they are pressured not to investigate.

But scientists elsewhere have been studying microcystin for 85 years. A massive cyanobacterial bloom erupted along the Ohio and Potomac rivers in the United States in 1931 and 5,000 people became ill. Scientists found the root cause to be microcystin.

6 https://en.wikipedia.org/wiki/Neurotoxin
7 https://en.wikipedia.org/wiki/Motor_neuron_disease
8 https://en.wikipedia.org/wiki/Anabaena
9 https://en.wikipedia.org/wiki/Anatoxin-a
10 https://en.wikipedia.org/wiki/Sarin
11 https://en.wikipedia.org/wiki/Cytotoxicity
12 https://en.wikipedia.org/wiki/Lipopolysaccharide
13 https://en.wikipedia.org/wiki/Hepatotoxin
14 http://www.ufrgs.br/imunovet/molecular_immunology/chemicalcauses_bacteria.html
15 This simply means enrichment with nutrients of which phosphate and nitrogen are the most important. See https://en.wikipedia.org/wiki/Eutrophication

In the 1950s an unusual neurological disorder was noted on the islands of Guam and Rota in the Pacific Ocean. Amyotrophic lateral sclerosis (ALS, sometimes known as Lou Gehrig's disease) and other degenerative diseases were affecting a disproportionately large percentage of the indigenous population, mostly the poor. Scientists dispatched to the area identified microcystin as the culprit.

Research has shown that microcystin causes brain damage that can take decades to be detected (Spencer *et al*., 1987). It has the potential to cross the placenta from mother to unborn child (Karlsson *et al*., 2009a; 2009b). More importantly, it bio-accumulates (Bradley and Cox, 2009), meaning that vegetables and fruit irrigated with contaminated water can transmit this poison. It is also linked to Alzheimer's (Murch *et al*., 2004) and other serious disorders shown in the chart below.

WHAT INTERNATIONAL PEER REVIEWED SCIENCE TELLS US ABOUT MICROCYSTIN	
Fact # 1:	A substance identified as ß-methylamino-L-alanine (BMAA), a form of microcystin synthesised by cyanobacteria (blue-green algae), bio-accumulates in seeds and is capable of entering the mammalian food chain (Bradley & Cox, 2009).
Fact # 2:	BMAA causes motor neuron degeneration in monkeys resembling Parkinson's Disease (Spencer *et al*., 1987).
Fact # 3:	Microcystin is linked to a range of liver pathologies (Ito *et al*., 1997; Nishiwaki-Matushima *et al*., 1991; Ueno *et al*., 1996).
Fact # 4:	Lettuce absorbs microcystin from contaminated irrigation water (Codd *et al*., 1999).
Fact # 5:	Microcystin contaminated irrigation water alters plant biochemistry (Abe *et al*., 1996).
Fact # 6:	Colon pathology is related to microcystin (Humpage *et al*., 2000).
Fact # 7:	BMAA is causally linked to Alzheimer's (Murch *et al*., 2004).
Fact # 8:	BMAA injures motor neurons in the mammalian brain (Rao *et al*., 2006).
Fact # 9:	BMAA causes necrosis of tissue in the hippocampus of the mammalian brain (Buenz & Howe, 2007).
Fact # 10:	BMAA crosses the placenta in mammals where it bio-accumulates in the foetal brain (Karlsson *et al*., 2009a).
Fact # 11:	Mammals born after BMAA exposure to their parents are cognitively impaired with reduced capacity for problem solving (Karlsson *et al*., 2009a).
Fact # 12:	BMAA is selectively toxic to motor neurons (Liu *et al*., 2010).

Source: compiled by author

The fundamental danger of microcystin is that South Africa's water treatment plants cannot remove the toxin. As the cyanobacteria cell ruptures or is distressed, it releases the toxin which then infiltrates the water stream. Since it is not a solid floating on the water, it is invisible to the mechanical filtration process typically used in this country.

3.2.3. Salinity

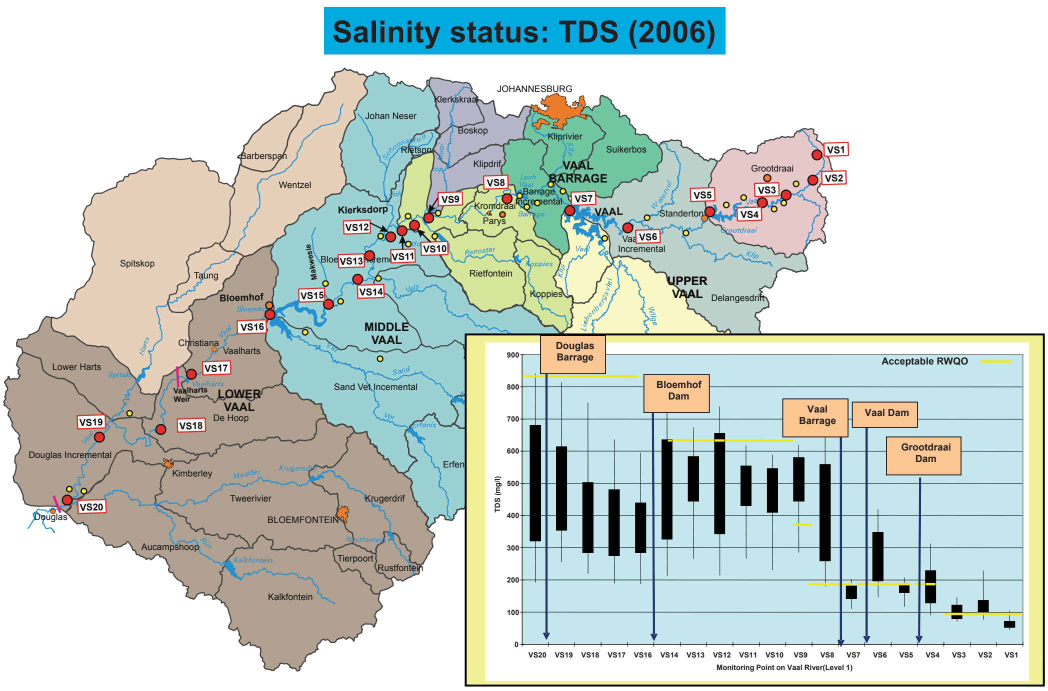
South Africa's reservoirs trap more than two-thirds of its average annual stream flow (Ashton *et al*., 2008). Water in these dams, often with large surface areas, evaporates at a faster rate than in flowing rivers. As a result, saline levels rise. Global warming exacerbates this salinity because higher temperatures create even more evaporation. Acid mine drainage (AMD), already highly saline because of its sulphates, adds to the salt buildup.

When these two factors—increased salt loads from AMD and greater losses to evaporation from higher temperatures—are added to the pathogen-loaded sewage flows, the resulting concoction is a highly saline system.

Alarmingly, rising saline levels are threatening the Vaal River, which supplies water to Gauteng, home to 45% of South Africa's population and the base of 60% of the country's GDP. A 2012 water department study examining acid mine drainage found that the total dissolved solids (TDS)—salts and other soluble material—found in the Vaal are low through the Grootdraai and Vaal dams (see Figure 2). However, when the water flows past the Vaal barrage, salinity spikes and remains high for the rest of its course.

AMD flows entering the system below the barrage are responsible for this rising salinity because this specific tributary drains the majority of the Witwatersrand goldfield. This tributary becomes polluted as it flows past combined tailings dams (dumps that store mining waste) containing about 400 kilotonnes of uranium (Casas *et al*., 1998; Coetzee *et al*., 2006; Camden-Smith *et al*., 2015; Turton, 2013; Winde, 2010a; 2010b).

***Figure 2:* Salinity status of the Vaal River system in terms of total dissolved solids as known in 2006**



Source: Department of Water Affairs, 2012

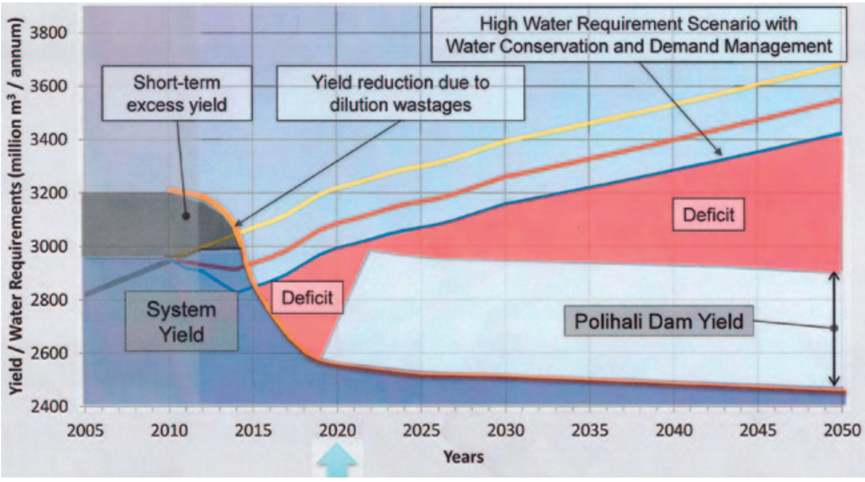
The 2012 water department study concluded that the only way to prevent significant cumulative pollution over time is to lower the salinity in the overall system. This requires raising the fresh water level, which can be accomplished two ways: introducing clean water from the Lesotho Highlands Water Project (LHWP) and reducing the flow of highly saline acid mine drainage.

Nearly 40% of the total dissolved solids in the Vaal system come from surface runoff impacted by tailings dams; 21% come from sewage return flows and 13% from discharged mine water. (Industry and agriculture account for the remaining 26%.) Mining and sewage flows are thus directly relevant to almost half of the national population and nearly two-thirds of the national economy.

The water department's 2012 acid mine drainage study also looked at the Vaal River's water balance and projected a deficit between demand (requirement) and available supply (yield) by 2015 (see Figure 3). The Polihali Dam in Lesotho could play a significant role in reducing this deficit, but only if Phase 2 of the LHWP is launched as scheduled in 2020. This phase has been delayed by five years, which means that first delivery of water may happen only in 2025, assuming that the project rollout does not encounter any other snags. This means that a possible drought in 2019—an election year—could have a devastating impact on the Gauteng region.

In effect, the Gauteng economy has been at growing risk since 2015, a scenario which is expected to last until 2025, even in an optimistic scenario without drought.

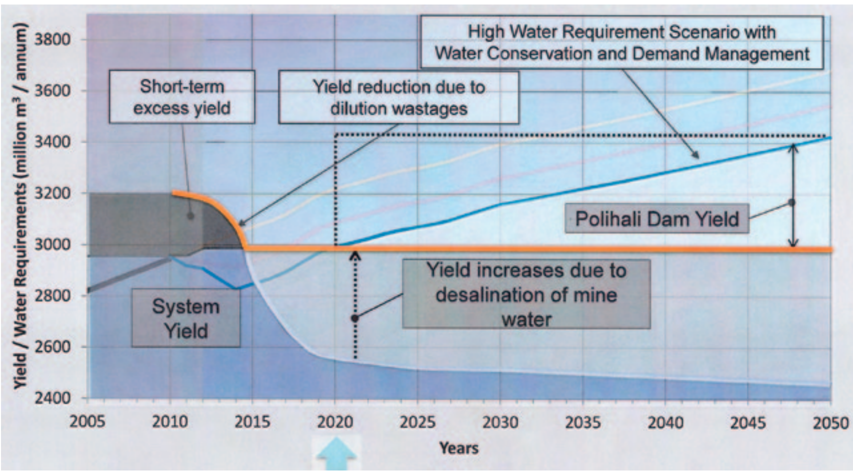
***Figure 3:* Water balance as it existed in the Vaal River System in 2012**



Source: Department of Water Affairs, 2012

To defuse the danger this growing deficit poses to the economy requires combining the added yield from Phase 2 of the LHWP and lowering the salt levels in the contaminated mine water. While Figure 3 shows that the yield from Phase 2 of the LHWP will fall short of the demand curve, Figure 4 shows that the combination of Phase 2 and desalination can balance demand and supply to Gauteng Province in 2020 under perfect circumstances.

***Figure 4:* Projected water balance in the Vaal River System**



Source: Department of Water Affairs, 2012

Until Phase 2 kicks in, pollution is very concentrated because of the lower volumes of water available for dilution. This makes desalination even more important to meet water quality objectives.

3.2.4. Cleaning mine water

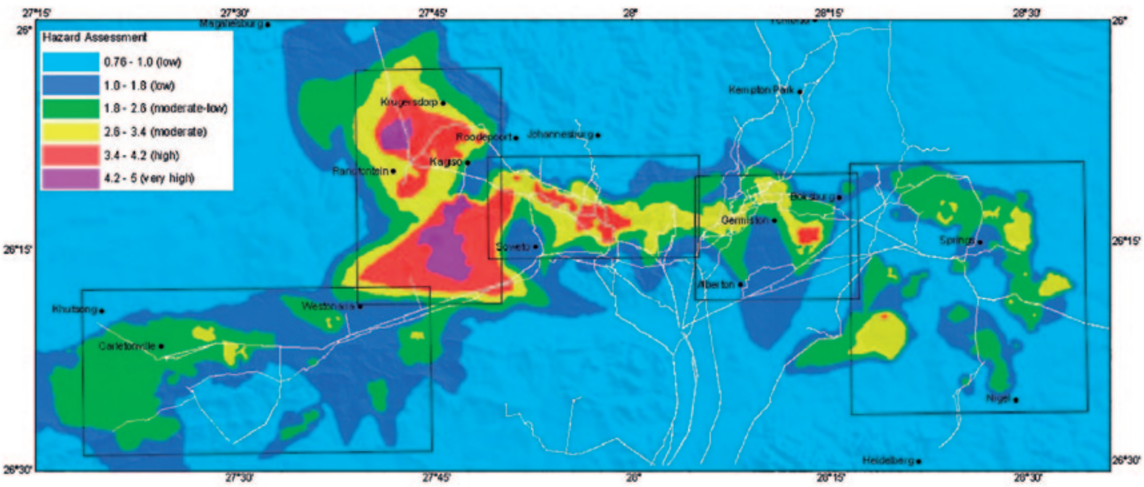
Enough mathematical modelling has been done on the movement of surface flowing acid mine drainage across the Witwatersrand goldfield to understand the sub-surface flows. Many of these acidic underground currents erode the dolomite (Hartnady *et al*., 2012) rock structure of calcium and magnesium carbonate found underneath the Witwatersrand. This leads to vast underground voids where highly acidic water moves rapidly, accelerating the formation of sinkholes at the surface.

The Witwatersrand goldfield stretches across four hydraulically distinct mining basins: the eastern basin in Ekurhuleni; the central one in Johannesburg; the western in Krugersdorp; and the far western in Carletonville. Acid mine drainage in the western basin is the swathe of red and purple in Figure 5 below. Three of the mine dumps known to be the most hazardous because of their high uranium content are connected hydraulically to this water course. Even worse, the Zuurbekom well field, a cluster of high-yielding boreholes in a series of dolomite compartments and a source of some of Johannesburg's potable water, is drawing that uranium-polluted plume through this aquifer.

The only way to prevent the spread of this contamination is to reverse the flow within the entire western basin. This requires pumping out the acid mine water so that it does not rise into contact with the dolomite compartments or the surrounding ground or surface water.

Mining companies once performed this task to make their deep-level operations safe. But as each has become insolvent over time and stopped mining, that burden has now shifted to the state and therefore to the taxpayer. Little has been done, however, because environmental activists have interpreted this action as a shifting of liability from mining companies to the state. This has resulted in a stalemate in which bankrupt mining companies no longer have the financial means and the state lacks the actual capacity.

***Figure 5:* Flow of acid mine drainage modelled mathematically**



Source: Chris Hartnady *et al*., 2012

4. Water pollution and how it affects the poor

The number of households with access to piped water has gone up from some 9,300 in 2005 to more than 13,200, an increase of 42%. While this has improved the living conditions of many South Africans, it has also put severe pressure on limited water resources and sewage treatment plants.

Managing the Vaal River system is paramount since almost half of South Africa's population and two-thirds of its national economy depend on this water resource. This requires increasing the supply and quality of water with the successful implementation of Phase 2 of the LHWP as well as the desalination and the removal of uranium toxicity from acid mine water. Doing either without doing both will not solve the problem.

It also requires managing sewage effluent with pathological loads, including microcystin. Uranium is chemically toxic to various organs of the human body in ways similar to microcystin.

South Africa's poor would be the biggest beneficiaries of good water management because water pollution affects the poor in at least four ways. Each entails a different solution that can be attained through reforming current policy and practices.

4.1. Direct contact with contaminated water

The geographic distribution of direct contact with polluted water is widespread. Inadequate infrastructure in rural areas means that the poor are drinking, bathing and washing clothes in water that is contaminated with inadequately treated wastewater (Fatoki *et al*., 2001).

In burgeoning townships and cities, the poor are growing food near polluted streams. They fill their irrigation buckets with water contaminated by free flowing sewage from failed infrastructure. Sometime this water is fouled with mine residue filled with toxic heavy metals. This includes uranium, found in heavy concentrations in wetlands and along floodplains of the streams draining the Witwatersrand goldfield (Barthel, 2007; Coetzee *et al*., 2002, 2005, 2006; Wade *et al*., 2002; Winde and van der Walt, 2004; Winde, 2009, 2010a, 2010b, 2013; Winde and Erasmus, 2011).

This means that food grown in these gardens is contaminated by both microcystin and heavy metals associated with AMD. Although the risk remains unquantified, it is surely unacceptably high. The risks of exposure to these toxins are further compounded because many poor communities live in townships built on land that is poisoned with mine residue. In other words, the poor are exposed to polluted water, land and dust in the air from these mines. (GDARD, 2011; Tang and Watkins, 2011; Toffa, 2012).

4.2. Indirect contact with contaminated food

The poor often buy food in *spazas* (local convenience stores) that are grown in informal gardens along contaminated streams. These purchasers and sellers are often unaware of the potential contaminants inherent in these vegetables and fruit, such as sewage-impacted pathogens, microcystin and toxic heavy metals from acid mine drainage.

Other consumers buy their food in the formal economy, most notably supermarkets which are also unaware that their produce could be contaminated by microcystin or sewage-borne pathogens. These supermarkets could unknowingly sell food that has been grown on land near mines that has been dusted with toxic uranium powder (Turton, 2015a, 2015b, 2015c). If the food is grown on farms near dams and rivers polluted with sewage, the microcystin contamination and pathological loads are potentially high.

4.3. Inadequate healthcare facilities

Clinics serving the poor are unlikely to be equipped to diagnose and treat patients who are suffering from central nervous system disorders in which environmental toxicity may have played a role. This is a new field of science in South Africa which is under-researched and poorly funded. Medical doctors trained to diagnose such pathology are likely to remain poorly distributed throughout this country.

Research in Guam on central nervous system dysfunction and amyotrophic lateral sclerosis should broaden the understanding of a range of neurological disorders associated with microcystin toxicity (Bradley and Cox, 2009; Murch *et al*., 2004; Spencer *et al*., 1987). Literature reviews indicate that microcystin loads in South Africa's large dams are orders of magnitude higher than those that were found in Guam, underlining the urgency of this research.

4.4. The potential emergence of a generation with cognitive disabilities

This possibility exists as a direct result of exposure to food irrigated with water contaminated with microcystin and/or uranium. Even low levels of uranium are known to cause neurological defects (Frisbie *et al*., 2015; Helene *et al*., 2009; Lestaevel *et al*., 2016) in addition to those caused by microcystin (Bradley and Cox, 2009; Murch *et al*., 2004; Spencer *et al*., 1987).

5. Solutions: ways to improve water quality

5.1. Politics and finances

The most powerful and cost-effective action to improve water quality is to honour the wisdom of *Plakkaat 12* and prevent contamination before it happens. However, this is not realistic given South Africa's infrastructure decay, public finances and the apparent lack of political will.

Ideally all sewerage works should be upgraded to cope with the hydraulic loads they are confronting. This is capital intensive and could cost up to R30 billion[16], which is simply not available under current economic conditions.

Tax revenues allocated to water management also need to be increased and used more efficiently. Official water department estimates indicate that more than R800 billion — or R80 billion a year — is needed over the next decade to overcome the maintenance backlog in water infrastructure. But annual budgetary allocations are generally below this sum, while many municipalities and other state entities either underspend their budgets or fritter away much of the money.

Overall, the country is not spending enough—or getting enough "bang for its buck"—even on essential maintenance, let alone the new technologies needed to manage microcystin, develop aquifer storage and recovery, or remove other pathogens that current sewage treatment methods cannot counter.

Instead of fulfilling their responsibilities to provide enough clean and safe water, government officials are diluting the SANS 241 water quality guidelines to hide the presence of specific metals, toxins and pathogens. Increasingly, they are engaging in the dangerous practice of excessive chlorination in the hope that it will destroy pathogens that are not removed in treatment plants. But too much chlorination leads to its decay into a carcinogenic substance known as trihalomethane[17].

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16 Confidential briefing given to managers of institutional investment funds seeking to understand risk to their respective portfolios.
17 See https://en.wikipedia.org/wiki/Trihalomethane

Responsible city managers, mayors and other concerned officials should issue regular updates on water quality that makes full disclosure of all pathogens, microcystins and metals. The growing availability of accurate test information, such as that provided by the dipstick kits mentioned below, should empower the public and civil society organisations to hold elected officials accountable. Class-actions law suits could be considered where enough individuals are found to be at risk.

5.2. Affordable technology

While the political will is lacking, other lower-cost methods exist to improve water quality. Hydro-Chemical Activation (HCA), a new technology and a South African invention, could be a viable alternative to a complete and costly retrofit of the country's sewerage works. Although costs are site specific, HCA should be cheaper than expanding an existing plant because of improvements to efficiency.

HCA is part of a family of technologies known as advanced oxidation processes, (AOPs), a set of chemical treatments that remove pathogens by exposing them to super-oxidants such as ozone and hydrogen peroxide, and sometimes ultraviolet light.

The advantage of this technology is that it spurs useful bacteria to digest raw sewage more quickly. This means that incoming flows can be increased without enlarging the plant's footprint while still releasing pathogen-free effluent to the nearest river. This is an immediate benefit because hydraulically overloaded wastewater treatment plants can be fixed without massive costs for civil works expansion.

This technology is too new for mainstream use, but is likely to find traction very rapidly as the benefits become known to municipal managers, regulators, consulting engineers and procurement officers involved in running wastewater treatment plants. Large-scale commercial farmers can also take advantage of HCA technology, specifically if their water is contaminated with microcystin and other pathogens.

Tests not yet in the public domain indicate that HCA destroys all sewage-related pathogens and microcystin is rendered harmless. More research is needed to find out if the denatured microcystin remains non-toxic as it chemically bonds to other elements. This on-going research is of national importance.

Activated carbon is another possible solution to improve water quality. It is a carbon that has been altered with small pores that enlarges its surface area to adsorb toxins. In large bulk water plants, the water is brought into contact with the carbon through massive containers. This system can be easily retrofitted into South African potable water treatment plants to remove microcystin. After any uranium and other heavy metals entering a water treatment plant are precipitated and become part of the sludge, municipalities running these plants can use activated carbon in the final phase of the water purification process.

Individuals can also buy various commercial products such as activated carbon cartridges that can be attached to taps. These cartridges are embedded with multiple processes that include an activated carbon stage, sometimes an ion exchange stage (that also removes toxic metals) and a membrane phase (that removes bacteria and some virus). This technology is becoming cheaper and with innovative funding models, even the poor could afford it.

A company in South Africa is testing a model in which an employer offers such a system to employees as part of a health and welfare package. A new development in Asia, named "point of entry", calls for inserting a filtration system into the mains water delivery pipe before it reaches a house.

Although the government has made great strides in providing more access to piped water, activated carbon modules are not practical for South Africa's poor where piped water into individual homes remains rare. This technology would probably not be suitable to add to communal standpipes in townships, as it could be vandalised easily.

The carbon system, however, is highly suited to a new generation of water vendor that can use this soon-to-be low-cost equipment to service a local community. Filtration systems containing activated carbon cartridges would also be practical and affordable to restaurants, schools, hotels and hospitals, where health standards require high-quality, pathogen- and toxin-free water.

Highly-precise dipstick test kits, most notably to detect microcystin levels in drinking water, are another way to test exposure levels and determine if a technological intervention is necessary. Accurate to within half a part per billion, these kits are easy to use and ideally suited for schools, clinics, hospitals, restaurants and hotels.

Charitable organisations could make these dipstick kits available to the poor through outreach programmes that educate about the risk of pathogens, microcystin and metal toxicity arising from vegetables and fruit irrigated with contaminated water and/or cultivated near mines.

Companies can use their corporate social responsibility to develop programmes that alert consumers about the hazards associated with eating food that has been grown using polluted water. Leading retail stores could take the lead by giving a public guarantee that their produce is free of microcystins, metals and pathogens. Environmental and health activists could expose, name and shame laggards who continue to sell contaminated food.

5.3. Policy reform

While South Africa is regarded as having excellent policy and legal frameworks, implementation is often weak, often because of political constraints, sometimes caused by trade union opposition.

Policy reform should encourage private-public partnerships (PPPs) in the water sector. But South Africa's only successful water management PPP is at the wastewater treatment plant south of Durban. In 1999 the government awarded a contract to Durban Water Recycling Pty Ltd to stop the plant from discharging sewage effluent into the ocean. Durban Recycling, with the support of other companies, upgraded the plant and by 2001 was diverting treated effluent to nearby factories that needed large volumes of processed water that did not need to be of potable standard. This venture has not received the acclaim it deserves because the companies using the water want to remain below the radar for fear that trade union action could derail a highly successful project.

Policy reform is also needed more specifically in other areas including:

- The re-invigoration of the national eutrophication program with sufficient funding and the required technical skills to monitor and measure multiple points over long time periods. The current programme is withering for a variety of reasons, including government denial. As a result, the eutrophication status of large dams is under-reported. There is a case to be made for public-private partnerships in such a venture. Plumes of blue-green algae are clearly visible from Google Earth images over time, yet these remain invisible to decision-makers because of the general systemic failure of critical instrumentation.
- Expanded funding for the remote sensing of cyanobacterial blooms linked to credible public reporting. The emerging technology of satellite remote sensing (Kutser, 2004; Mathews, 2014; Mathews *et al*., 2010, 2012; Mathews and Barnard, 2013, 2015) gives an accurate near real-time reporting capability

over large geographic areas. This research and applied science should become central elements to any response by corporate and regulatory policymakers. This could go a long way to rebuilding the trust between society and the state.

- A fully funded multi-disciplinary national research program on the ß-methylamino-L-alanine (BMAA) microcystin, a risk for everyone, but especially the poor. While the experiences from Guam are important, South Africa may still not be able to extrapolate these findings because of fundamentally different toxicity levels and exposure pathways. A specific sub-set of this programme requires an accurate risk assessment of impoverished communities with an epidemiological study of:
  - Central nervous system dysfunction such as amyotrophic lateral sclerosis, motor neuron disease, early ons*et Al*zheimer's and other disorders related to Parkinson's disease;
  - Cognitive impairment of children who might have been exposed to microcystin *in utero*;
  - Prevalence of liver and colon cancers associated with chronic exposure to low levels of microcystin;
  - Distribution of uranium and metal-related pathology among communities reliant on food grown in gardens on contaminated river banks.
- The food producing, processing and distribution industry should consider launching its own quality assurance programme. This should be designed to prevent contaminated food from entering the value chain in the first place, while also educating consumers about risk.
- Specialised training for media professionals to encourage accurate and responsible reporting.

6. Conclusion

Water quality is a measurable indicator of government management. South Africa's first environmental law, *Plakkaat 12*, exhorted great wisdom: do not make "trouble" upstream.

In the modern era, the African National Congress-led government has rejected this elegant admonition by permitting critical portions of the water sector to collapse. Instrumentation systems have failed, with no apparent effort to rectify this critical monitoring. The administration of sewage flows has also broken down.

More important than this malpractice is the absence of credible research into human health risks associated with uranium and microcystin exposure. This has left the poor increasingly vulnerable because of this country's collective ignorance of risk from direct and indirect exposure pathways. Yet research conducted elsewhere shows that neurological impairment occurs when toxins bio-accumulate and cross the placenta from mother to child. The same best practice science reports that dementia-like symptoms can occur years after initial exposure, with learning disorders manifesting in children that have been inadvertently exposed.

The actual flow of microcystin into South Africa's drinking water systems is unknown because the science needed to establish this has never been funded to the extent it deserves. Will South Africa give rise to a generation of citizens with cognitive disabilities? Will the country have a generation of abnormal people manifesting neurological impairment resembling Parkinson's disease? Is the burden of this risk unevenly distributed across society with the poor left most vulnerable?

These questions could be answered with a national research programme designed specifically to increase understanding of the causes and effects of sewage effluent in rivers, the blooming of cyanobacteria, and the subsequent pathway of microcystins into the human population.

It is only logical to infer that the poor are at greater risk, most notably from food grown on the banks of contaminated rivers. This is followed by the growing probability of drug-resistant pathogens mutating in sewage-contaminated rivers and dams, also entering the food chain.

The next five years will be critical because even in opposition-coalition controlled municipalities and metros, sewerage infrastructure is so degraded that the likelihood of success in the short term is low. What is needed is a credible task team—made up of technically competent specialists without any partisan interests—to develop a turnaround strategy and rebuild the public trust that has been lost. The politics of the country at national level suggest that such a task team is unlikely to be appointed because the prevailing discourse is centred on blame-seeking and deflecting liability.

A glimmer of hope, however, lies at the municipal and metropolitan levels, where opposition-coalition leadership is potentially more amenable to appointing such a task team. This is critical to prevent the return of polio or the emergence of drug-resistant pathogens that could turn cholera into a killer. Impossible to predict, but with all of the fundamental precursors in place, such a doomsday scenario might be needed to galvanise us into collective action.

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