WATER POVERTY MAPPING AS A MANAGEMENT TOOL

C van der Vyver, MSc

Thesis submitted in fulfilment of the requirements for the PhD degree in the School of Information Technology at the Vaal Triangle Campus of the North-West University

VANDERBIJLPARK

May 2011

“It always seems impossible until it is done”

Nelson Mandela

Abstract

In recent years it has been widely recognised that water was managed with little regard to the efficiency of its utilisation and with no or very little effective pollution control. The amount of fresh water on earth will continue to decline because of irresponsible usage, population growth and increasing pollution amongst others. The purpose of this research is not a management study, but to document how water poverty mapping can assist water management in three towns in South Africa. It should assist with as many as possible of the following aspects: the collection and analysis of all relevant information regarding the availability of water; its various uses; current supply status; future prospect; current water allocation details and the state and processes of water deprivation; and dissemination of information and messages arising from the analysis thereof to all concerned.

This study recommends that water poverty mapping be used as a management tool by local municipalities, water service providers and governments. All three entities can use water poverty mapping to replace, supplement or validate their water demand predictions so that future supply can be guaranteed. Local municipalities can also use it as part of their master plan, which in turn guides urban expansion and infrastructure development.

Opsomming

Gedurende die afgelope paar jare is dit algemeen erken dat water met baie min agting vir effektiewe gebruik en met geen of baie min effektiewe besoedelingsbeheer bestuur is. Die hoeveelheid varswater op aarde sal aanhou afneem as gevolg van onder andere onverantwoordelike gebruik, populasiegroei en toenemende besoedeling. Die doel van hierdie navorsing is nie ‘n bestuurstudie nie, maar om te dokumenteer hoe waterarmoede-kartering die bestuur van water in drie dorpe in Suid-Afrika kan bystaan. Dit moet met soveel as moontlik van die volgende aspekte help: die versameling en analise van alle relevante inligting rakende die beskikbaarheid van water; die onderskeie gebruike daarvan; huidige aanbod; toekomstige vooruitsigte; huidige waterallokasiebesonderhede en die status en prosesse van waterafsetting; en die verspreiding van inligting en boodskappe wat ontstaan na aanleiding van die analise daarvan na alle rolspelers.

Hierdie studie beveel aan dat waterarmoede-kartering as ŉ bestuursinstrument by plaaslike munisipaliteite, waterdiensteverskaffers en regerings gebruik word. Al drie entiteite kan waterarmoede-kartering gebruik om hulle wateraanvraagvoorspellings te vervang, aan te vul of te verifieer sodat toekomstige wateraanbod verseker kan word. Plaaslike munisipaliteite kan dit ook as deel van hulle meesterplan gebruik, wat op sy beurt weer leiding kan gee in dorps/stedelike uitbreiding en infrastruktuurontwikkeling.

This research was presented as a poster at the IWA – Young Water Professionals Conference that was held in Sydney, Australia, from 5–7 July 2010. The presentation was made possible by a partial sponsorship from the CuDyWat research niche area.

This research was presented as a full paper at the 15th IBIMA conference that was held in Cairo, Egypt, from 6–7 November 2010. It was published as part of the conference proceedings and has been fast-tracked for publication in the "Communications of the IBIMA" journal (see Appendix A for the accepted paper).

TABLE OF CONTENTS

List of Figures

List of Tables

Acronyms

DBSA	Development Bank of Southern Africa
DM	District Municipality
DPLG	Department of Provincial and Local Government
DWAF	Department of Water Affairs and Forestry[1]
EA	Enumerator Area
GIS	Geographical Information System
HDI	Human Development Index
HPI	Human Poverty Index
IWRM	Integrated Water Resource Management
ISP	Internal Strategic Perspectives
IWSF	Integrated Water Services Forum
LM	Local Municipality
MDGs	Millennium Development Goals
MIG	Municipal Infrastructure Grant
PES	Present Ecological Status
RDM	Resource Directed Measures
RDP	Reconstruction and Development Programme
RSA	Republic of South Africa
WARMS	Water-use Authorisation and Management System
WPI	Water Poverty Index
WPM	Water Poverty Map
WRC	Water Research Commission
WSA	Water Service Authority
WSAM	Water Situation Assessment Model
WSDP	Water Service Development Plan
WSP	Water Service Provider
WSSD	World Summit on Sustainable Development

---

[1] Known as the Department of Water Affairs and Forestry until 2009, when the department's name changed to the Department of Water Affairs (DWA). The slogan of the department is “some water for all forever”.

1 Conceptualisation of the research

1.1 Introduction

In recent years it has been widely recognised that water was managed with little regard to the efficiency of its utilisation and with no or very little effective pollution control (Pallett, 1997). South Africa, being a water-stressed country with less than 1 700 m^3 of water for each person per year (Rand Water, 2008), has limited fresh water resources and budgets for the supply of basic infrastructure services. Currently over 6 million people in South Africa are without access to even a basic level of water supply or have only a very limited level of access (Cullis, 2005).

The norm has been to think of water poverty purely in terms of a lack of the actual resource; however, Sullivan, Meigh, Giacomello, Fediw, Lawrence, Samad, Mlote, Hutton, Allan, Schulze, Dlamini, Cosgrove, Delli Priscoli, Gleick, Smout, Cobbing, Calow, Hunt, Hussain, Acreman, King, Malomo, Tate, O'Regan, Milner & Steyl, (2003) and Sullivan, Meigh & Lawrence (2005) have shown that water poverty should be expressed in terms of resource, access, capacity, use and environment. These five components are contained in the Water Poverty Index (WPI) as developed by Sullivan, Meigh & Fediw (2002), and refined by researchers at the Centre for Ecology and Hydrology in Wallingford, United Kingdom.

Graphical representations of the WPI are a very effective and understandable way of communicating information to the various stakeholders and role players, as no knowledge of the underlying data and its transformation is required. These graphical representations of the WPI are known as water poverty maps. The role that these maps can play in assisting the management of water poverty is as yet unclear, although it is believed that they can be very helpful in this regard.

1.2 Background

Water management has been carried out since the 19th century wherever there has been a need to provide water to large numbers of people. Complex social norms have developed around water management and competing users have established political (governance) and economic cooperative relationships. For example, community-managed irrigation schemes in Bali and the cloud-collection canals built by the Incas at Inca Pirca in Peru are examples of water management systems which still currently supply water to people (Sullivan, 2005). According to Rand Water (2008), South Africa is a water-stressed country. Water stress is an indicator that is commonly used to measure the degree of water resources vulnerability, and typically occurs when the demand for water exceeds the supply (Perveen & James, 2011). Water stress causes deterioration of fresh water resources in terms of quantity and quality. Figure 1 shows the water availability of the world population as a percentage of each of the five water availability categories.

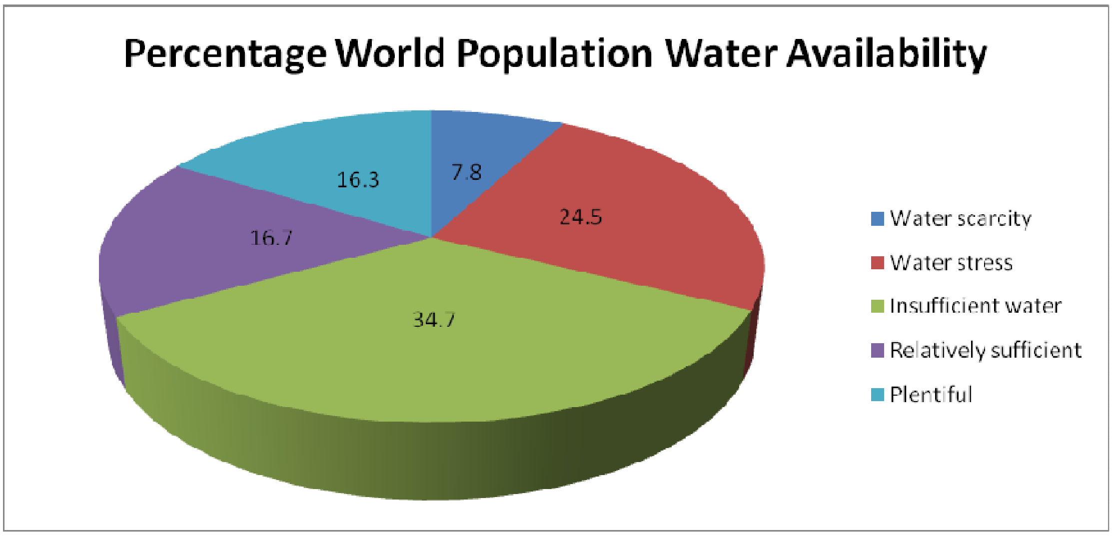

Figure 1 Percentage world population water availability

(Source: Clarke & King, 2004)

Water resources will steadily decline because of population growth, pollution and expected climate change (Hemson, Kulindwa, Lein & Mascarenhas, 2008). It has been estimated that the global demand for water doubles approximately every two decades (Meyer, 2007) and that water will even become as expensive as oil in the future (Holland, 2005). “In the year 2000, global water use was twice as high as it was in 1960” (Clarke *et al.*, 2004:19). Unfortunately this trend is expected to continue.

Rijsberman (2005) states that water scarcity occurs when a large number of people in an area do not have access to safe and affordable water to satisfy their needs for drinking, washing or their livelihoods for a significant period of time. Rand Water (2008) warns that if we do not learn how to use our limited water supplies wisely, we will move into a water scarcity category – that is, less than 1 000 m^3 per person per year – by 2025. On a worldwide scale the World Bank estimates that roughly 166 million people in 18 countries are affected by water scarcity and another 270 million people in 11 countries are water stressed (Hemson *et al.*, 2008). The way in which water resources have been managed, allocated and used in Southern African countries reflects a very obvious fact: “*Well-watered gated communities reside alongside sprawling under-serviced townships, themselves ringed by squatter camps*” (Swatuk, 2008:44). As the townships and squatter camps are classified as water scarce, South Africa has limited fresh water resources, and about 12% of the population does not have access to sufficient water. Given these figures it is easy to see why we can refer to the existence of a so-called global water crisis. According to Newson (2009), there are various components contributing to the global water crisis, not only high demand. Table 1 lists these components along with the associated impacts of each.

Table 1 Global water crisis components

Component	Impact
1. Demand	Water demand exceeds supply or little remaining ‘head-room’.
2. Food	Major component of demand is irrigated agriculture: food.
3. Pollution	Water supplies are finite but increasingly polluted, including groundwater.
4. Ecological impacts	Water storage and use compromises ecosystem health.
5. Health	Widespread lack of clean supplies and sanitation, with resulting mortality and morbidity.
6. Global climate change	Climate change impacting on water scarcity in the next two decades.

1.3 Responding to the different dimensions of water poverty

National and local governments hold the key and have a primary responsibility for good water management, but businesses and consumers must also play a positive role. Policies and programmes to supply people with sustainable water should be developed on the basis of consultation with the people with respect to their priority water security needs (Ahmad, 2003). Some of the steps that have been taken by government include (DWA, 2011):

- Agenda 21.
- 1996 Constitution (Act No. 108 of 1996), which guarantees the rights of all people in South Africa.
- 1998 National Environmental Management Act (Act No. 107 of 1998).

- 1998 National Water Act (Act No. 36 of 1998), which is the most prominent example.

Different tools are available to respond to the various dimensions of water poverty. These include policies, legislation frameworks, regulatory arrangements and instruments, and financial arrangements all working together to create an enabling environment. However, according to Swatuk (2010), the policies, laws and various forms of infrastructure that have been developed in South Africa during the last couple of decades constitute a complex political ecological terrain that is not easily amenable to over-simplified frameworks for good water governance.

To create an enabling environment an appropriate framework needs to be established, which allows adjustment and implementation of appropriate policies and programmes at various levels of society. Solid background information and proper assessment of needs are necessary to prepare plans and projects. The issues that need to be analysed and addressed include the following (Ahmad, 2003):

- The rate and pattern of urbanisation and urban water needs for drinking, sanitation and other purposes.
- Institutional and delivery mechanisms.
- The question of equitable access of water to all.
- The valuation and pricing of water and subsidies for the deserving to guide water allocation and water demand management.
- The question of the quality of water and its efficient delivery at affordable prices.
- Conflict resolution: institutions, principles and procedures.
- Technological aspects.

- How best to ensure participation of water users and other stakeholders in the decision and implementation processes relating to all water sector activities, including the development (with due regard to appropriate technologies) and management of irrigation infrastructure and water allocation mechanisms.
- The decentralisation of water management to ensure local government's pre-eminent role and people's effective participation.
- The sensitisation of everybody regarding proper water allocation for social harmony and the larger benefits for all concerned.
- Public and private management as appropriate.
- The mobilisation of finances from public to private sources.
- Informing everybody so that they understand their rights and are enabled to better respond to situations.
- The sensitisation and training of policy makers, administrators, water professionals, development experts and community leaders with respect to the approaches, imperatives and realities.

Water resource management and water poverty alleviation efforts tend not to be as efficient and effective as they could be as more often than not only single factors are considered when determining where to focus resources/funding. This leads to incorrect situational analyses and resources not being allocated to areas that need it the most.

1.4 Problem statement

For the purpose of this research the following problem statement was formulated:

There is a need for a water poverty mapping model to assist in managing water poverty.

This management tool should assist in as many as possible of the following aspects: the collection and analysis of all relevant information regarding the availability of water, its various uses, current supply status, future prospects, current water allocation details and the state and processes of water deprivation, and dissemination of information and messages arising from the analysis thereof to all concerned.

This addresses various needs that were highlighted in the 1994 Reconstruction and Development Program (RDP), which listed "*meeting basic needs"* as one of its five broad programmes (Melville & Goddard, 1996). Some of the areas that were highlighted in the RDP as being extremely relevant, and therefore in need of research include, amongst others:

- Water, including its provision, sanitation and conservation.
- The environment.
- Social welfare.

This research, either directly or indirectly, assists in addressing all of these needs.

1.5 Main research question

The following question was formulated as the main research question for this for this research:

How can water poverty mapping be used as a management tool to assist in addressing water poverty?

1.5.1 Secondary research questions

From the main research question the following secondary research questions were formulated:

1. What role can water poverty mapping play in water management?
2. What variables define water poverty in terms of domestic water management?
3. Are data available for the different components of the water poverty index, and if so, how reliable are these data?
4. Is it possible to produce a water poverty map?

1.6 Hypothesis

For the purpose of this research the following hypothesis was formulated:

Modelling techniques and geographical mapping can be used to produce a water poverty map in such a way that it can assist management in addressing water poverty issues.

1.7 Method of investigation

1.7.1 Literature review

Literature on water poverty, water poverty mapping, modelling techniques and all relevant concepts were reviewed. Most of the sources used were obtained from text books, scientific journals and research documents which are scientifically verifiable.

1.7.2 Case study

The literature study is followed by a case study where the water poverty map suggested in this research project is used in a specific area. The model has to provide answers to real-life business situations. The advantages and disadvantages of using case studies as a research strategy are discussed in the following section.

1.7.3 Research methodology

This section summarizes the research methodology used in this research. A more detailed description can be found in section 3.2.

This research is an example of mixed methods research. It combines aspects from quantitative research, in terms of some of the statistical analysis performed and some of the data sources used, as well as aspects from qualitative research, in terms of choosing the case study approach and some of the data collection. When the three stages of mixed methods research is considered, as discussed in section 3.2.1.3, this research:

1. Is an exploratory study. Unlike with the confirmatory study, this research does not test the validity of an existing theory. It uses the WPI and WPM to explore and document the levels of water poverty in the demarcated area of this study (see section 1.9).

2. Uses open-ended interviews as its data collection method for its primary data and uses data sources that have been compiled by the Census Bureau and the DWA for its secondary data. According to Melville *et al.* (1996) one of the major advantages of using interviews as a data collection method is that one can clarify answers and can follow up on interesting answers. This research used interviews to obtain the values for the resource component of the WPI, and to obtain the possible uses of the final water poverty map. The access, capacity, use and environment components of the WPI were calculated using existing sources, namely Census data and the Water Situation Assessment Model (WSAM) from the DWA.

3. Uses a case study for its data analysis to calculate the WPI and to construct the WPM for the demarcated area. The value of this research lies in the inferences that can be drawn regarding the use of the WPI and WPM by management to aid with the alleviation of water poverty.

The advantages of a case study as a research strategy include (Denscombe, 2003):

- It allows the researcher to deal with the subtleties and intricacies of complex situations.
- It allows the use of a variety of research methods.
- It fosters the use of multiple sources of data.
- It is suitable for when the researcher has little control over events.
- Concentrates effort on one research site.
- Suitable to both theory-building and theory-testing research.

A case study has some disadvantages, of which the majority do not apply to this research. Some of these disadvantages include:

- Doubtful credibility of generalizations made from its findings (for a detailed discussion on generalizations made from research see Polit & Beck, 2010).
- Perceived as producing soft data.
- The boundaries of the case can prove difficult to define.
- Negotiating access to case study settings can be demanding.
- Difficult to achieve the aim of the investigation without any effect arising from the presence of the investigator.

1.8 Contribution to the field of IT

This study forms part of the *Cultural Dynamics of Water* (CuDyWat) niche area at the North-West University's Vaal Triangle Campus as well as the *Data Mining* interest group. It will contribute to the niche area by addressing water poverty through the use of a geographical information system to enhance management. Its contribution to the interest group will be through the analysis of National census data as well as various databases from water service providers, processing and combining this data into an index, and then using these indices to construct the water poverty map which will be available to management.

The CuDyWat niche area started operating informally in 2005 when a group of academics on the Potchefstroom and Vanderbijlpark campuses of the North-West University collaborated in a multidisciplinary research project dealing with the floods in the southern Cape in 2004/5. Since then the research group, together with its postgraduate students, and in collaboration with a broad spectrum of stakeholders, have completed five transdisciplinary research projects dealing with local hotspot water issues in various parts of South Africa (obtained from the chairman of the niche area during 2009).

1.9 Demarcation of the study

Water poverty maps can be developed on almost any scale depending on the requirements, available financial resources and manpower. As water poverty mapping is not the only focus of this study, and due to very limited financial resources and manpower, the area for the water poverty map of this study has been limited to the three towns and neighbouring townships that form the Vaal Triangle, namely Vanderbijlpark, Vereeniging and Sasolburg. Vanderbijlpark and Vereeniging are located right on the southern border of the Gauteng Province and Sasolburg is located right on the northern border of the Free State Province in South Africa.

One of the two local municipalities in the demarcated area is the Emfuleni local municipality (ELM). The ELM consists of the two main towns Vanderbijlpark and Vereeniging, along with their surrounding townships and settlements. Figure 2 illustrates the municipal boundaries of the ELM.

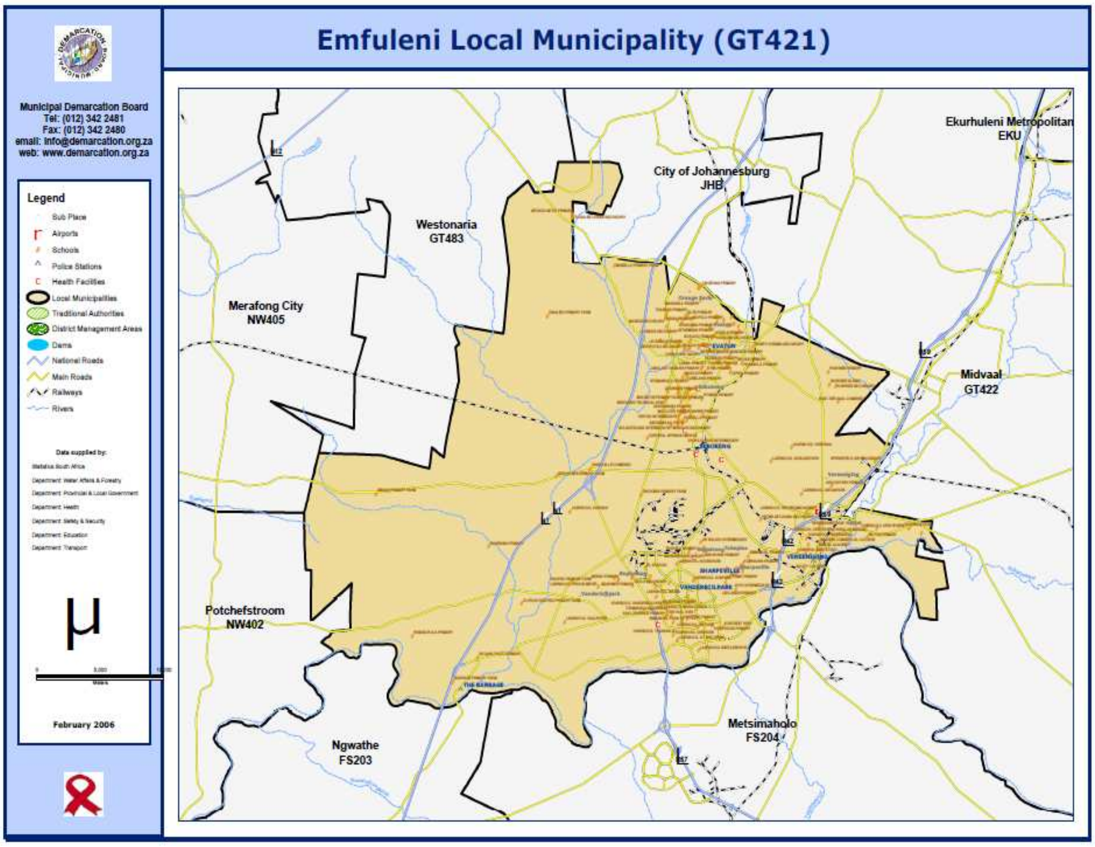

Figure 2 Boundaries of the Emfuleni local municipality

(Source: Municipal Demarcation Board http://www.demarcation.org.za)

The other municipality in the area is the Metsimaholo local municipality (MLM), which consists mainly of the town Sasolburg, along with its surrounding townships and settlements. Figure 3 illustrates the municipal boundaries of the MLM.

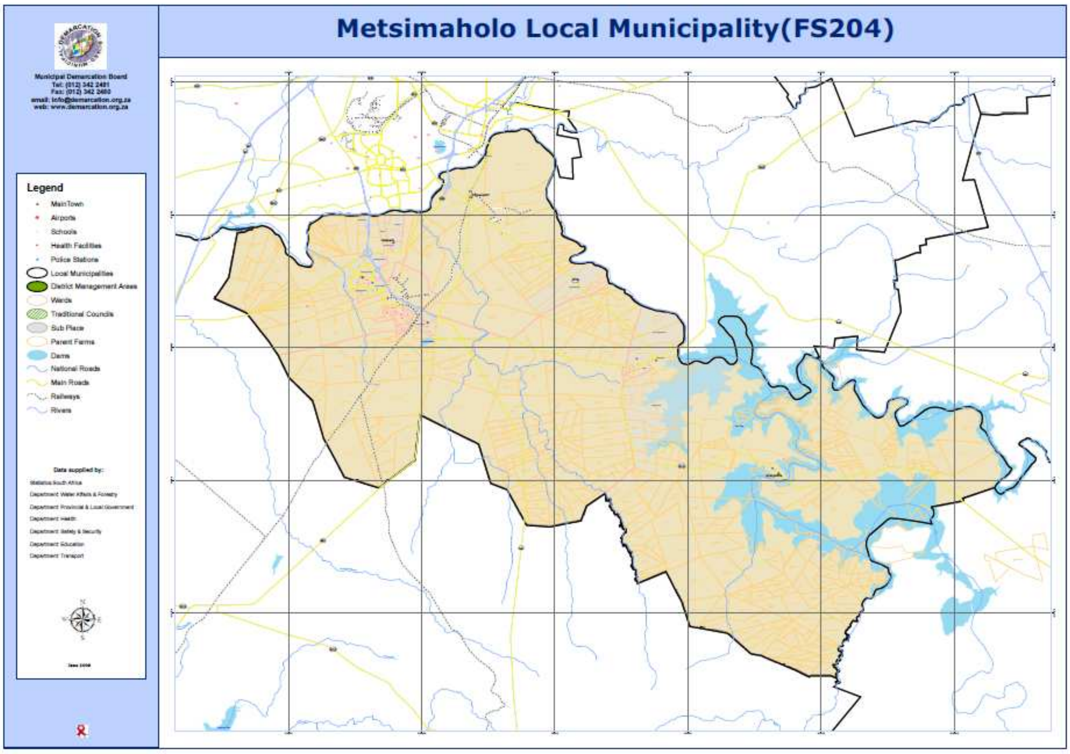

Figure 3 Boundaries of the Metsimaholo local municipality

(Source: Municipal Demarcation Board http://www.demarcation.org.za)

One of the ELM's major recent achievements was the Department of Water Affairs (DWA) awarding them a blue drop status for their drinking water quality management during 2010. Some of their other recent achievements include the installation of water meters and basic water supply in some parts of the informal settlements, and the upgrading of the Vaaloewer water purification plant and reservoir system (obtained from an interview that was held with a representative from the local municipality).

They have however also highlighted some challenges that they foresee with regards to their water and sanitation services. These challenges include:

- An ageing water infrastructure.
- A limited preventative maintenance program due to a shortage of personnel.

- Rapid development.
- Flat rate billing for water consumption in certain areas.
- Un-metered areas.

In the ELM area, Metsi-a-Lekoa is responsible for the distribution of potable water, the collection and conveyance of wastewater, and the treatment of the wastewater. Metsi-A-Lekoa is the dedicated water services authority entity for the ELM and its core functions are the water and sanitation functions of the municipality. They utilize some of the assets of the municipality to accomplish these tasks, and are also responsible for the maintenance and the costs of the water services systems (ELM, 2010). The water system consists of a small potable water treatment plant, 10 low level reservoirs, and the pipe networks. The sanitation system consists of gravity pipelines, and 48 sewage pump stations and their pumping mains. The wastewater treatment system consists of 3 wastewater treatment works. The Sebokeng facility is the largest works with a capacity of 116 Mℓ/day, the second largest works is the Leeuwkuil facility with a capacity of 32 Mℓ/day, and the smallest works is the Rietspruit facility with a capacity of 23 Mℓ/day (ELM, 2010).

As in the rest of South Africa, unemployment continues to remain a problem in the Vaal Triangle. This leads to high poverty levels and a high dependency ratio within the municipality, which directly hampers the ability of the population to save and/or engage in other entrepreneurship activities (ELM, 2010). Figure 4 illustrates the employment profile of the Emfuleni local municipality. Unemployed refers to people aged between 16 and 65 who are currently looking for a job opportunity, and not economically active refers to people who are employable but who are not currently looking for a job opportunity.

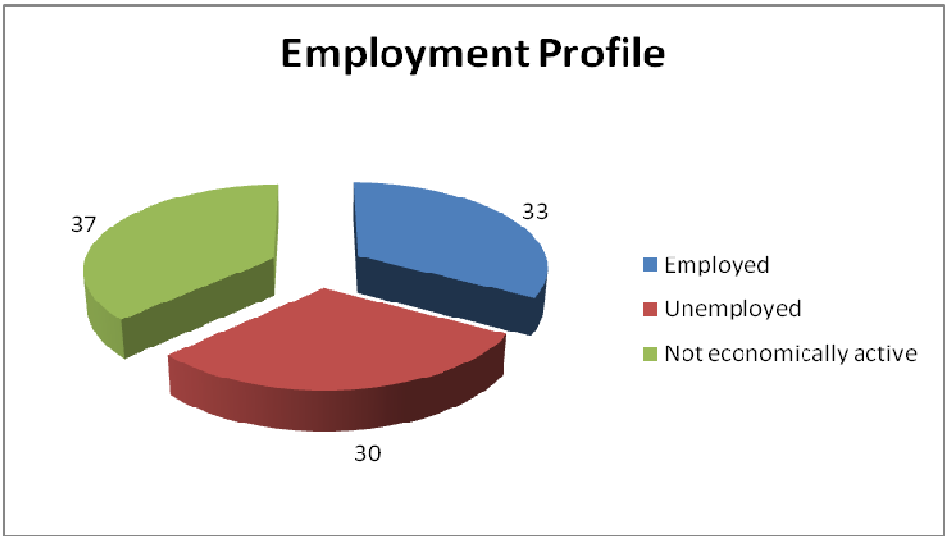

Figure 4 Emfuleni local municipality employment profile

(Source: Emfuleni Local Municipality, 2010)

The economic growth for the municipality has been quite slow when compared to the targets that were set for the region by the Gauteng Growth and Development Strategy (or GGDS). For the period from 1995 – 2000 the growth rate was 0.4%, for 2000 – 2006 it was 1.8%, and for the period from 2006 – 2011 it is projected to be 1.1% (ELM, 2010).

1.10 Chapter layout

Chapter 1: An introduction is given, the problem statement and research questions are formulated, and some background information is provided.

Chapter 2: The literature review, where the concepts water poverty, the water poverty index and water poverty mapping are discussed, amongst others.

Chapter 3: Discussions on the research methodology and the calculation methods of each component.

Chapter 4: The collection, analysis and representation of data in the water poverty mapping model. Each component value and the WPI is calculated, after which it is represented graphically.

Chapter 5: The management applications of the water poverty index and water poverty mapping are discussed, with specific reference to the local municipality, the bulk water services provider, and the government.

Chapter 6: The findings, recommendations, shortcomings and further research are discussed.

1.11 Conclusion

This chapter highlighted the importance of proper water management and the need to conserve our already scarce water resources. It started with a discussion on the background to the current water management problem, followed by the different dimensions of water poverty. The problem statement, the main and secondary research questions, and the hypothesis were then formulated, and the chapter concluded with sections on the method of investigation, the contribution to the field of IT, and the chapter layout of the study.

The next chapter contains the literature review which expands on the various important concepts and terminology that are used in this study.

2 Literature review

2.1 Introduction

According to Clarke *et al.* (2004), the world's water supply is critically low, and it is not foreseen that the situation will improve. "*As we move further into the twenty-first century, humanity faces the serious crisis of increasing water scarcity*", Weiner (2007:128). This idea is further supported by Coles (2005:14), who states that: "*the world water supply is in crisis, and things are getting worse, not better*".

Although many plans for water conservation have been made during the last few decades, their practical implementation and management have led to a vast number of problems. The amount of water that is suitable for human consumption is fixed, which means that less water is available per capita as the world population and demand from industry and agriculture increase.

According to Clarke *et al.* (2004), nearly half the world's population (or roughly 4 billion people) is expected to live in countries that are in a constant state of water shortage by 2050. In 2000 about 500 million people were already living in countries that were chronically short of water, and another 2.4 billion were living in countries whose water systems were under stress. Adding to this is the fact that fewer than a dozen countries contain 60% of the world's water supplies (Weiner, 2007). Water plays an important role in poverty alleviation, and any water shortage directly affects the prosperity of a country's inhabitants. The biggest global consumer of water is agriculture, which consumes roughly 70% of all global water resources. Industry is the second-largest consumer, with roughly 20% consumption, and domestic use is the smallest consumer, with only about 10% (Clarke *et al.*, 2004). Although industry consumes less than a third the amount of water that agriculture consumes, a ton of water used in industry can produce items that can generate roughly 70 times more income than when the same amount of water is used in agriculture.

The total water resource of the planet is made up of roughly 97.5% salt water, or 1 351 000 000 km^3, and 2.5% fresh water, or 35 000 000 km^3 (Clarke *et al.*, 2004). Figure 5 presents these figures graphically.

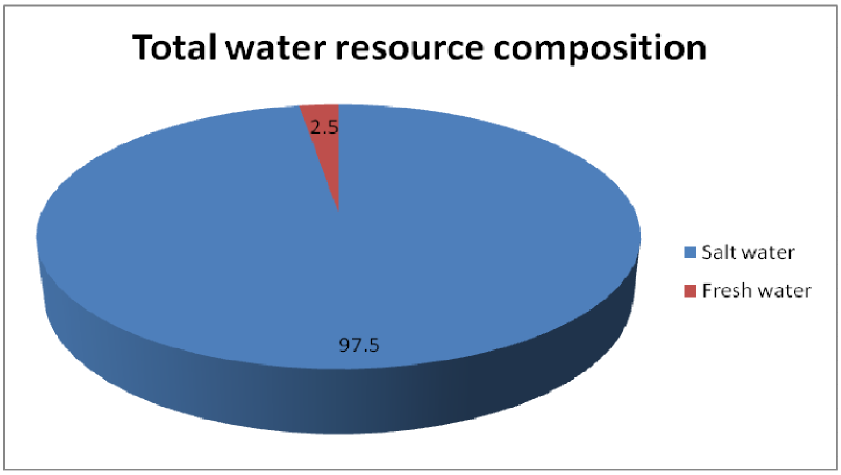

Figure 5 Total water resource composition

Although 2.5% of the total water resource of the planet is fresh water, only about 30.5%, or 10 635 000 km^3, of this water is available for human consumption, and is contained in surface water as well as underground water. The 69.5% that is unavailable is locked up in glaciers, snow, ice and permafrost (Clarke *et al.*, 2004). Figure 6 presents this graphically. This means that only in the region of 0.7625% of all the water on the planet is available and suitable for human consumption, a truly alarming figure when one considers that the world population was already in the region of 6 billion in 2000. *"While specific requirements vary, it is undeniable that everyone needs water"*, Swatuk (2010).

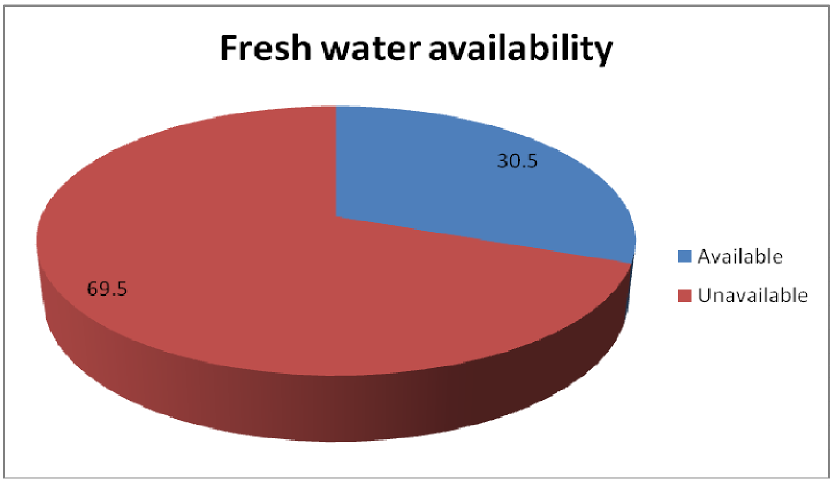

Figure 6 Fresh water availability

Figure 7 summarises this information and takes it one step further by looking at the composition of the 0.7625% of the water on the planet that is available for consumption.

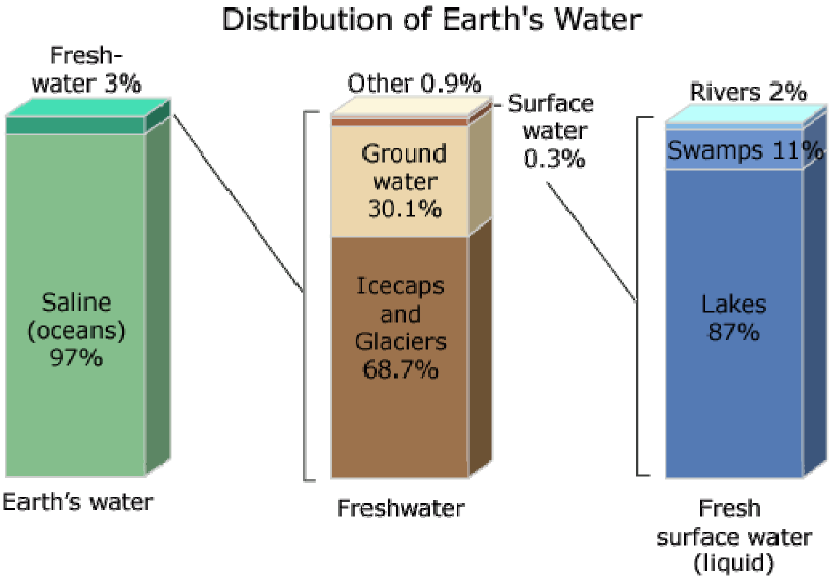

Figure 7 Summary of fresh water composition and availability

(Source: Rain Harvesting Systems http://www.rainharvesting.co.za/article.php?a_id=17)

2.2 Water management

During the last few years the two major shortcomings of water management that have been widely recognised are firstly very little or no pollution control, and secondly inefficient utilisation. According to Pallett (1997), the aim of water management should be to supply people with essential water supplies while ensuring that water continues to be shared among all the components of the human and natural environment in a river basin. Clarke *et al.* (2004) highlight the importance of good water management in determining the water fate of the majority of the world's population.

Ahmad (2003) makes it very clear that management is one of the major problems in the water sector, and according to Langford (2005), the reasons why we currently find ourselves in a water and sanitation crisis are:

- Insufficient and decaying infrastructure for water service delivery, especially in deprived rural and urban areas.
- Insufficient capacity and funding for the expansion and maintenance of water supply systems.[2]
- Pollution of traditional water sources, particularly from industrial waste, agricultural runoff and human and animal waste. Figure 8 is an example of some pollution that recently occurred in the Vaal river system showing the accompanying casualties of the fish population as well.

---

[2] According to Clarke *et al.* (2004), 39% of water in large African cities was lost through leaking pipes in 2000, a direct result of poor maintenance.

Figure 8 Example of polluted water in the Vaal river system

(Source: Eyewitness News http://www.ewn.co.za/featprog.aspx?id=78)

- Reduced access to, and depletion of, water resources due to drought, population growth, armed conflict and the dominance of commercial agricultural and industrial activities.

Many researchers (Ahmad, 2003; Cullis, 2005; Sullivan, 2002) suggest that a shift of emphasis to a more holistic approach to water management is necessary. As a first step, the concept of an integrated water resource management (IWRM) as a holistic approached-based framework for water management was introduced. This approach focuses on poverty reduction and sustainability of ecosystems among other things; in other words to achieve a sustainable water world. The Global Water Partnership (2000:15) defines IWRM as "*a process which promotes the co-ordinated development and management of water, land, and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*".

At the United Nations Conference on the Environment and Development that was held in 1992 in Rio de Janeiro, IWRM was a major item on the agenda.

During this conference the various stakeholders came up with an action plan for the world environmental crisis, called Agenda 21. Under this agenda, the four main objectives of IWRM are (Pallett, 1997):

1. To plan the sustainable and rational utilisation, protection, conservation and management of water resources.

2. To identify and strengthen or develop, as required, in particular in developing countries, the appropriate institutional, legal and financial mechanisms to ensure that water policy and its implementation are a catalyst for sustainable social progress and economic growth.

3. To promote a dynamic, iterative, interactive and multisectoral approach to water resources management.

4. To design, implement and evaluate projects and programmes that are both economically efficient and socially appropriate within clearly defined strategies.

Unfortunately, according to Swatuk (2010), although supporting the principle of IWRM, South Africa will experience some difficulties in realising the ideals of IWRM in practice. Examples of some of the contributing factors to these expected difficulties include:

- The loss of more than 1 000 000 jobs in the first post-apartheid decade, which resulted in major economic implications.

- Fault lines that have appeared within and between the major political parties.

- Capital flight and the out-migration of skilled workers to other countries, which limit the capacity of the state and society to shift toward more efficient, equitable and sustainable processes of wealth creation.

Water and poverty interface in more than one way (Ahmad, 2003), and the management of water resources is therefore a vital process element of sustainable human development. According to Meyer (2007), under sustainable development:

1. No degradation of resources is permitted.
2. The economy should be run in such a way that the welfare of future generations can be sustained indefinitely at or above some minimum level.

Directly linked to sustainable human development are the following main millennium development goals (MDGs) that were set during the Earth Summit held in 2002 in Johannesburg (Hemson *et al.*, 2008):

1. Eradicate extreme poverty and hunger.
2. Reduce child mortality.
3. Combat HIV/AIDS, malaria and other diseases.
4. Promote gender equality and empower women.
5. Improve maternal health.
6. Ensure environmental sustainability.
7. Achieve universal primary education.
8. Develop a global partnership for development.

The MDGs were reinforced when the United Nations proclaimed the decade from 2005 to 2015 as the decade for action (or ‘Water for life’), with 2008 being the International Year of Sanitation (Hemson *et al.*, 2008). The importance of proper water management should therefore not be underestimated, as sustainable access to safe water resources can play a major role in achieving almost all of the above goals.

Hemson *et al.* (2008) have analysed many years of work and development in the water sector. This analysis has led them to compile the following set of guidelines, which, when adhered to, will greatly improve the effectiveness of any water management entity’s efforts:

- Set lower goals, as sufficient funding will not be available, rather than argue strongly for more resources.
- Emphasise the very simplest level of technology with wells and village hand pumps to make local water resources more available to the poor within existing budgets.
- Place responsibility first on communities and second on national governments rather than on international organisations.
- Place the responsibility for initial capital resources on communities and require communities to be responsible for operations and maintenance.
- Make water provision an aspect of community development rather than a public health issue.
- Seek ways in which more can be achieved with more or less the same financial commitment by fixing systems rather than providing greater funding.
- Pay greater attention to the role of women in managing water resources and benefiting from delivery.
- Stress better utilisation of water to improve health conditions, for example personal hygiene and proper sanitation.

According to Coles (2005), some better water-management techniques could include, amongst others, installing water-saving appliances in the home, using more-economical methods of irrigation, and conserving supplies by repairing underground pipes. As mentioned earlier various attempts have been made and documented, all of which have experienced varying levels of success.

In 1997, Mr K. Asmal, the then Minister of the Department of Water Affairs and Forestry of South Africa, noted that there needed to be a paradigm shift from a supply-oriented mindset towards one of water conservation and water demand management (WDM). It was felt that this shift was necessary to ensure the sustainability of water resources and the environment, as well as for economic efficiency and social development. Meyer (2007:23) defines water conservation as *“The minimisation of loss or waste, the care and protection of water resources and the efficient and effective use of water”,* and water demand management as *“The adaptation and implementation of a strategy by a water institution to influence the demand for water as well as its usage”.* Water conservation gained a major boost the day that it was realised that water is not a limitless resource, and neither is it ‘free’, but that it has an economic value and as such should be treated as a commodity.

Perhaps one of the most well-known examples of poor water management relates to the Aral Sea in Kazakhstan and Uzbekistan. The Aral Sea has shrunk by 66% in volume and by 50% in area since 1957, due to the diversion of two rivers that used to feed it for irrigation (Clarke *et al.*, 2004). The water level of the Aral Sea has dropped by more than 13 metres, and its mineral content has increased fourfold, which has effectively killed off the entire fish population. It went from a sea supporting 60 000 fishermen in producing 40 000 tons of fish, to a poisoned wasteland with no fish production. About half the populations of the once seaside Aral towns and villages have fled, leaving the people who were forced to stay in a constant battle with a deadly mix of pollutants. The infant mortality rate in the Aral region is among the highest in the world (Clarke *et al.*, 2004).

“Unless radical steps are taken to alter the way water is withdrawn, used and managed, the outlook is bleak” (Clarke *et al.*, 2004:90). If we continue to use our water resources as we currently do, the world will be facing a severe water shortage as early as 2025. This will lead to reduced food production, which in turn will lead to malnutrition and disease, and also to increased ecological damage. Figure 9 is a graphical representation of what global water consumption might look like in 2025 if we merely continue using our water

resources as we currently do (consumption is expressed in cubic kilometres). It clearly indicates that we will have to change our consumptions patterns if we want any water at all in the future. This is easier said than done, especially when one considers the fact that agricultural water consumption will have to increase, considering that the world population will keep increasing and therefore more food will have to be produced. The rate of increase can however be minimized, as soon as people start realizing the value of water and start to use it more efficiently and effectively.

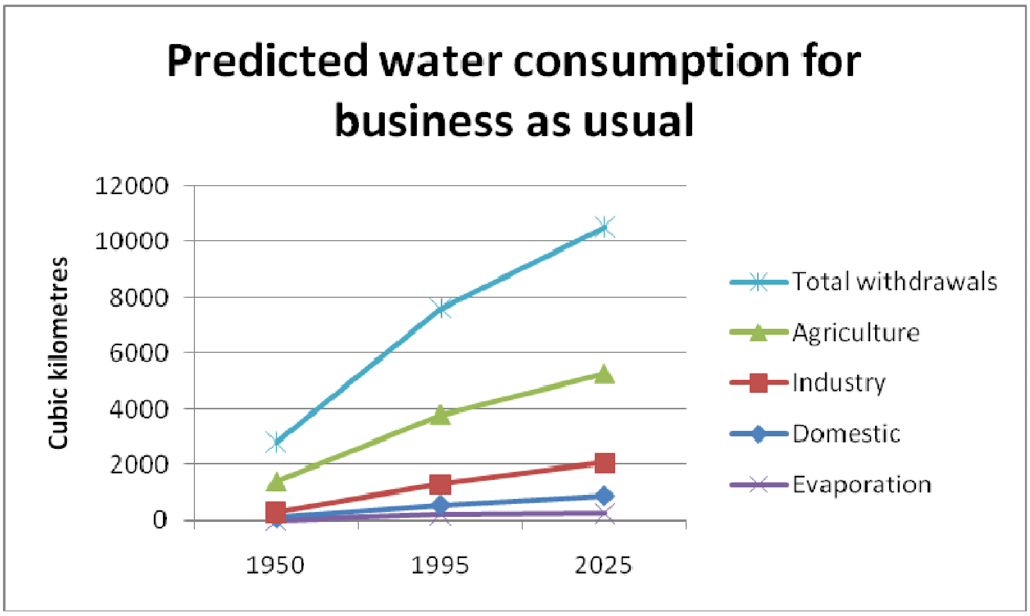

Figure 9 Predicted water consumption for business as usual

(Source: Clarke et al., 2004)

Proper water management that considers the entire picture, and that values community involvement, is essential in conserving our water resources for generations to come. Different regions tend to have different water circumstances, for example different resource availability, different water infrastructure, etc., and these differences tend to determine the appropriate water management strategy for that region.

The next few subsections will look at the two most common water management strategies, as well as some issues and challenges that people or entities in management positions should be aware of.

2.2.1 Total Water Management

In the 1990s the concept of Total Water Management (TWM) was developed, under which all stakeholders are required to exhibit stewardship over water resources (Grigg, 2008). Stewardship entails that all citizens should partake in caring for our water resources, and that it is not only the responsibility of government, whether national or local. According to Grigg (2008), the two main philosophical ideas behind TWM are corporate social responsibility and environmental ethics, and that the water supply industry should assume leadership in resource conservation and the application of water management to the entire hydrological cycle. TWM is required as we need to conserve the environment, and we absolutely cannot afford to waste or misuse our scarce water resources. Grigg (2008) states that good policy and government commitment are absolutely essential in ensuring the success of TWM, and that one of the most difficult principles of TWM is shared governance. With shared governance the responsibility for the water resource is shared by all the stakeholders involved, and it is not under the control of only one entity. Under shared governance authority is shared so that decisions can be reached that will benefit all the parties concerned.

2.2.2 Natural resource management

According to Barker (2007), natural resource management (NRM) is a management strategy that stresses the importance of considering the complete system (or larger hydrological cycle) that delivers water to our taps, and not only the purified water that is consumed by users. Under NRM the importance of a holistic and inclusive view of natural systems and their human counterparts is emphasised, along with the participation in and buy-in to the management of actions and regulation activities by stakeholders.

As human activity is one of the major causes of risks to drinking water safety (Barker, 2007), water users have to be made aware of their role in resource stewardship by having them realise both their role in creating and eliminating risks. Buy-in and support of NRM initiatives can be increased by managers when they provide people (or water users) with a voice and a space to participate in the management process. Such a space will lead to collaboration between water managers, water users, service providers, etc. The two areas of collaboration that are important for NRM are collaborative management and collaborative learning. Collaborative management refers to the management of water resources by all parties concerned, and collaborative learning refers to the idea that a problem or situation can be better understood by combining the perspectives of many.

"Water, as a common property resource that crosses political and social boundaries, calls for collaboration between its managers and users to ensure appropriate allocation and conservation decisions are being made throughout the system", Barker (2007:14).

2.2.3 Water management issues and challenges

According to Bouwer (2000), the following are the major issues and challenges facing modern integrated water management:

- **Global population and water supplies.** With the earth's population set to double in the latter half of the 21st century, increasing stress will be placed on our water resources. The majority of this increase will occur in the Third World, which already has a high degree of water poverty. Water management will have to consider this population increase when planning ahead, as irresponsible use of our current water resources will have catastrophic consequences in the future.

- **Water storage via artificial recharge and water banking.** To protect water supplies against climatic extremes and changes, increased water storage is needed. This includes long-term storage so that water reserves are built up during times of surplus for use in times of shortage.

- **Water reuse.** Even though all water is recycled through the global hydrological cycle, local water reuse is becoming increasingly important for two main reasons. The first is that discharging sewage effluent into surface water is becoming more difficult due to rising costs and more stringent treatment requirements. The second is that municipal wastewater is a significant water resource that can be used for a number of purposes, especially in areas where water shortages are experienced.

- **Non-point source pollution of groundwater.** Point source pollution (for example leaking ponds or tanks) of groundwater is relatively simple to rectify, but unfortunately the same cannot be said for non-point source pollution. The major non-point source polluter is agriculture, with fertiliser, pesticides and salt-containing irrigation water that filters down through from the root zone to the underground water, the biggest supply of fresh water on the planet. About a quarter of the world’s population is dependent on groundwater for their drinking water, but unfortunately in many places the water is being withdrawn faster than it is being replaced (Clarke *et al.*, 2004).

- **Virtual water.** Virtual water refers to the water that was required in the production of a certain item or commodity. Therefore whenever an item is imported or exported, the virtual water contained in the item is imported or exported as well. Areas experiencing water shortages can minimise the stress on their water resources by importing items with a high virtual water content. Ideally the production of items with a high virtual water content should be limited to water-rich countries, so that these products can be exported to water-stressed or water-scarce countries. For example, the virtual water contained in 1 kg of potatoes is roughly 500 litres, for 1 kg of rice it is roughly 1 900 litres, and for 1kg of beef it is in the region of 15 000 litres (Clarke *et al.*, 2004).

2.3 Poverty and poverty research

"*Poverty is still the greatest insult to human dignity. Poverty is the scar on humanity's face. Poverty is prevalent despite decades of international efforts to eradicate it*", in the words of Gro Harlem Brundtland, the then prime minister of Norway in the foreword to Oyen, Miller & Samad (1996:2).

According to Oyen *et al.* (1996), there is a direct relationship between poverty in a country and the occurrence of poverty research. The poorer a country, the less knowledge is available about poverty in that country. This might be caused by a number of reasons. The first reason might be the fact that poverty research is a luxury commodity that cannot be afforded by a poor country, secondly it might be the immature development of the social sciences in general in many African countries, and lastly it might even be the fear of the political impact of poverty research. Oyen *et al.* (1996) warn that although research into poverty measurement is very important and always relevant, poverty researchers should not neglect research into poverty understanding and poverty alleviation. In many African countries the gaps in poverty research have been filled by outside companies/organisations, thereby causing poverty to be defined in an economic sense, which leads to an international understanding of poverty instead of a definition of poverty tailored to national perceptions of poverty (Oyen *et al.*, 1996).

When considering poverty in Africa, especially sub-Saharan Africa which is semi-arid to arid, water needs to be included in the poverty definition. The poor have less access to clean water, and are likely to pay more for water than the non-poor (Oyen *et al.*, 1996).

2.4 The water poverty index

The conventional methods to assess water management were purely deterministic, relying on the availability of large-scale data. A method that is easy to calculate, cost effective to implement, based mostly on existing data, and that uses a transparent process (i.e. easy to understand) was needed.

This motivated Sullivan *et al.* (2002) to design the Water Poverty Index (WPI) as an alternative water situation assessment tool. The WPI has the following advantages over conventional methods:

- It is a mechanism to prioritise water needs.
- It provides a better understanding of the relationship between the physical availability of water, its ease of abstraction, and the level of welfare.
- The WPI is mainly designed to help improve the situation for people facing poor water endowments and poor adaptive capacity.
- It is a tool for monitoring progress in the water sector.

The Water Poverty Index captures the whole range of issues related to water resources availability as well as their impacts on people (Sullivan *et al.*, 2005). The primary goal was to enable holistic water-resource assessments on a site-specific basis at the community level. The WPI allows the use of different scales to be applied for different needs and defines water poverty according to five components. These component variables, which capture a more comprehensive picture of water management challenges (Sullivan *et al.*, 2003), are the following:

- **Resources**. The availability of water, taking into account the variations in seasonal and inter-annual fluctuations and water quality.
- **Access**. The accessibility of water for human use taking into account the distance to a safe source and the time needed to collect the water for household and other needs – including the irrigation of crops and for industrial use.
- **Capacity**. The ability to effectively manage water. "*Capacity is interpreted in the sense of income to allow purchase of improved water, and education and health, which interact with income and indicate a capacity to lobby for and manage a water supply*" (Cullis, 2005:5).

- **Use**. This captures the actual amount of water being used and extracted from the system. Use includes domestic, agricultural and industrial use (Lawrence, Meigh & Sullivan, 2002).

- **Environment**. This variable captures the environmental impact of water management with the intention to ensure long-term ecological integrity. "*Environmental factors which are likely to impact on regulation will affect capacity*" (Lawrence *et al.,* 2002:1).

A composite index approach is used to calculate the WPI (Cullis, 2005). Each of the five components consists of a number of sub-components and a weighting can be applied to each component to indicate the component's importance. The components are standardised to fall in the range 0 to 100, resulting in a final WPI value between 0 and 100. The highest value, 100 is taken as the best situation with 0 being the worst. To avoid subjectivity, a baseline value of the WPI should be calculated with the weightings set equally. The purpose of the weightings is to emphasise a specific component of the WPI structure, and the importance of any component should not be predetermined by researchers as it is clearly a political decision (Sullivan, 2005).

The five key components are combined together in a general expression:

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

Where

WPI = Water Poverty Index score of a particular location

R = Resources component (score out of 100)

A = Access component (score out of 100)

C = Capacity component (score out of 100)

U = Use component (score out of 100)

E = Environment component (score out of 100)

w = weighting factor for each component

(See Chapter 3 for a discussion on the various weighting possibilities as well as the weightings used in this study)

Table 2 is an example of data used for the different components in a pilot study (Sullivan *et al.*, 2005) when the WPI was applied to different communities in South Africa, and Figure 10 indicates the graphical WPI for the four selected communities.

Table 2 Data selected as WPI component variables for community assessment

(Source: Sullivan et al., 2002; Sullivan et al., 2003)

WPI component	Data used
Resources (R_i) This measure provides some assessment of a qualitatively adjusted value of the per capita quantitative measure of ground and surface water availability, for region *i*	• Assessment of surface water and groundwater availability using hydrological and hydro-geological techniques • Quantitative and qualitative evaluation of the variability or reliability of resources • Quantitative and qualitative assessment of water quality
Access (A_i) This indicates the access people have to water for effective use for their survival for region *i*	• Access to clean water as a percentage of households having a piped water supply • Reports of conflict over water use • Access to sanitation as a percentage of population • % of water carried by women • Time spent in water collection, including waiting • Access to irrigation coverage adjusted by climate and cultural characteristics
Capacity (C_i) This indicates the level of human and financial capacity to manage the system for region *i*	• Wealth proxied by ownership of durable items • Under-five mortality rate • Educational level • Membership of water users' associations • % of households reporting illness due to water supplies • % of households receiving a pension/remittance or wage

Use (U_i) Indicated by the level of water use by different sectors of the economy, and the economic returns from that use in region *i*	• Domestic water consumption rate • Agricultural water use, expressed as the proportion of irrigated land to total cultivated land • Livestock water use, based on livestock holdings and standard water needs • Industrial water use (purposes other than domestic and agricultural)
Environment (E_i) In the absence of any acceptable figures to represent environmental integrity or environmental water needs, these alternative proxy data were used	• People's use of natural resources • Reports of crop loss during last 5 years • % of households reporting erosion on their land • Ecological reserve as defined in the SA National Water Act of 1998 (the water required to protect the aquatic ecosystems of the water resource)

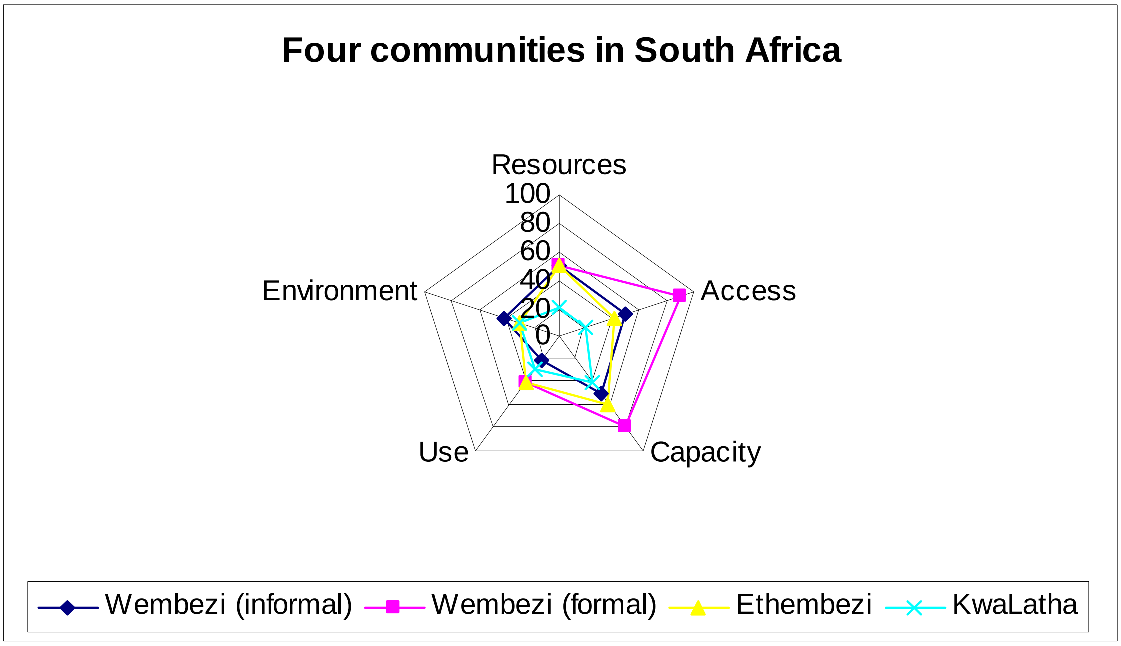

Figure 10 Graphical representation of the WPI for community assessment

(Source: Sullivan et al., 2002; Sullivan et al., 2003)

As the component scores of the WPI should ideally be as close as possible to 100, when improving water poverty Figure 5 can be interpreted as follows:

- In Wembezi (informal) the focus should be on the use component, improving it so that it approaches the optimum level of use.
- In Wembezi (formal) the focus should be on improving the state of the environment.
- In Ethembezi the focus should also be on improving the state of the environment.
- In KwaLatha both the resource and access components are virtually non-existent. As a lack of the actual resource will imply a lack of access to the resource, the focus should be on improving resource availability.

2.5 Water poverty

The question of the vulnerability of people, a community or an individual to water poverty has led to the definition of water poverty in terms of reduced water security (Cullis, 2005). Water security is a condition where people and communities have access to good quality water to meet their needs.

The concept of water poverty is based on ensuring that people have access to water. While people survive and live with poverty, perhaps all their lives, they simply cannot last without water for more than a few days (Hemson *et al.*, 2008). The livelihood of hundreds of thousands of people, or even millions of people, is threatened every time there is a drought or flood. On a global scale, in the 10 years from 1992 to 2001, the number of worldwide floods has increased from 57 in 1992, to 156 in 2001 (Clarke *et al.*, 2004), an increase of almost 200%. In the same 10-year period 277 574 people died worldwide of drought or drought-induced famine. Further worsening the situation are inefficiencies in usage, inequities in allocation and population growth. Secure and sustainable access to water is usually not governed by exclusive control as it depends on the societal rules that define who can get what, where and when (Soussan, 2003).

Sullivan (2002) draws a link between ‘water poverty’ and ‘income poverty’. A lack of adequate and reliable water supplies leads to low levels of output and health. According to Clarke *et al.* (2004), around 80% of diseases in developing countries are water-related, which translates to about 1.7 million deaths a year that are caused by dirty water. This translates to roughly 200 deaths per hour, or about 3 deaths per minute worldwide. Figure 11 is a graphical representation of the global deaths from dirty water for the year 2000, with all three the major contributors being from the developing world.

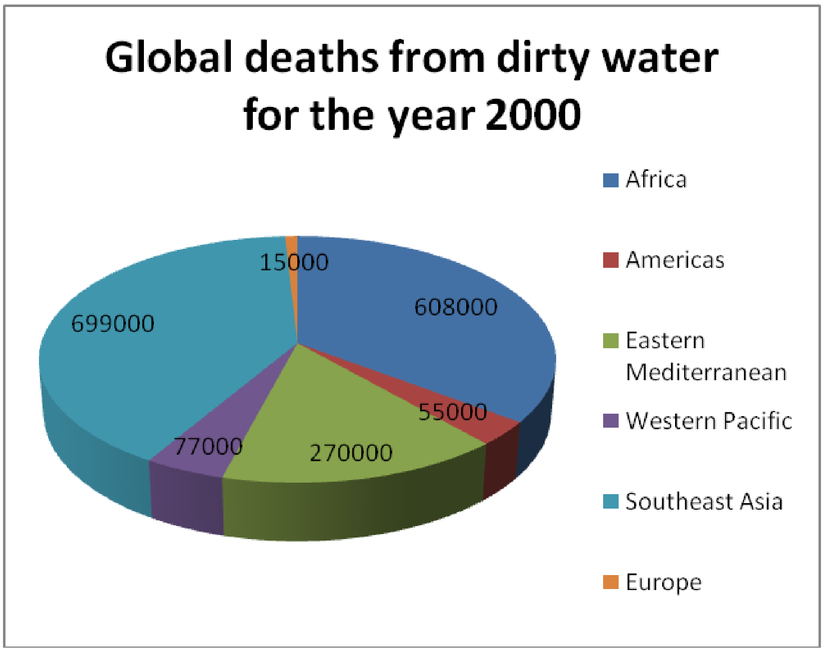

Figure 11 Global deaths from dirty water for the year 2000

(Source: Clarke et al. 2004)

Low income levels can prevent people paying the user cost (the price per Kilolitre (or Kℓ) of water that the water service provider charges consumers) of water even where water supply is adequate and reliable. This can drive people and communities to use inadequate and unreliable water supply sources. The underlying conceptual framework of a poverty index therefore needs to include the following: the capacity for sustaining access, the environmental factors which impact on water quality, the use of water, the availability of and accessibility to water, and the ecology which the water sustains. Availability of water means the water resources which can be drawn upon by communities and countries. Access includes safe water for drinking and cooking, as well as water for irrigating crops or for non-agricultural use (Lawrence *et al.*, 2002).

A step towards the development of a more comprehensive measure of water poverty was taken by Ohlsson & Turton (1999), who defined a Social Water Stress/Scarcity Index by linking an assessment of available renewable water (first-order water scarcity) to an assessment of adaptive capacity (second-order water scarcity) as defined by the Human Development Index (HDI). The HDI was developed by the United Nations Development Programme (UNDP) and ranks countries according to their performance in providing for their people (Oyen *et al.*, 1996). In the human development report for 2007/2008 that was set up by the United Nations, South Africa had an HDI score of 0.674, which gave the country a global ranking of 121. This approach not only measured the state of water scarcity in terms of the number of people without access to water, but also attempted to provide some indication of the underlying causes that define the concept of water scarcity and its impact on livelihoods. Hemson *et al.* (2008) state that water scarcity is a term that links the availability of water with its use, and that it is the result of the interplay between resource availability, consumption patterns and the management (or mismanagement) of the resources. Based on this measurement of water poverty, any country or community could be placed in one of four quadrants as shown in Figure 11. In figure 12 the adaptive status of an area increases with movement towards the right and the water resource of the area becomes more abundant with movement towards the top.

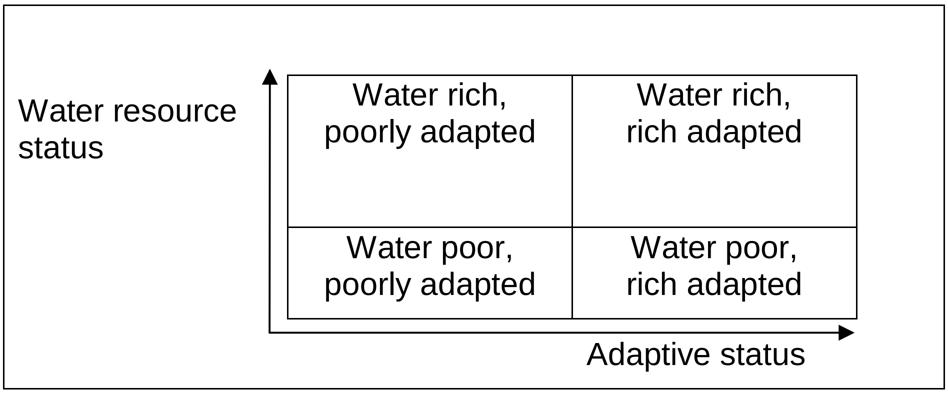

Figure 12 Water resources and adaptive capacity

(Source: adapted from Sullivan et al., 2002)

This comprehensive approach to measuring water poverty was taken forward by researchers at the Centre for Ecology and Hydrology in Wallingford, UK. They refined the Water Poverty Index (WPI) that was developed by Sullivan *et al.* (2002) in an attempt to quantify the link between water and poverty by combing hydrological data with socio-economic data to provide a complex indicator that reflects the true nature of a community and its access to clean water (Schulze & Dlamini, 2002). These researchers, along with experts from the World Water Council, calculated the WPI for 147 countries all over the world (World Water Forum, 2003). Table 3 shows the 10 countries that scored the highest on the index, as well as the 10 countries that scored the lowest, with the actual WPI value indicated in brackets. South Africa scored a WPI value of 52, which places it in the lower half of the table. Considering that 100 is the perfect goal score, its score of 52 places South Africa roughly in the middle order. This means that there is still a lot of room for improvement.

Table 3 Highest and lowest scores on the WPI

Highest scores	**Lowest scores**
1. Finland (78)	147. Haiti (35)
2. Canada (78)	146. Niger (35)
3. Iceland (77)	145. Ethiopia (35)
4. Norway (77)	144. Eritrea (37)
5. Guyana (76)	143. Malawi (38)
6. Suriname (75)	142. Djibouti (38)
7. Austria (75)	141. Chad (39)
8. Ireland (73)	140. Benin (39)
9. Sweden (72)	139. Rwanda (39)
10. Switzerland (72)	138. Burundi (40)

The majority of countries in the top ten are in the developed world, are water rich, and have extreme winters (i.e. snowfall), whereas all the countries in the lowest ten positions are in the developing world where there are relatively mild winters, and under-development plays a larger role in water poverty than the availability of the resource. Although 78 is quite a high WPI score, it is still a reasonable distance from 100, showing that even the countries that have no water ‘problems’ as such, can still improve.

2.5.1 Other water poverty indicators

Apart from the water poverty index, various other indicators exist. These indicators are briefly discussed below.

- **Falkenmark Water Stress Index (WSI).** The WSI measures the amount of water available in a country as a function of population (Gleick, 2002).

- **Water-Economy Investment, Learning and Assessment Indicator (WEILAI).** A composite indicator which was specifically designed as a tool for rural poverty alleviation project planning, monitoring and evaluation, as well as targeting and prioritisation (Cohen, 2007).

- **Benchmark indicator of water scarcity.** An indicator developed by Falkenmark and Gleick stating that a country with less than 1 000 m^3 of water per capita per year is a water-scarce country (Asheesh, 2004).

- **Water scarcity index.** An indicator that shows developments in the water situation of a riparian country. It points out the size of the gaps that should be covered or amounts to be returned into the system in order to secure the balance between available water and water demand (Asheesh, 2004).

- **Receiver Operating Characteristics (ROC).** A ROC curve resembles an inverted Lorenz curve. It plots the probability that a poor household will be classified as poor on the vertical axis, and it plots the probability that a non-poor household will be classified as a poor household on the horizontal axis. The convention is to link the ROC analysis to the incidence of type I and type II statistical errors. The curve illustrates how the two types of errors vary with the choice of a particular level of indicators. The area under the curve can be used to provide a statistical summary measure of the overall performance and predictive value of the underlying poverty targeting model (Maliki & Benhabib, 2008).

- **Water Resources Vulnerability Index.** An indicator that expresses total annual water withdrawals as a percentage of available water resources. Water withdrawals refer to the amount of water taken out of rivers, streams or underground aquifers to satisfy human needs for water (Rijsberman, 2005). A figure between 20 and 40% indicates water scarcity, and a figure above 40% indicates severe water scarcity.

- **Human Poverty Index.** The HPI is a poverty index that expresses poverty in terms of three factors (Putcha, 2008), namely:

    1. Probability at birth of not surviving to age 40.
    2. Adult literacy rate.
    3. Unweighted average of population without sustainable access to an improved water source and children under weight for age.

All of the indicators mentioned above do not provide sufficient detail, especially when working on a smaller scale. A high level of detail is required to allow targeting of resources to address specific problems. Table 4 summarizes the strengths and weaknesses of each of the indicators discussed above.

Table 4 Summary of the various water poverty indicators

Indicator	**Strength**	**Weakness**
Falkenmark Water Stress Index (WSI)	Indicates the total resources available per person.	Only looks at physical availability without looking at the state of the resource or considering the social and developmental factors of water poverty.
Water-Economy Investment, Learning and Assessment Indicator	Provides a lucid overview of where problems may exist at a local level.	Very costly, as an experienced interviewer takes 15 minutes to conduct a closed interview and complete the WEILAI questionnaire for a household.
Benchmark indicator of water scarcity	States whether a country should be classified as water scarce or not by looking at available water per capita per year.	Only looks at physical availability without looking at the state of the resource or considering the social and developmental factors of water poverty.
Water scarcity index	Indicates the amount of water that is being over-utilized, i.e. how much water should be returned into the system to restore the balance between available water and water demand.	Only looks at physical availability without looking at the state of the resource or considering the social and developmental factors of water poverty.

Receiver Operating Characteristics (ROC)	Makes targeting more effective and also makes it possible to determine truly poor households on one side, and the variables to select as pertinent targeting indicators on the other.	Uses non-hypothesis testing, requires large samples and capitalizes on chance.
Water Resources Vulnerability Index	Indicates the total annual withdrawals as a percentage of available water resources.	Does not consider how much water could be made available for human use, how much water is consumptively used, or what a society's adaptive capacity to cope with stress is.
Human Poverty Index	Indicator of the standard of living in a country.	Does not include important factors like the economy of the household.
Water Poverty Index (WPI)	It provides a better understanding of the relationship between the physical availability of water, the level of welfare, and its ease of abstraction. It is a mechanism to prioritize water needs and a tool for monitoring progress in the water sector.	Needs the appropriate degree of institutional acceptance and political will which will allow the index to be used as an objective criterion for addressing water poverty.

2.5.2 Priorities of water allocation

According to Pallett (1997), clearly defined policy rarely governs the allocation of water in the real world. Especially in Southern Africa, the two major causes of inefficiencies in allocation are related to formal rights as well as historical rights to water. An example of formal rights to water is the idea that owning property next to the river entitles you to use the water in the river, and an example of historical rights is the idea that the first person or entity that arrives at a water source has the right to use the water from that source. Listed below are the four priorities which, according to Pallett (1997), should govern water allocation, in decreasing importance:

1. **Basic** consumption. The water required by humans for survival, sanitation and health.

2. **Environmental** consumption. The water used by ecosystems in order to function.

   The above two consumption categories are crucial for sustaining life, and have to receive the amount of water they require. The consumption of these two categories should determine the amount of water that is available for categories 3 and 4, and not the other way round.

3. Consumption for **production** purposes. Water used for production purposes include:

   - Mining, industrial and manufacturing use.
   - Agricultural use (usually the largest water consumer).
   - Household use other than basic human needs.

4. Water use for **navigation (or transport) and recreational** purposes.

Since the hydrological state often differs between countries or even between regions within a country, the above-mentioned priorities might change slightly depending on the needs of the country or region. Whatever a country's needs might be though, basic consumption should always remain the main priority for water allocation.

2.5.3 The South African context

South Africa's water resources are limited and in global terms are scarce (Hemson *et al.*, 2008). When the country's average annual rainfall of 464 mm (SouthAfrica.info, 2008) is compared to the global average of 860mm, it becomes even clearer that South Africa is a relatively dry country. South Africa is a semi-arid country and about 65% of the country receives less than the average annual rainfall. The average annual evaporation is roughly four times the average annual rainfall, and consequently the country has been rated as one of the 20 most water-deficient countries in the world (Meyer, 2007).

Water resources are not spread evenly across the country, and many cities and industrial centres find themselves far away from major water resources, a situation which is worsened by periodical floods and droughts. According to Clarke *et al.* (2004), the eastern part of the country has a major groundwater basin with highly productive aquifers, whereas the western part of the country is an area with generally poor aquifers. According to Pallett (1997), water management in Southern African countries has in the past focused too much on the technical side of supplying water, i.e. pipes, dams, etc. Although the technical side has its place, the environmental, economic, social and political aspects have unfortunately often been neglected. South Africa is no different, as it is highly dependent on dams as a solution to its massive water shortage, which according to Newson (2009) is a result of its colonial past, engineering skills and relative wealth.

South Africa has a high unemployment rate, which means that many people simply cannot afford to pay for basic water and sanitation, and adding to the problem is many people who can afford to pay do not, because they consider it a right (Holland, 2005). This lack of willingness to pay is a major concern. Recently DWA Minister Buyelwa Sonjica stated that the funding that will be required over the next three years for the required up-skilling, additional staff hiring and infrastructural water and sanitation repairs is expected to be in the region of R100 billion (Bateman, 2010). A major step taken by South Africa in its water poverty alleviation efforts was the introduction of the free basic supply of water regulation in 2001 (DPLG, 2001). According to the World Health Organisation (WHO), a person requires roughly 25 litres of water per day for healthy living. Assuming eight people per household, the standard was set at 6 000 litres of free water per household per month (Hemson *et al.*, 2008). Unfortunately many municipalities experienced difficulties in implementing the free basic water supply regulation, and by 2002, a year after the introduction of the regulation, only 57% of the population was receiving their free basic water supply (Holland, 2005). In 2006 this figure has climbed to 35 300 000 people or roughly 73% of the population receiving their free basic water supply (DOH, 2006). By 2010, every household in the Emfuleni Local Municipality was receiving their 6 Kℓ of free basic water per month (ELM, 2010).

Table 5 contains some facts relating to South Africa's water needs, resources, uses and abuses, as calculated in 2000 (from Clarke *et al.*, 2004).

Table 5 South African water facts

Aspect	**Value**
Total population	43 300 000
% of population with access to improved water source	86%
% of population in demarcated area of study with access to improved water source (ELM, 2007)	91%
% of population with access to improved sanitation	87%
% of population in demarcated area of study with access to improved sanitation (ELM, 2007)	86%
Internal renewable water resources	1 034 m^3/capita/year
% of renewable water originating outside country	10%

Annual groundwater withdrawals	65 m^3/capita
Annual domestic water use	59 m^3/capita
Annual agricultural water use	257 m^3/capita
Annual industrial water use	37 m^3/capita
% of total crop area under irrigation	8%
Organic water pollutants emitted	17 kg/capita/day
Wetlands of international importance	499 000 hectares

As the overwhelming majority of the earth's water resources are salt water, desalination might be considered a possibility (desalination is the conversion of salt or brackish water into fresh water). South Africa has a relatively large coastline with a desalination capacity of roughly 80 000 m^3/day (Clarke *et al.*, 2004). The desalination process requires a lot of energy and some expensive technology, which in turn requires a lot of water, either for energy generation or for cooling (see Western Cape Reconciliation Strategy (or WCRS), DWAF (2005), where desalination was considered as an option to augment the Western Cape's water supply). Desalination should therefore not be considered a viable general alternative for South Africa, but rather a last resort. Although it might be an option in relatively affluent areas, their high cost means that the poor simply cannot afford it. The WCRS estimated that the cost to produce one m^3 of water will vary between R9,80 and R11,60/m^3, whereas the Rand Water tariff per m^3 of water is in the region of R5.

2.5.3.1 The National Water Act

The National Water Act No. 36 of 1998 of South Africa (NWA) re-established water as a public good in South Africa, with the responsibility of allocation being held by the state (Newson, 2009). Under the Act basic human needs include water for drinking, food preparation and personal hygiene. The principal political drive of the 1998 NWA is the allocation of scarce resources, and includes the following policy principles (Newson, 2009):

- ‘Some for all’, rather than ‘all for some’.
- The user pays.
- Development should be command driven and community based.
- Environmental integrity.
- Basic services are a human right.
- Water has economic value.
- Integrated development.
- Equitable regional allocation of resources necessary for development.

The authority of the NWA was further amplified by the 1996 Constitution of South Africa, according to which access to sufficient food and water, and more specifically clean drinking water and proper sanitation, is a right of every citizen of the country. Through the NWA the government sent a very strong signal that it would use the power of state to support the most vulnerable before it supported anyone else (Swatuk, 2010). This was achieved through the free basic water provision of 6 Kℓ/household/month, along with the environmental reserve provision, which ensures the survival of the ecosystems supported by the water resource.

2.5.3.2 The municipal indigent policy

In 2005 the Department of Provincial and Local Government (DPLG) created a policy that provides a basis for the provision of free basic services to the indigent. These basic services include free basic water and sanitation, free basic electricity and a zero rating of low value properties in terms of the Municipal Property Rates Act No.6 of 2004 (DPLG, 2005). According to this policy, an indigent is someone who '*lacks the necessities of life'.* In a broad sense, these necessities typically include:

- Housing.
- Sufficient water.
- Food and clothing.
- Basic sanitation.
- Environmental health.
- Basic energy.
- Refuse removal in denser settlements.
- Health care.

Under this policy, people who have been classified as indigent, and have undergone a successful registration process, will receive their basic services free of charge. Instead of the local municipality carrying this financial burden, they will be reimbursed by the state. The main objective of this policy is to substantially eradicate those elements of poverty over which local government has control by 2012 (DPLG, 2005). In the region of 21 000 indigents were registered at one of the major local municipalities in the area under consideration on 30 June 2009, the end of their financial year.

2.5.3.3 The looming acidic mine water crisis

The Witwatersrand region of South Africa's Gauteng province used to be home to some of the richest gold reserves in the world, and as a result many mining companies have come and gone. This has left behind many abandoned mine shafts and tunnels which have been filling up with acidic water at an estimated rate of between 35 to 40 cm per day due to acid mine drainage (Waterlovers, 2010). *"Acid mine drainage is formed by a series of chemical reactions that occur between water and sulphide minerals, such as* *pyrite and oxygen, which combine to form an iron-rich sulphuric acid solution",* Ramontja (2010:85). In recent years some of the acid mine drainage (AMD) containing salts, heavy metals, and particularly radioactive uranium, which typically accompanies the gold in the mined reefs, have started decanting along the West and East Rand of the Witwatersrand. The situation has become so serious, that the National Nuclear Regulator of South Africa has declared some of the sites where the AMD water has surfaced as access-restricted radiation areas (Winde & Stoch, 2010). Unfortunately the uranium is not only found in the groundwater, but also in surface water, quite often in much higher concentrations. By 2012 AMD will start decanting in some of the low-lying urban centers of Boksburg and Johannesburg. Acid mine drainage water also has a very high pH level, in addition to the various toxic heavy metals it carries. The detrimental effects of acid mine drainage include (Rainharvest, 2010; Ramontja, 2010):

- Regional impacts on major river systems.
- The decreasing quality of water supply.
- The degradation of human health and welfare.
- Serious negative ecological impacts.
- The destruction of nature and eco systems, infrastructure and heritage sites.
- The poisoning of harvests.
- Localized flooding in low lying areas.
- The corrosion of the foundations of buildings and the formation of sinkholes when the AMD water gets too close to the surface.

Further adding to the problem is the issue of up-to-date mining databases. These databases should typically include all mining related data, as well as detailed plans or maps of the underground network of shafts. With sufficient and accurate data in these databases, predictions with regards to future AMD damage and possible decant points will be much more effective and accurate (Winde *et al.,* 2010), thereby aiding the attempted minimization of the consequences.

A recent step taken by the DWA was a directive that was issued by them. The directive ordered a mine that was responsible for the decanting of AMD water, to capture the decant water, and after reducing the levels of uranium, sulphate and iron levels in this water, to release it back into the surface water system (Winde *et al.,* 2010). All of this has taken place despite the fact that various technologies exist to combat acid mine drainage that both mines and government are aware of (Rainharvest, 2010). The treatment technologies that are available for the treatment of AMD can be classified as active, passive or in situ methods (Ramontja, 2010). "*Global experience has shown that there will not be one single treatment method that can be used in every situation and that appropriate treatment methods need to be selected from the range available for each mine water type encountered"*, Ramontja (2010:71). Active treatment usually requires the construction of a treatment plant with a variety of reactor systems, and tends to be a quite expensive option. Passive treatment involves the improvement of water quality using only naturally available energy sources. This has the advantage of only needing infrequent maintenance to ensure efficient operation of the system. In situ treatment typically involves the introduction of alkaline material into the mine water body, and is not a relevant method for the Witwatersrand area (Ramontja, 2010). Although the national government is responsible for a large proportion of the rehabilitation costs involved, due to the fact that the majority of the mining took place before environmental laws were in place, mining houses also have to contribute their share as they did not have the appropriate processes in place.

Figure 13 is an example of the damage that can be caused by acid mine drainage. On the right of the image is a healthy, clean stream/ecosystem, and on the left hand side is the same stream/ecosystem after it has been damaged by exposure to acid mine drainage.

Figure 13 Example of acid mine drainage damage

(Source: STOP Mountaintop Removal Coal Mining http://endmtr.com/2008/09/21/pollution-continues-long-after-mining-has-ended/)

2.6 Poverty mapping and geographic targeting

Policy makers or planners need information to focus their efforts for maximum impact. Poverty mapping involves a visual (graphical) presentation of certain welfare indicators in a spatial context (Cullis, 2005; Henninger, 1998). Visual (graphical) representations are a very effective and understandable way of communicating information to the various stakeholders and role players, as no knowledge of the underlying data and its transformation is required.

Geographic targeting is a term used to describe efforts that are focused on a specific key area. Miller (1996) observed that poverty exists in pockets caused by a combination of individual and structural factors. This idea of pockets supports the idea of geographic targeting. Pockets can be fairly easily identified in urban and rural areas and poverty maps can be used as a cost-effective way to facilitate geographic targeting for the development of the poor (Bigman & Fofack, 2000). O'Hare (2000) illustrated how mapping can even be used to analyse a disaster-struck area and its population, so that geographic targeting can guide relief efforts to where it is needed the most.

Poverty can be reduced by using geographic targeting (Cullis, 2005) but geographic targeting will not work in all situations (Gomez-lobo, Foster & Halpern, 2000). Examples of where geographic targeting will not work include using maps that are out of date, that are of the wrong scale, that contain unreliable information, etc.

2.7 Water poverty mapping

Cullis (2005:8) defines water poverty mapping as *"the mapping of indicators of water poverty aggregated to a suitable spatial scale"*. Water poverty mapping is used to identify areas of high levels of water poverty with the aim of assisting in the targeting of water-related policies to ensure the most efficient use of resources to meet the development objectives of the country. The strengths of the Water Poverty Index (WPI), poverty mapping and geographic targeting are combined in water poverty mapping (Cullis, 2005).

The concept of water poverty mapping as a policy tool was introduced by Cullis (2002) by way of a small case study of the Estcourt Municipality in South Africa. In 2005 Cullis expanded the concept by constructing a water poverty map for the Eastern Cape Province in South Africa. Figure 14 is the resulting provincial water poverty map for the Eastern Cape on a municipal scale. A darker shade of blue indicates a higher WPI value for a municipality, and a lighter shade of blue indicates a lower WPI value for a municipality.

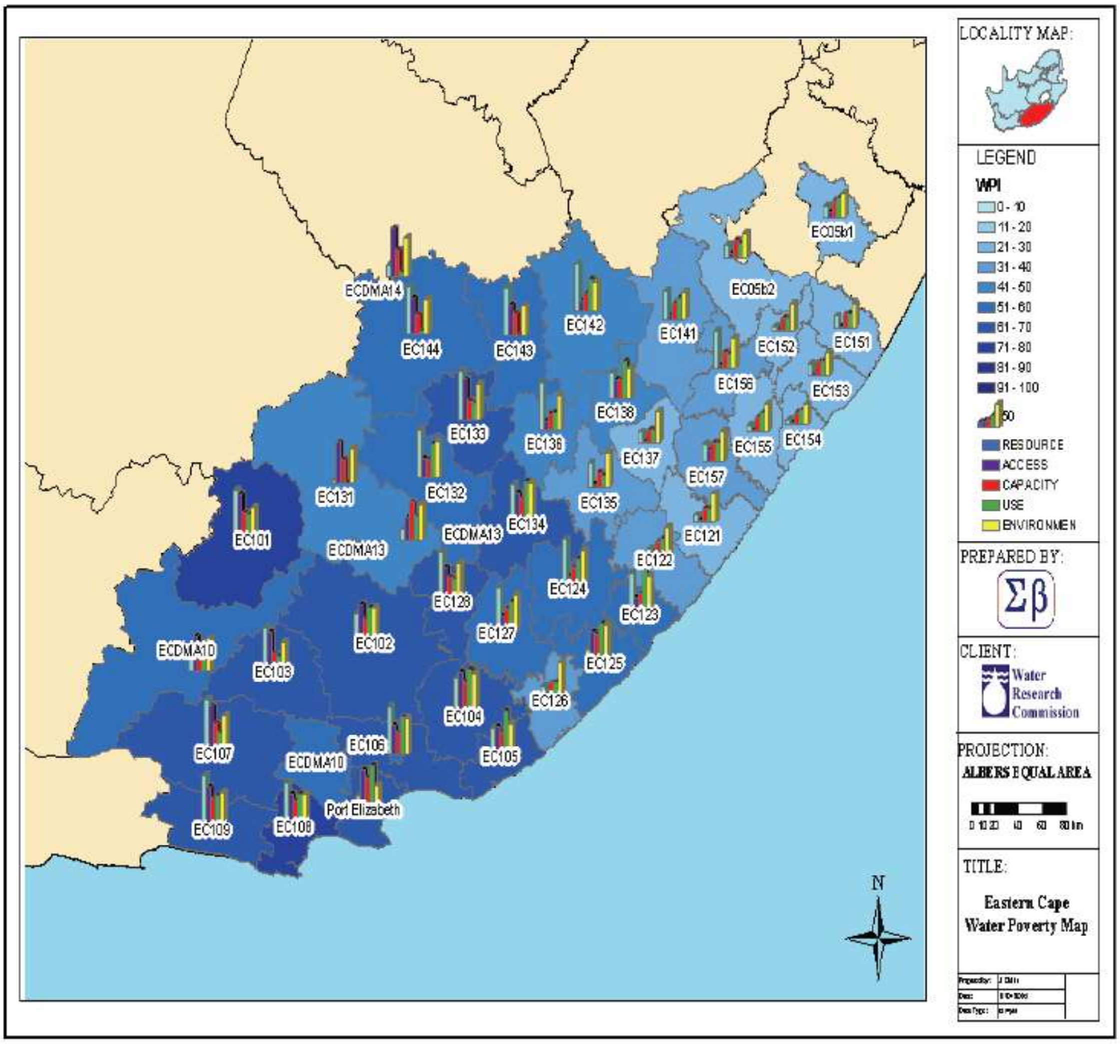

Figure 14 Provincial water poverty map on a municipal scale

(Source: Cullis, 2005)

Based on the research that has been done by Cullis (2002; 2005) on the WPI and WPM in the South African context, especially on the relevant variables to be used and different scales, his steps and processes will be used as a guideline for this research.

Figure 15 is an example of an international water poverty map on a national scale. Once again the majority of the developing world have low WPI values and are therefore classified as having severe or major water poverty problems.

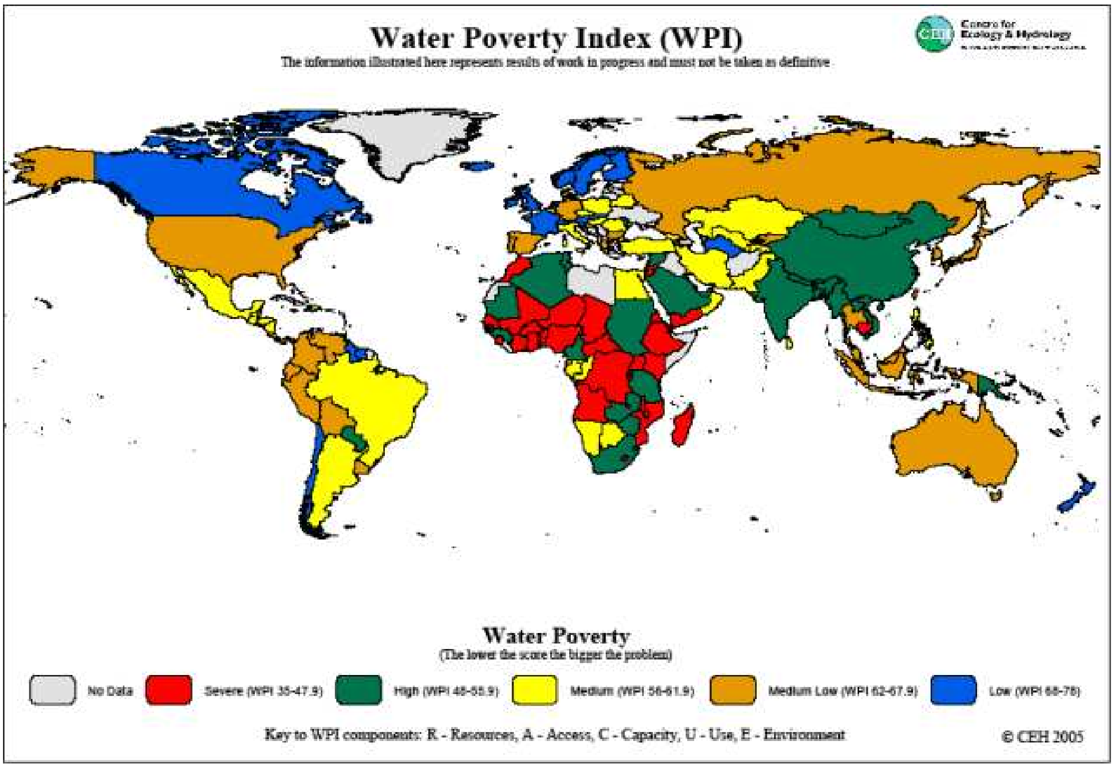

Figure 15 International water poverty map on a national scale

(*Source: The Oxford Centre for Water Research http://ocwr.ouce.ox.ac.uk/research/wmpg/wpi/#links*)

Water poverty mapping can utilise many of the benefits provided by GIS-based mapping, a selection of these benefits are listed below (Henninger, 1998; Cullis, 2005).

- Internationally compatible poverty maps, applying a constant set of indicators at sub-national level, can improve the decision making and strategy planning of international development organisations.

- Maps are a powerful visual tool and are more easily understood by a wider audience of stakeholders, particularly in developing countries.

- WPMs can not only help in our understanding of the spatial nature of water poverty, but the use of layering can also be useful in identifying the underlying causes of water poverty in an area.

- A GIS WPM makes it easier to integrate data from different sources and allows the switch to new units of analysis from, for example, administrative boundaries to ecological boundaries such as sub-catchments.

- Water poverty maps can be expanded to include political factors as well as ecological factors, such as water and environmental quality not included in traditional poverty surveys.
- Water poverty maps can be produced at a number of different resolutions depending on their purpose and the cost guidelines of data collection.
- The spatial nature of water poverty, such as the distance to the nearest water source or the water supply infrastructure, can also be incorporated easily in a GIS and used in the calculation of the WPI.

2.7.1 The role of water poverty mapping

Water poverty maps can be used to monitor the water poverty in an area, and as a result identify areas in which efforts and resources should be focused. The water poverty map can also indicate the type of intervention that would be the most appropriate. For example, if the score of the access component was the lowest in a specific area, efforts and resources should be focused on providing more access to water, or if the capacity component scored the lowest, capacity should be built by increasing access to education and by creating jobs, etc. Water poverty mapping provides an evaluation and monitoring tool that is much more comprehensive than existing water poverty indicators (as discussed in section 2.5.1). As a result a great degree of efficiency is achieved in using scarce resources to meet water-related development objectives (Cullis, 2005).

2.7.2 Different maps for different uses

The intended purpose of the monitoring tool should be very clear. The complex nature of the role that water plays in achieving a variety of development objectives makes it particularly true in this case (Cullis, 2005).

The intended purpose of the water poverty mapping exercise must define the scale of aggregation, the selection of the supporting indicators, and the relative weighting of the indicators and components in the calculation of the final water poverty map. This flexibility makes it possible for a variety of stakeholders to use water poverty maps. *“Each of these users has different requirements which result in water poverty maps that are unique to a specific objective and differ in terms of scale, indicators and weighting factors”* (Cullis, 2005:10).

2.7.3 Scale issues when developing a water poverty map

One of the most important considerations in water poverty mapping and geographic targeting is the selection of an appropriate scale (Cullis, 2005), and the appropriate resolution of any water poverty map depends on the kind of information required, the environment under consideration and the study’s objectives (Stephen & Downing, 2001). If the resolution is too coarse the map is of little use for many applications as it neglects the heterogeneity within each unit. Smaller scales are more useful to create the patterns that identify those who could possibly be water-poor (Stephen *et al.*, 2001). These local level factors are of particular importance when dealing with complex and multivariate problems such as water poverty (Fotheringham, 1997). A balance needs to be struck between the assumption of homogeneity and the additional logistics and costs of producing a more detailed map (Henninger, 1998). The question of whether information about a particular phenomenon occurring at one scale can be applied to another scale, and the empirical issue of spatial resolution, have still to be answered, particularly in the social sciences (Gibson *et al.*, 2000). Stephen *et al.* (2001) argues that the real world is not constant at all scales, as the presence of fractals in the mapping sciences tends to show. It is therefore very important to use the right scale when using geographic targeting for development policies. If, for example, a household-level development policy, such as a food subsidy or a basic water supply system, is targeted at households defined as poor at the sub-catchment or provincial scale, and it turns out that the factors determining the poverty level differs at the sub-catchment or provincial level to what they are at the household level, then the policy will fail in its attempt to address the needs of the poorest households (Cullis, 2005). This implies that a coarser resolution should be used to ensure that the correct households are being targeted when trying to address poverty at a household level. Dlamini, Schulze & Jewitt (2003) show that the difficulty of selecting a suitable spatial unit for evaluating multidisciplinary indices such as the WPI is an inevitable consequence of their multidisciplinary nature as the components are suited by different scales and spatial units (Cullis, 2005).

2.7.4 Water poverty mapping in South Africa

"Water poverty mapping is faced with the dilemma of balancing the importance of measuring water poverty at the household level with the cost of gathering the data necessary to put together a detailed household-level water poverty map" (Cullis, 2005:11). Table 6 gives the percentage of the total population in developing countries with access to safe water, and is included to indicate the global scale of the problem.

Table 6 Percentage of the total population in developing countries with access to safe water

(Source: Jolly, 2003)

	1970(%)	1980(%)	1990(%)	2000(%)
Urban Population	67	75	95	94
Rural Population	14	29	66	71
Total Population	29	43	79	82

Hemson *et al.* (2008) state that although the statistics show an appreciable increase for the decade 1980 – 1990, the mere increase of 3% for the decade 1990 – 2000 is a major cause for concern, and overall not nearly enough has been done to address the problem (the problem of providing access to safe water). This is further highlighted by the fact that it is estimated that in 2000 there were still roughly 1.1 billion people on the planet without access to safe water (Hemson *et al.*, 2008). In a South African context, as South Africa is also seen as a developing country, this equates to roughly 10 million people without access to safe water.

2.7.4.1 Water poverty maps for strategic and regulatory purposes

Cullis (2005) proposes that if there is a division in responsibilities to manage water, for example at the regional and national level, water poverty maps at different scales and with different supporting indicators be developed for these two different sides (regional and national) of water management. These maps have to be in line with their different focus areas, requirements, aims and objectives.

Socio-economic-focused water poverty maps

It is clear from the research by Ahmad (2003) that only the current state of water poverty and not the process is measured by current systems that identify water-poor municipalities in terms of water supply backlog. A water-poor municipality can either be described as one without enough water resources available to meet the demand, as one without enough access to safe water due to insufficient infrastructure, or both. Water poverty mapping measures not only the state of water poverty (i.e. in terms of access) but also gives an indication of the underlying causes of this water poverty in terms of the available supply, capacity and use (Cullis, 2005). It is important that the municipalities that need assistance, as well as some indication of the type of assistance required to address this water poverty, be identified – an issue that the water poverty map will address.

"*If, for example, the WPI of a municipality was low due to limited access, but there was sufficient available resource, then the development of water supply infrastructure should be encouraged. If, however, the WPI was low due to limited capacity, then DWAF should encourage job creation to improve individual capacity to purchase water before they consider introducing more than a basic level of service*" (Cullis, 2005:13).

Water resource-focused water poverty maps

If the objective of the water poverty map required is clearly defined, it could be expanded to include other water uses such as irrigation and industrial usage (Cullis, 2005; Dlamini *et al.*, 2003). It might be possible to identify catchments where water resource development may not be the solution because of an already high resource component, but potentially a low access which may be due to low capacity or low environmental quality leading to low use. As a result, different strategic approaches are necessary to address water poverty in these catchments and may require co-operative management (Cullis, 2005). For example, an increase in employment capacity in an area could be encouraged or environmental pollution of the resource could be reduced. A more complex problem arises when one has to decide on the most beneficial allocation of water in a catchment when faced with the challenge of comparing different types of water use. This is much more complex than measuring water poverty in terms of domestic water supply only (Cullis, 2005).

2.7.4.2 Water poverty maps for local implementation purposes

For the purpose of implementation, the water service provider needs to know which areas within the local municipality have to be targeted first in order to reduce household water poverty. The water poverty map, at a finer resolution, is ideal for this purpose as it would be able to pick up the small-scale issues that are often the most significant in terms of water poverty (Cullis, 2005). On the regional level, the small-scale water poverty map would be useful for making a first-order estimate of the most appropriate way of addressing water poverty in the targeted areas.

At this level of detail, household information on capacity and use would have to be obtained either from Census data at a finer resolution than for the more strategic-level water poverty maps or from municipal records of water use, and in some cases even from selected household surveys (Cullis, 2005). A GIS will be very beneficial in this case as much of the information that will have to be collected would be spatial in nature. An example is the information on the distances to communal taps and the number of people using a particular tap, which will influence the access of individual households to this water supply (Cullis, 2005).

The location of bulk distribution systems could be used to give a more complete description of the available resources, which is required for the implementation of water supply systems by municipalities. Municipalities can use these more detailed water poverty maps for implementation planning and to show other stakeholders how the allocation of funds for water supply services has impacted on water poverty and why certain areas were specifically targeted. "*This would provide an important feedback mechanism to ensure that the allocated resources are being used efficiently. The use of a comprehensive measure of water poverty such as the WPI would also provide a far better tool for monitoring the performance-based outcomes of the WSDP, in terms of addressing water poverty*" (Cullis, 2005:15). To reduce water poverty, a comprehensive, outcomes-based monitoring tool such as that provided by the WPI and water poverty mapping is required.

2.8 Conclusion

In this chapter the various facets of water, water poverty, water management and some threats to our continued supply of potable water have been discussed. The chapter started off with a section on water management, in which total water management, natural resource management, and water management issues and challenges were discussed. The chapter continued with a section on poverty and poverty research, followed by a section on water poverty, which included subsections on the water poverty index, other water poverty indicators, priorities of water allocation, and the South African context. As part of the South African context discussion, the National Water Act, the municipal indigent policy and the looming acidic mine water crisis, which is seriously threatening Gauteng's and the country's water supply, were discussed. The chapter concluded with sections on poverty mapping and geographical targeting, as well as water poverty mapping, under which were subsections on the role of water poverty mapping, different maps for different uses, scale issues when developing a water poverty map, and lastly water poverty mapping in South Africa.

The next chapter looks at the formulae and theory behind the calculation of each of the WPI components. It also discusses the benchmark levels of each component along with the various weighting options that are available for the WPI.

3 Research methodology and component calculation methods

3.1 Introduction

According to Bensimon, Polkinghorne, Bauman & Vallejo (2004), one of the major problems with research is the gap between the research and the policymakers and practitioners. Possible solutions for closing this gap could be studying problems that are of greater relevance to policymakers and practitioners, and possibly by more effectively disseminating the results obtained from it. However they suggest that instead of the researcher initiating a research project and merely disseminating the results to the practitioner, the practitioner should be involved with and cooperate with the researcher from the start, which will greatly enhance the value and usefulness of the study. In this research it was achieved by working with representatives from both the local municipality and the bulk water service provider right from the inception of the research. As mentioned in Sections 2.7.2 and 2.7.3, the intended purpose of the final water poverty map should govern the scale on which it is constructed, as well as the choice of components and individual indicators to be included in the calculation. The intended purpose of the water poverty map has to be defined by the practitioner or policymaker, and excluding them from this process will most likely jeopardize the validity of the map and the recommendations and conclusions drawn from it.

According to Cullis (2005), the five components that form part of the WPI and therefore water poverty mapping are based on the idea that that poverty inevitably leads to capability deprivation. This in turns influences a person’s ability to gain access to a sustainable water supply, and therefore impacts negatively on health. *“The five components of the WPI recognise that any measure of water poverty must include not only the physical availability of the resource, but also the socio-economic, political and environmental entitlements that govern a person's ability to command a secure and sustainable access to the resource in order to sustain a healthy livelihood”*

(Cullis, 2005:5). Water poverty therefore encompasses a number of factors such as water availability, access to water, capacity for sustaining access, the use of water and the environmental factors which impact on water quality and the ecology which sustains the water resource (Lawrence *et al.*, 2002).

3.2 Research methodology

According to Warfield (2010), Information Systems/Information Technology (or IS/IT) research typically involves both technology and business, and this invariably leads to the combining of different disciplines and paradigms. To achieve good research, researchers should follow the standards of the scientific method to generate dependable data through professionally conducted practices (Swanson & Holton, 2005). According to Galliers & Land (1987), research in an applied topic or field can be considered successful when the knowledge that has been obtained through the research can be applied successfully in practice. If the research has produced conflicting or misleading results, the researcher should typically reconsider the method and the design of the research, especially if it was conducted in an established field. *"Our research methods must take account of the nature of the subject matter and the complexity of the real world"* (Galliers *et al.*, 1987:901). According to Baker (2001), the cycle of scientific research in the pure sciences would typically follow the following sequence:

1. The problem, a rebuttal of existing theory or expectation.
2. The proposed solution, a new theory or hypothesis.
3. Deduction, of testable propositions from the new theory.
4. Tests, attempted refutation including observation and experimentation.
5. Preference, established between old and new theory.

The next few subsections will look at some of the various research methodologies, strategies/designs and data collection methods that are available to the researcher, as well as highlighting the options that have been applied in this research.

3.2.1 Research methodologies

Traditional purists argue that research has to be conducted from within either the quantitative methodology (with a predominantly positivist view) or the qualitative methodology (with a predominantly interpretivist view). However, the pragmatist movement argues that there are more similarities between the quantitative and qualitative perspectives than there are differences, and therefore should be used in combination (Onwuegbuzie & Leech, 2005). It is therefore clear that whatever research methodology has been chosen, it ultimately determines validity in the research and the value of the research (Warfield, 2010).

3.2.1.1 Quantitative methodology

Under the quantitative methodology researchers use the scientific method, which starts with the specific theory and hypotheses, and then quantitatively measure and analyze based on established research procedures (Swanson *et al.*, 2005). It typically consists of five steps which include:

1. Determining the basic questions to be answered by the research.
2. Determining the participants in the research. Quantitative research benefits greatly from generalizability, or being able to draw conclusions about a population from sample data.
3. Selection of methods to answer the research questions.
4. Selection of statistical analysis tools for analyzing the collected data.
5. Performing the interpretation of the results of the analysis based on the statistical significance determined.

3.2.1.2 Qualitative methodology

Under the qualitative methodology researchers approach the research from the researcher as an observer perspective, with data collection and interpretation through contact with the field (Miles & Huberman, 1994). These interpretations are often influenced by the philosophical assumptions of the researcher, and typically include ontological beliefs, epistemological beliefs, axiological beliefs, rhetorical beliefs and methodological beliefs (Creswell, 2007). This has caused qualitative researchers to acknowledge that their views invariably influence their research, and are the basis for the research results (Warfield, 2010).

3.2.1.3 Mixed method

Mixed methods research combines or mixes quantitative research and qualitative research in the same study or a series of studies (Swanson *et al.*, 2005). It evolved from researchers who started realising that aspects from both quantitative and qualitative research were required in order for them to answer their research questions. This view is supported by Onwuegbuzie *et al.* (2005), who also argue that a combination of both methodologies should be used as both have inherent strengths and weaknesses. According to Warfield (2010), mixed methods research is a three stage process, namely:

1. Determine whether the study is a confirmatory or exploratory study.
2. Determine the type of data collection and operation.
3. The type of data analysis and inference.

Onwuegbuzie *et al.* (2005) refer to researchers that apply mixed methods research as pragmatic researchers. According to them pragmatic researchers enjoy the following advantages over mono-method (purely quantitative or purely qualitative) researchers:

- More likely to promote collaboration among researchers, regardless of philosophical orientation.
- Flexibility in their investigative techniques.
- Having the opportunity to combine the macro and micro levels of a research issue.
- More likely to view research as a holistic endeavour.
- More able to combine empirical precision with descriptive precision.
- In a better position to use qualitative research to inform the quantitative portion of research studies, and vice versa.

3.2.2 Research strategies/designs

According to Denscombe (2003), putting together a good piece of research is not something that can be achieved by blindly following a set of prescriptions about what is wrong and what is right. Numerous options are available, each with its own advantages and disadvantages, and gains in one will inevitably lead to losses in another. *"The crucial thing for good research is that the choices are reasonable and that they are made explicit as part of any research report",* Denscombe (2003:3). The following are some examples of various research strategies (Denscombe, 2003; Baker, 2001; Naess & Saglie, 2000):

- Surveys, or viewing with the aim to obtain detailed data about the situation.
- Case studies, which focus on one instance of a particular phenomenon with a view to provide an in-depth description.
- Internet research, or e-research, which provides access to huge volumes of data at a relatively low cost.

- Experiments, with the aim to isolate individual factors and to observe their effect in detail.
- Action research, normally associated with hands-on, small scale research projects with the focus on practical issues.
- Ethnography, which aims to provide a detailed and permanent account of cultures and peoples.
- Phenomenology, a research strategy that typically deals with people's feelings and emotions, attitudes and beliefs, and perceptions or meanings.
- Grounded theory, where theories are developed on the basis of empirical research, which then build up general theories that emerge from the data.

3.2.3 Data collection methods

According to Melville *et al.* (1996), any data collection instrument should produce measurements that are reliable and valid, i.e. measurements that are consistent and correct, and suggest the following data collection methods especially for science and engineering students:

- Laboratory work.
- Modelling and simulation, which includes models, simulations and written simulations.
- Data from people, which includes questionnaires and interviews.

As this research uses both primary data analysis and secondary data analysis it is important to distinguish between the two. Primary data analysis refers to the analysis of data that has been collected as part of the study, and secondary data analysis refers to the analysis of data that has been collected previously. According to Doolan & Froelicher (2009), the use of secondary data analysis is appropriate if an existing data set is suitable for answering new research questions as the research can then be completed in less time and for less money.

3.3 Component benchmark levels

As discussed in Section 2.4, the WPI consists of five components, namely resource, access, capacity, use and environment. These five components all have different scales and different units of measurement, and the only way in which they can be combined and compared is by converting each indicator value to an indicator score (Cullis, 2005). The ability to integrate data with different scales neatly encompasses many of the institutional, social and scientific dilemmas inherent in water management (Newson, 2009). All the components, except resource and use have absolute maximum values, whereas resource and use have optimum levels of use, with anything above or below this level adjusted accordingly. The benchmark level of each component will be mentioned along with the discussion of its calculation in Section 3.4.

3.4 Component calculation

The following sections discuss the calculation method for each of the component values, its benchmark level and the calculation of the final score that will be used to calculate the WPI. The indicators to be used for the various components as well as the benchmark levels have been selected according to the guidelines developed by Cullis (2005).

3.4.1 Resource

In the traditional WPI, the resource component is expressed in terms of the total surface water and groundwater resources that are available in an area, measured in m^3/c/a (m^3/capita/annum). When using this measurement a minimum benchmark level (usually 0 m^3/c/a) has to be used along with some or other maximum benchmark level. To obtain the final resource component score the resource component value is then merely expressed as a percentage of the maximum benchmark level.

Every five years the bulk water service providers undergo a process whereby they acquire a permit from the Department of Water Affairs and Forestry (DWAF). The permit states how much water they may extract from the water system, and this amount is based on ensuring that the sustainability of the resource is not jeopardised and that they will be able to meet the demand for water in the area. The local water services provider has just completed this process, and according to the latest figures, they are extracting about 90% of their allowance. The service provider has also made provision for a 2% annual growth rate, which means that they will be using 100% of their allowance by the time they have to renew their permit.

Representatives from both the local municipality and the local water services provider suggested that the total resource availability in an area in terms of groundwater and surface water availability is an irrelevant method for the Vaal Triangle area (the area under consideration in this study). It was felt that it is an irrelevant method because merely looking at total resource availability does not consider the state (or pollution levels) of the resource and because no groundwater is used to meet the demand for water in the area. The method suggested by the representatives is motivated firstly by the fact that it is the method currently used by management when considering the total resource availability, and secondly because it is a method that supports prediction. It requires that the resources of the area should rather be expressed in terms of what percentage of the water that the service provider may extract from the water system is actually extracted.

Due to the sensitive nature of the actual figures, the input for this component will be the percentage of the allowance that is actually extracted. The minimum benchmark level for this component is 0 and the maximum benchmark level is 100. The value of the optimum extraction rate has been set at 90%, as this is the current extraction rate that satisfies the total demand.

A resource component score of 100 indicates an optimum extraction rate of 90%. Any value above or below this optimum level is adjusted so that it reflects consumption in terms of a percentage of the optimum level.

3.4.2 Access

The access component value is calculated as:

$$A = \frac{\text{Households with access to secure water source}}{\text{Total households}}$$

A secure water source is defined as being piped water either inside the dwelling or inside the yard. This study is limited to these two sources of water because there are too many factors influencing access to a communal water source. Some of these factors include limited access due to a large number of households using the communal source and certain community factions monopolising the facility. This would not provide individuals with sufficient control over their water supply (Cullis, 2005).

Figure 16 is an example of an unsecure water source and the negative impact it has on the community. Instead of these children being in school, and therefore improving the educational capacity of the region (which will be discussed in the next section), they spend hours, if not the entire day, trying to get water for their family. They are probably doing it because their parents or older siblings are working, or trying to find work, in an attempt to make ends meet.

Figure 16 Example of an unsecure water source

(Source: Ripples for Good http://www.mariag4g.blogspot.com/)

The minimum benchmark level for access is 0%, and the maximum level is 100% as access expresses the percentage of people with access to a safe water source.

3.4.3 Capacity

The capacity component consists of educational capacity as well as income capacity. The educational capacity value is calculated as:

$$EC = \frac{\text{People with education greater than grade 4}}{\text{Urban population}}$$

and the income capacity value is calculated as:

$$IC = \frac{\text{Households with income greater than R26 400 per annum}}{\text{Total households}}$$

In previous work done by Cullis (2005) for the Eastern Cape Province, it was determined that grade 4 is the educational level at which information regarding responsible water use is disseminated to learners. As the same education plan is still in place, grade 4 will be used as the threshold level for educational capacity. According to the WSDP (the Water Service Development Plan which is available from the DWAF), the average person is willing to spend roughly 5% of their disposable income on services. After discussions with a local municipality representative it was determined that a basic suite of services costs approximately R110 per household per month, or R1 320 per household per year. If R1 320 equals 5% of disposable income, 100% will equate to R26 400, the threshold level for income capacity.

Based on previous work done by Cullis (2002; 2005) in South Africa, the two sub-components used for the capacity component have been assigned equal importance (weighting). The capacity component value is therefore merely the average of the two sub-components, and is calculated as:

$$C = \frac{EC + IC}{2}$$

The minimum benchmark level for capacity is 0%, and the maximum level is 100%. The levels have been set at 0 and 100 as capacity expresses the percentage of people with a certain education level and the number of households with a certain income level.

3.4.4 Use

The use component value is calculated as:

$$U = \frac{\text{Direct requirement urban}}{\text{Urban population}} * \frac{10^9}{365} \text{ l/c/d (litres/capita/day).}$$

The minimum benchmark levels for the use component are 0 l/c/d and 320 l/c/d (as an optimum level is used), and according to Cullis (2005) the maximum (optimum) level for use in the South African environment is 160 l/c/d. Although the use component reflects the average usage, it should be mentioned that although the Vaal Triangle is a summer rainfall area, the demand for water in the Vaal Triangle peaks during spring (roughly from September to November), due to gardening requirements.

A use component score of 100 indicates an optimum consumption level of 160 l/c/d. Any value above or below this optimum level is adjusted so that it reflects consumption in terms of a percentage of the optimum level.

3.4.5 Environment

The environment component value is obtained directly from the WSAM (Water Situation Assessment Model), and no calculation is required to determine the component value.

The minimum benchmark level for environment is 0, and the maximum level is 5. These minimum and maximum levels are appropriate as it is the exact measurement scale used by the DWA to express the present ecological class (PEC) in the WSAM. According to Fuggle & Rabie (2009), the attributes that the DWA use to determine the PEC in the WSAM include flow characteristics, inundation, water quality, stream bed condition, introduced stream bed biota and riparian condition.

The environment component score is then calculated by multiplying the component value by 20, as this expresses the component as a score out of 100, and therefore as a percentage.

As discussed in section 2.5.3.3, acid mine drainage has the potential to seriously damage the environment. Even though some damage has already occurred, swift action in rectifying the situation will minimize the effects of the damage. If swift action is however not taken, acid mine drainage and its effects will have to be accounted for in the calculation of the environment component, in order for it to remain relevant. This should ideally be catered for in upcoming versions of the WSAM of the DWA, if required.

From the discussions in the previous sections, Table 7 summarises the minimum and maximum/optimum benchmark levels that were used in this study.

Table 7 Component benchmark levels

Component	Indicator	Minimum value	Maximum value
Resource	Percentage water extraction rate	0/100 (both values are treated as minimum values as both will lead to a component score of 0)	90 (optimum)
Access	Percentage with access to a secure water source	0	100
Capacity	Percentage households with above-threshold income Percentage population with education above grade 4	0	100
Use	Per capita domestic water use requirement	0/320 (both values are treated as minimum values as both will lead to a component score of 0)	160 (optimum)
Environment	Present ecological class	0	5

3.5 Component weighting

The option of adding different weightings to the components have been included in the WPI to compensate for different priorities and circumstances depending on the area or region for which the WPI calculation is performed. When deciding which weightings to use for the calculation of the WPI, the three broad descriptors that need to be considered for the area under consideration include hydrological conditions, economic conditions, and national/regional priorities. The intended use of the obtained WPI and accompanying water poverty map will dictate the specific descriptors that have to be used. Table 8 contains the various weighting groupings, as compiled by Sullivan *et al.* (2002).

Table 8 Weighting options for the WPI

Local condition descriptors			**Component weights**				
Hydrological condition	Economic condition	National priorities	Resource	Access	Capacity	Use	Environment
Very good	Unknown	Agriculture, Industry & Social Development	1	2	2	3	1
Average	Average	Social Development	1	2	2	1	1
Very good	Good	Environment & Social Development	1	2	2	1	2
Unknown	Unknown	Industry & Agriculture	1	2	2	2	1

This table is not exhaustive and can be adapted as required based on the hydrological condition, economic condition and national priorities of a specific region. Only four combinations have been given as these combinations have been prevalent in other studies on the WPI and WPM (see Sullivan *et al.* (2002), Cullis (2002, 2004 and 2005)). The second grouping of weightings will be used (1 for resource, 2 for access, 2 for capacity, 1 for use and 1 for environment) as the descriptors that are related to the chosen weightings are the closest match to the conditions found in the area under consideration.

3.6 Conclusion

In this chapter the various components of the WPI were discussed. The chapter started off with a discussion on research methodology, which was followed by a discussion on the various benchmark levels of the components. This was followed by sections on the calculation of each of the components, after which the chapter concluded with a section on component weightings and their influence on the WPI.

The next chapter looks at the actual calculation of the WPI, which is done by calculating each of the components individually, and presents the map that has been constructed.

4 The collection, analysis and representation of data in the water poverty mapping model

4.1 Introduction

According to Sullivan (2002), a tool such as the WPI would have to be derived in an inclusive and participatory manner before it is widely applied, adopted and accepted. Its calculation would need to be completely transparent to indicate its validity, and it would have to be a tool that can be used by various stakeholders at various scales for a variety of purposes. Therefore everybody who would benefit from the construction of the water poverty map has to be involved continuously right from the beginning. *"While this may be seen by some as a daunting challenge, it is clear that the potential of its achievement to bring forth a new era of accountability in water management and use makes the effort worthwhile"* (Sullivan, 2002:1202). It is therefore clear that if the processes of identifying the purpose and scale of the water poverty map and the selection of the components and individual indicators have been thorough, the benefits and usefulness of the constructed water poverty map that is obtained in the end will be far reaching.

4.2 Data sources

The data for this study were obtained from three sources. The first source was representatives from the local municipality and the local bulk water services provider, and the second source was the Census data from 2001, which can be accessed from the website of Statistics SA (http://www.statssa.gov.za). The third source was the Water Situation Assessment Model (or WSAM) version 5.001, which was released on 1 October 2008 and is available from the Department of Water Affairs. All the data in the WSAM were at the 98% assurance level. Table 9 lists each of the WPI components and the respective data source.

Table 9 WPI component data sources

Component	Data source
Resource	Representatives
Access	Census 2001
Capacity	Census 2001
Use	WSAM Version 5
Environment	WSAM Version 5

The WSAM uses abbreviations for the various parameters which are explained in Table 10.

Table 10 Parameter abbreviations for the WSAM

Abbreviation	Represents	Part of component
oPOPi	Urban population	Capacity, Use
nUDRo	Direct requirement urban (measured in Mm^3/a)	Use
cEPCi	Present ecology (class index)	Environment

4.3 WPI calculation

As discussed in Chapter 1, Section 1.9, the water poverty map will be constructed for Vanderbijlpark, Vereeniging and Sasolburg. In the next few subsections each of the components are calculated individually (refer to Chapter 3 for the relevant formulae), after which the final WPI for each of the three towns is calculated.

4.3.1 Resource

The resource component gives an indication of the amount of water that the water services provider is extracting from the water system. The component value has a minimum level of 0, an optimum level of 90, and a maximum level of 100. The score is determined by expressing the actual extraction rate as a percentage of the optimum level. Table 11 shows the resource component scores for each of the three towns (as obtained from a representative from the local bulk water services provider).

Table 11 Resource component calculation

	Value (Extraction rate %)	**Score** (%)
Vanderbijlpark	90	100
Vereeniging	90	100
Sasolburg	90	100

The values for the three towns under consideration are the same because all three towns get their water from the same water system.

4.3.2 Access

The access component gives an indication of what proportion of households has access to a safe water source. A safe water source is one that is either inside the dwelling or inside the yard. A proportion has a range of 0 to 1. Table 12 gives the access component scores for each of the three towns (as obtained from Census data).

Table 12 Access component calculation

	Households with Safe Water Source	Total Households	Value (Proportion)	Score (%)
Vanderbijlpark	25 422	26 602	0.955	95.564
Vereeniging	21 103	22 884	0.922	92.217
Sasolburg	7 456	7 644	0.975	97.541

4.3.3 Capacity

The capacity component is an indication of people's ability to 'cope' with water poverty. It considers the proportion of people with an education level higher than grade 4 as well as the proportion of households that have a combined income level of more than R26 400. The final score is merely the average of educational capacity and income capacity, expressed as a percentage. Table 13 gives the capacity component scores for each of the three towns (as obtained from Census data).

Table 13 Capacity component calculation

	People with Education > Grade 4	Total Population	Education Capacity (%)	Households with Income > R26 400	Total Households	Income Capacity (%)	Score (%)
Vanderbijlpark	63 529	474 081	13.4	18 432	26 602	69.288	41.344
Vereeniging	58 649	497 600	11.786	15 135	22 884	66.14	38.963
Sasolburg	19 906	141 000	14.118	6 220	7 644	81.371	47.745

In its Integrated Development Plan (or IDP) for 2009/2010, the Emfuleni local municipality have identified the following constraints with regard to economic growth in the area (ELM, 2010):

1. Population growth has continuously been higher than economic growth, which leads to a decrease in the standard of living.
2. The level of socio-economic disparity between population groups is high, with pockets of severe poverty to be found.
3. The municipality has to compete harder with more centrally located areas for new investment, owing to its relative distance from the core of the Gauteng province.

4.3.4 Use

The use component is an indication of the actual water usage for the area under consideration. It is measured in litres per capita per day (or l/c/d). The optimum level of use is 160 l/c/d, with a maximum level of 320 l/c/d. The score expresses the actual usage as a percentage of the optimum level.

As this study and water poverty mapping in general focus on residential water poverty alleviation, it is important to differentiate between residential and non-residential water use. A representative from the Emfuleni local municipality indicated that on a month-to-month basis, residential water use tends to fluctuate between 50% and 55% of the total water use, and non-residential use between 45% and 50% of the total water use. Based on the information obtained from the representative, a figure of 52% is used for residential use and a figure of 48% is used for non-residential use. According to Clarke *et al.* (2004), residential use can typically be divided into 70% for sanitation (or cleaning, flushing the toilet and bathing or showering), 20% for laundry and 10% for cooking and drinking.

Of the three towns under consideration, Vanderbijlpark was the only one whose use component value was not adjusted, as the major non-residential water consumer in the town obtains their water directly from the local water services provider, instead of from the local municipality. This is, however, not the case for Vereeniging and Sasolburg, as both of these towns have major non-residential water consumers that obtain their water from the local municipality, and including them in the usage figures corrupts the use component score. In the three towns used in this study, the major non-residential water consumers are industries. Table 14 gives the use component scores for each of the three towns (as obtained from the WSAM).

Table 14 Use component calculation

	Direct Requirement Urban	Population	Value (l/c/d)	Score (%)
Vanderbijlpark	22.26	474 081	128.641	80.401
Vereeniging	25.896	497 600	142.58	89.113
Sasolburg	10.598	141 000	205.926	71.296

4.3.5 Environment

The environment component describes the state of the environment and the ecology of the area under consideration, and is calculated using the attributes discussed in section 3.4.5. It has a range of 0 to 5, with 0 indicating a ‘very poor’ ecological state, and 5 indicating a ‘perfect’ ecological state. These ratings are obtained directly from the WSAM. Table 15 shows the environment component scores for each of the three towns (as obtained from the WSAM).

Table 15 Environment component calculation

	Index (Rating)	Score (%)
Vanderbijlpark	4.086	81.72
Vereeniging	3.641	72.82
Sasolburg	3.856	77.12

4.3.6 Index calculation

After calculating each of the individual component scores, the weightings have to be used to calculate the final WPI for each town. The formula to be used for the final calculation of the WPI is given below, which was discussed in Chapter 2, Section 2.4.

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

Therefore the WPI for Vanderbijlpark is:

$$WPI = \frac{(1*100)+(2*95.564)+(2*41.344)+(1*80.401)+(1*81.72)}{1+2+2+1+1} = 76.562,$$

the WPI for Vereeniging is:

$$WPI = \frac{(1*100)+(2*92.217)+(2*38.963)+(1*89.113)+(1*72.82)}{1+2+2+1+1} = 74.899,$$

and the WPI for Sasolburg is:

$$WPI = \frac{(1*100)+(2*97.541)+(2*47.745)+(1*71.296)+(1*77.12)}{1+2+2+1+1} = 76.998.$$

Table 16 summarises the WPI for each of the three towns in tabular form.

Table 16 WPI calculation

	Resource (Weighting=1)	**Access** (Weighting=2)	**Capacity** (Weighting=2)	**Use** (Weighting=1)	**Environment** (Weighting=1)	**WPI**
Vanderbijlpark	100	95.564	41.344	80.401	81.72	76.562
Vereeniging	100	92.217	38.963	89.113	72.82	74.899
Sasolburg	100	97.541	47.745	71.296	77.12	76.998

As mentioned earlier, when working with water poverty mapping and the water poverty index, the contributions of each of the components to the final index value is just as important as the final index value itself. Figure 17 is a graphical representation of the component contributions and water poverty indices of the three towns in the Vaal Triangle. The figure clearly indicates that improving the capacity component, i.e. improving the education capacity and/or income capacity, for each of the towns in the Vaal Triangle should be the priority for improving the water poverty in the region.

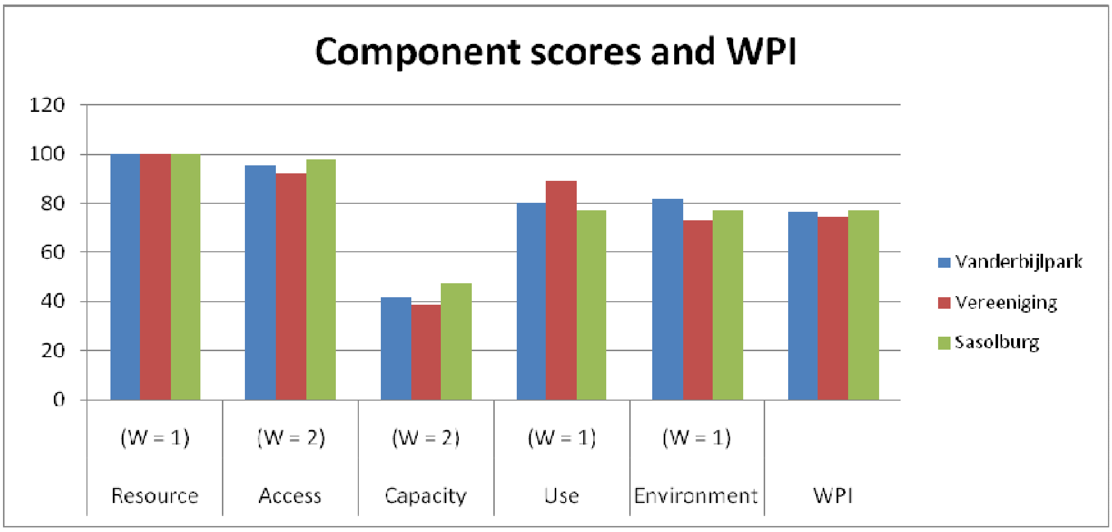

Figure 17 Graphical representation of component scores and WPI

A WPI of 100 indicates that there are no water-related problems at all in an area. It implies that the resource is not being over-utilised, everyone has access to a safe water source, everyone has a sufficient educational and income capacity, everyone is using the optimal amount of water, and the environment is in a perfect ecological state. The worst WPI that an area or region can have is 0, which indicates that there are numerous water-related problems and that a lot of time and money will have to be spent in an effort to rectify the situation. The three towns in this study all have a WPI in the high seventies, which is relatively high in comparison with the entire country, which has a WPI of only 52. The capacity component score was the lowest of all the components for each of the three towns in the study, mainly due to extremely low education level figures. Therefore improving educational capacity in each of the towns should be the priority for improving the water poverty in the region.

4.4 Map construction

One of the major advantages of water poverty mapping is that it provides a visual representation of the WPI. Any map can be used, as long as it is reliable and accurate, and it adheres to the required scale. After calculating the various water poverty indices, the next step in the process is to construct the water poverty map. For the purpose of this study, the image of the area under consideration was obtained from Google Earth, and the mapping was done using Map Maker version 3.5. The WPI, as calculated in section 4.3.6 and summarised in table 16, was plotted on the map, and the resulting water poverty map is represented in figure 18.

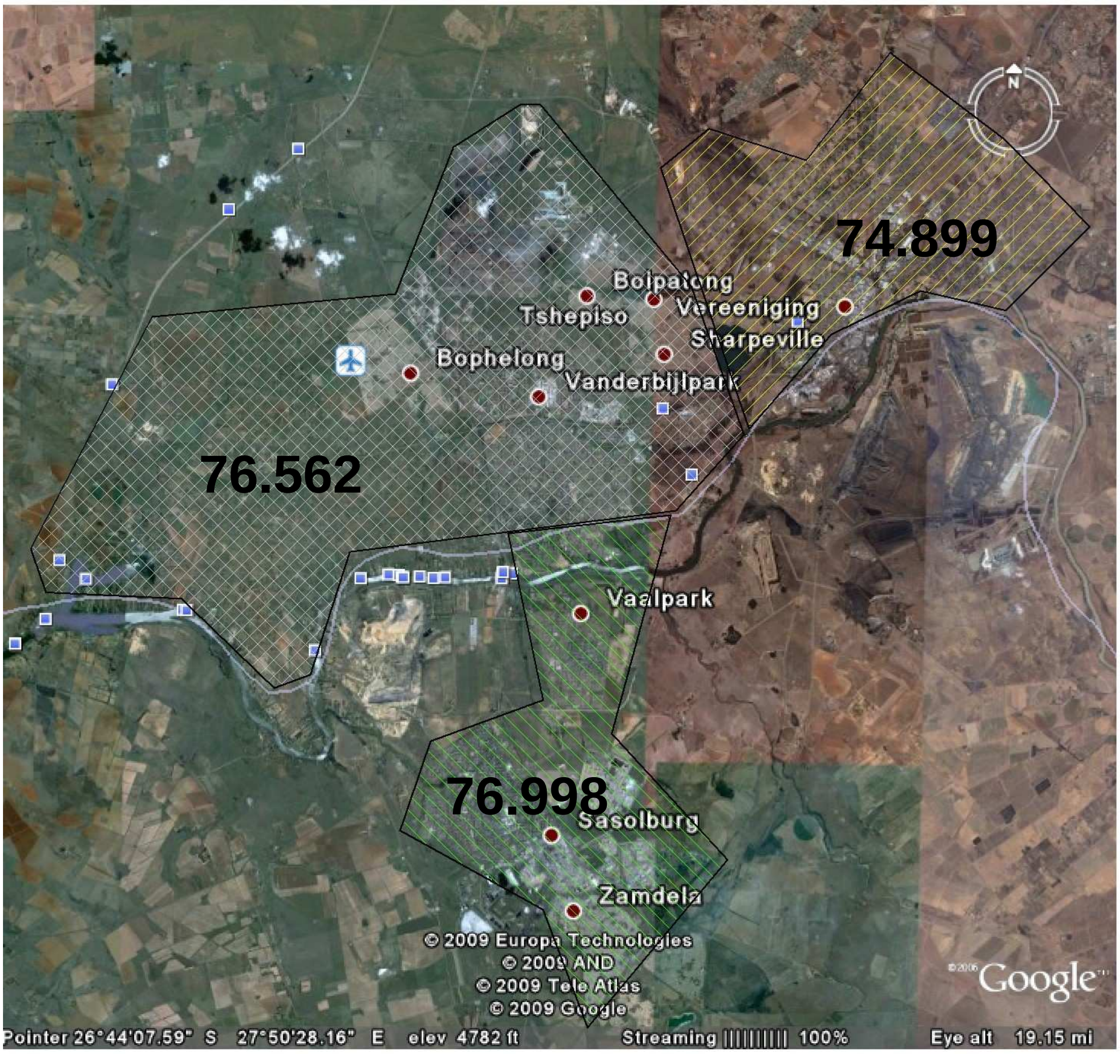

Figure 18 Water poverty map for the Vaal Triangle

On the map the various colours indicate the boundaries of the three towns, namely Vanderbijlpark: white, Vereeniging: yellow and Sasolburg: green. The three numbers on the map represent the water poverty indices for each of the towns.

As mentioned in Chapter 2, the scale at which a map is constructed depends on its intended purpose. Table 17 contains the data that were used to construct the map in Figure 18 after it had been aggregated to a regional scale for the entire Vaal Triangle.

Table 17 Data for the regional water poverty map of the Vaal Triangle

Resource	
Value (Extraction rate %)	90
Score (%)	100
Access	
Households with safe water source	53 981
Total households	57 130
Value (proportion)	0.945
Score (%)	94.486
Capacity	
People with education > grade 4	142 084
Total population	1 112 681
Education capacity (%)	12.77
Households with income > R26 400	39 787
Total households	57 130
Income capacity (%)	69.642
Score (%)	41.206
Use	
Direct requirement urban	58.754
Population	1 112 681
Value (l/c/d)	144.668
Score (%)	90.418
Environment	
Index (Rating)	3.861
Score (%)	77.22
WPI	
Resource	100
Access	94.486
Capacity	41.206
Use	90.418
Environment	77.22
WPI	77.003

Figure 19 is an example of what the water poverty map for the Vaal Triangle would look like if it were part of a provincial or catchment-scale water poverty map. These types of maps are typically constructed and used by local government or the local water services provider. For this study, the image of the area under consideration was obtained from Google Earth, and the mapping was done using Map Maker version 3.5. The WPI, as summarised in table 17, was plotted on the map as shown in figure 19. This map is included to illustrate the effect that scale can have on the mapping process.

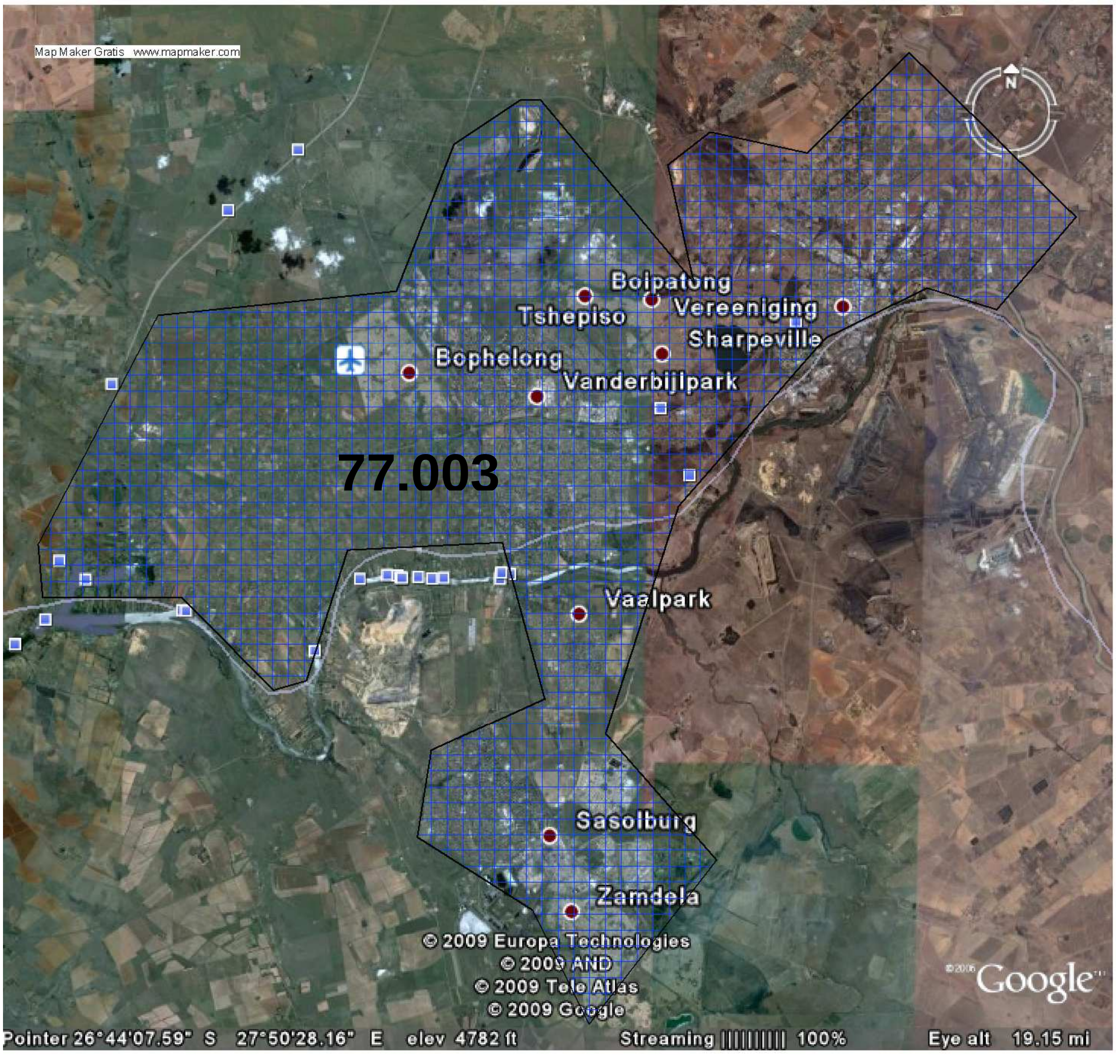

Figure 19 Regional water poverty map for the Vaal Triangle

Although it might be expected that the aggregated WPI should be the average of the WPIs of each of the towns in the area (that is (76.562 + 74.899 + 76.998) / 3 = 76.153), it is higher (77.003) in this case due to the use component. The component values (measured in l/c/d) for each of the towns in the area were 128.641 for Vanderbijlpark, 142.58 for Vereeniging and 205.926 for Sasolburg. As the use component expresses usage in terms of a percentage of the optimum usage (160 l/c/d), when aggregating the value of 205.926 will raise the other two values closer to 160, and the values of 128.641 and 142.58 will lower the 205.926 closer to 160, thereby giving an overall aggregated use component score of 90.418. It is this raised aggregated use component score that causes the overall WPI to increase to 77.003.

4.5 Conclusion

This chapter highlighted the processes that are involved in calculating the WPI and constructing the water poverty map. The chapter started with a section on the various data sources that are used in WPI calculation, followed by a section that examined the calculation of each individual component as well as the final WPI calculation. The chapter concluded with a section that presents the final map that has been constructed.

The next chapter investigates the various management applications of water poverty mapping and how the WPI and water poverty mapping can be used as a tool to assist in water management.

5 Management applications

5.1 Introduction

"Good water management is literally vital for the arid and semi-arid regions of the planet" (Voorsluys *et al.,* 2007:1609). Proper water management and good choices regarding water usage and conservation require multidisciplinary knowledge. Typically, knowledge is required about the hydrological, social and economical aspects of water, which are all contained in the WPI and its indicators. The multidisciplinary knowledge requirement means that people from different backgrounds should collaborate to ensure that the needs of all riparians are sustainably met. Sustainability in this context refers not only to meeting current demand, but also being able to keep up with development and ensuring adequate availability of the already scarce resource for the future. Taking care of our water resources should be the responsibility of everyone on the planet, not only those in management positions with decision-making powers.

5.2 Predictions

When planning for the future, local municipalities, water service providers and governments have to ensure that they can keep up with growth and development. This is particularly important when it comes to water and the demand for water, as it is an extremely valuable but also very limited resource. The following three subsections will describe how the local municipality, the water service provider of the area under consideration, and the government currently make and use their water demand predictions, and how water poverty maps and water poverty mapping can be used to improve the process and the accuracy of the predictions.

5.2.1 Local municipality

A local municipality has to predict its future water requirements on a regular basis. These predictions are given to the water services provider so that they can ensure that they have everything in place to meet the demand for water.

Currently these predictions are based on two measurements: the trend of demand for water and the population growth rate. The demand and the growth figures are available on a month-to-month basis, and when determining the value for the prediction, the average of the two measurements is used. This process only changes if it is known beforehand that an intervention will occur or that major changes will be made to the system or infrastructure. An example of both an intervention and a major change to the system that occurred recently in the municipality’s area of governance was the introduction of a pressure station (obtained from an interview with a representative from the Emfuleni local municipality). Pressure stations are used in areas where a lot of water is wasted, either through leaks or irresponsible usage. Pressure stations cause a decrease in the water pressure during times of low usage, typically between 22:00 and 5:00. The municipality took this intervention and associated water saving into account when they made their most recent prediction. During the investigation that was conducted by the local municipality, loss due to leakage (also referred to as non-revenue water, or NRW) was estimated to be in the region of 31%. This is a significant figure which indicates that almost a third of the water that the municipality is being billed for is being wasted. According to Sharma & Vairavamoorthy (2009), the average amount of NRW in developing countries in Africa and Asia tends to vary between 20 – 70%. As the current method for determining individual usage does not consider this loss factor, and is therefore less accurate, the following formula was developed as part of this research to more accurately determine individual usage by compensating for the loss factor. It was derived by incorporating two changes to the formula suggested by Sullivan *et al.* (2002). The original formula calculated a yearly usage figure, whereas the derived formula can be used to calculate a specific monthly usage figure, which facilitates more accurate analysis, and the second change was the introduction of the loss factor into the equation, as discussed above. This formula can be used for expressing use on its own as well as for expressing use in the water poverty index and the accompanying water poverty map.

$$Use = \frac{Total\ Kilolitres\ Billed * 1000}{Total\ Population / Days\ in\ Month} * (1 - Loss\ Factor)$$

Predicting future water requirements to ensure an adequate supply is only one of the purposes of the short-term demand predictions. These demand predictions are also used when determining the relevant tariff that the end user will be charged. In the long-term these predictions are used to plan ahead for projects such as infrastructure improvement, maintenance, expansion, etc.

The result of an investigation into the processes of the local municipality was that the use component of the WPI and the water poverty map can immediately form part of their predictions, and that if water poverty maps can be constructed at regular intervals they would even have the potential to completely replace the current prediction system. The use component can either replace the current method of looking at overall demand, or it can be used as a verification tool. Currently, when determining overall demand, the municipality looks at the total number of Kℓ that was supplied to them by the water services provider. Unfortunately this total also contains the water that has been lost, for example through leaking pipes, and this affects the accuracy of the information. By multiplying the usage (measured in l/c/d) as calculated from the formula given above with the population size, it can be used as a more accurate measure of overall demand. Alternatively it can be used to confirm whether the overall demand obtained earlier is reasonably accurate or not. It was also highlighted that if water poverty maps were constructed on a relatively regular basis, perhaps monthly or even every two months, using the most up-to-date data, the maps could become the sole basis of the municipality’s predictions. A series of regularly constructed maps will make it much easier to measure the impacts of development, which will also provide users with a relevant and up-to-date overall picture, taking into consideration not only the resource, but also the factors influencing its responsible usage. As mentioned in section 1.9, rapid development in the region has been identified as one of the major challenges of the local municipality with regard to provision of water and sanitation services.

In municipalities that are responsible for their own water supply, i.e. that do not obtain their water from a bulk water services provider, accurate predictions are even more important. If these municipalities do not have an adequate supply, the impact is far reaching, as they cannot simply request more water from the provider, and this in turn places an even greater strain on their perhaps already stressed infrastructure. During the consultation it was highlighted that water poverty maps can be especially useful to these municipalities as they have a far greater responsibility for ensuring a sustainable water supply.

It can also be useful to all municipalities when predicting the impact on demand caused by changing volumes due to the introduction and expansion of water and sanitation.

5.2.2 Water service provider

Water services providers need to consider all the predictions from the municipalities they serve when preparing their projections for government. Although they annually predict the demand for the coming year, every five years they have to predict the demand for the following five years when they apply for their permit from the DWA. The permit they obtain from the DWA firstly gives them permission to extract water from the system, and secondly it states how much water they are allowed to extract. The advantages of the use of water poverty maps by the water services providers is similar to those experienced by local municipalities, the only difference being the scale at which the water poverty map is constructed.

5.2.3 Government

When it comes to the government and the responsible state department, the advantages of more accurate predictions increase ten-fold. Government has to ensure that it can meet the water demand of its people, and to enable this accurate predictions are needed so that they can have a clear idea of when the demand is going to overtake the supply. The sooner they know when this is likely to happen, the more time they have to look for alternatives. In recent years one such alternative that has been implemented was the first phase of the Lesotho Highlands Water Scheme (Du Toit De Villiers, Schmitz & Booysen, 1996). It feeds water directly from the Lesotho Highlands into the Vaal Dam. If the demand for water keeps increasing at its current rate, it is foreseen that the second phase of the scheme will have to be implemented within the next decade. Other incentives and initiatives that have been initiated and supported by government in an effort to decrease the total water demand include, amongst others, the National Waterwise Campaign, training of communities to make people more water wise, installing water saving devices where possible, providing incentives to water users to use less water, municipal bylaws, and regulations, guidelines and standards to make bathroom accessories and white appliances more water efficient (DWAF, 2008).

At the level of provincial government, water poverty maps at municipal level can be used to identify the municipalities or districts most in need of an intervention. This information can then be used when assigning resources to ensure that the water poverty is addressed efficiently. On a national level the benefits of water poverty mapping are similar. The maps can be constructed at a provincial level to identify the province with the highest water poverty. Once the province has been identified, a map on a smaller scale can be used to identify the worst district in that province, and from there a map on an even smaller scale can be used to identify the worst municipality in that district. As mentioned in Sections 2.7.2 and 2.7.3, the purpose of the map will determine and influence the components to be used as well as the scale on which the map is developed.

5.3 Regression analysis

A regression analysis was performed to obtain an equation for making water demand predictions as well as for benchmarking the municipality predictions. After performing the analysis on the total water demand data, the following regression equation was obtained from the analysis. In the equation the first month for which data are available (July 2004) is treated as time period 1.

$$y = 10\,989.37x + 5\,855\,543$$

Figure 20 represents the total water demand (measured in Kℓ) in the municipal area from the period July 2004 to March 2010. Also included in the figure is the trend line for total demand. In the figure monthly total water demand peaks around September and October, this can be attributed to increased gardening at the start of spring.

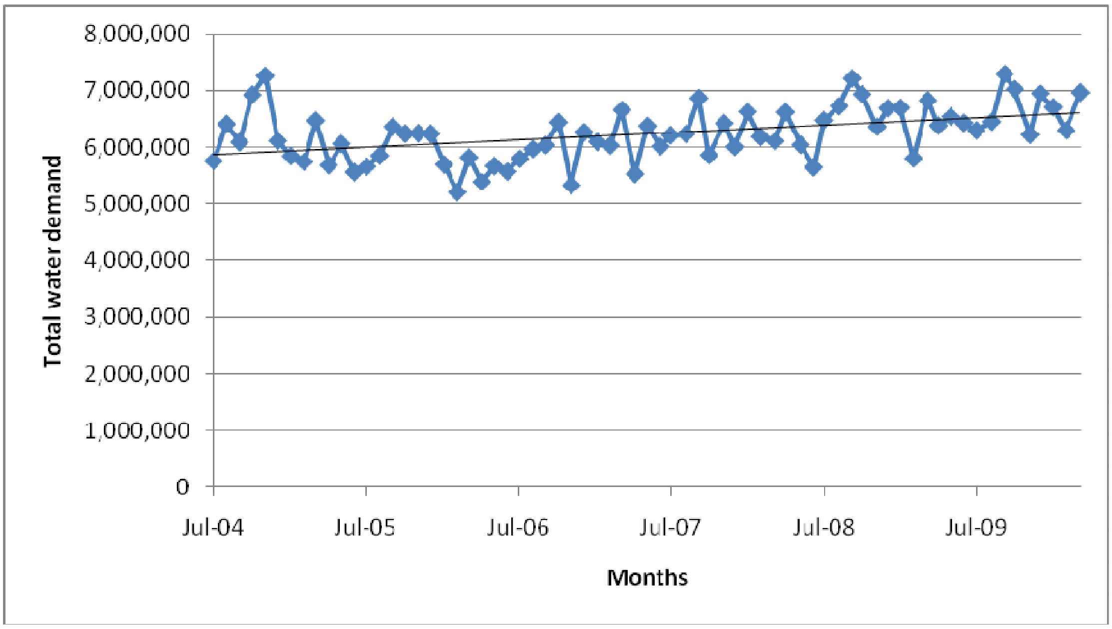

Figure 20 Total Kℓ bought

As linear regression has been used to obtain the equation, it should be updated continuously as soon as more data become available. This will ensure that it always stays as accurate and relevant as possible. Using this equation, predictions were made for the four years 2005/6, 2006/7, 2007/8 and 2008/9. The predictions are made for 1 July to 30 June of the following year as this period corresponds to the municipality's financial year. Figure 21 is a graphical representation of the predictions made by the Emfuleni local municipality, the predictions made with the regression equation and the actual Kℓ billed.

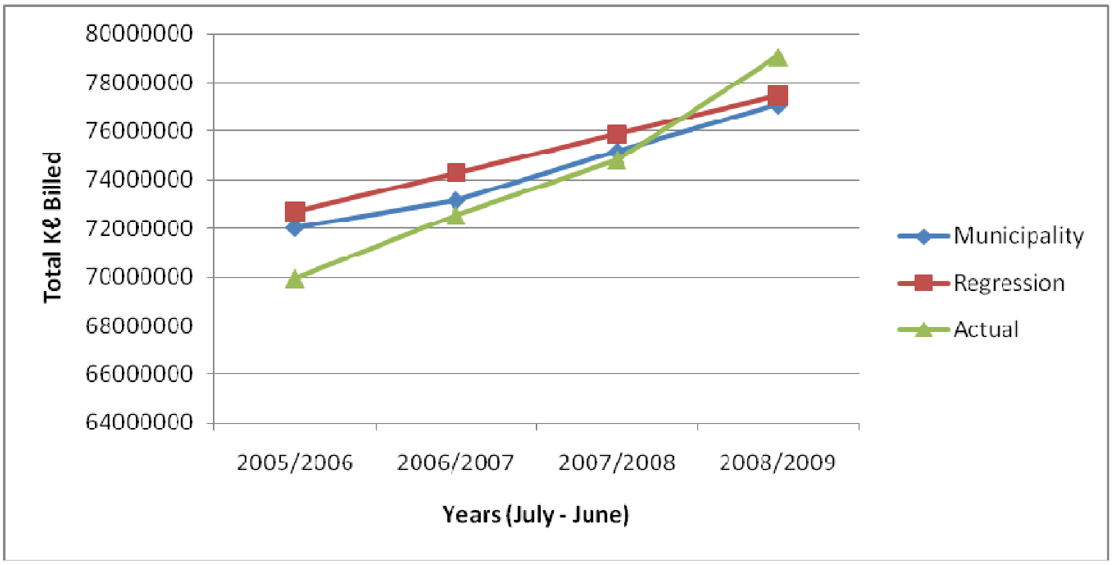

Figure 21 Water demand prediction comparison

Table 18 shows the values of these predictions as well as the actual total Kℓ billed. It also lists the differences and percentage differences of each prediction when compared to the actual value. As there are a lot of factors that could influence the demand for water, extrapolation (predicting into the future) with this model should be limited to one or two time periods into the future at most.

Table 18 Water demand prediction figures

	Emfuleni Local Municipality	Regression	Actual	Municipality Difference	% Difference	Regression Difference	% Difference
2005/2006	72 034 597	72 706 156	69 965 001	2 069 596	2.958045	2 741 155.14	3.917895
2006/2007	73 153 021	74 288 625	72 559 566	593 455	0.817887	1 729 059.42	2.382952
2007/2008	75 163 291	75 871 095	74 840 278	323 013	0.431603	1 030 816.7	1.377356
2008/2009	77 096 381	77 453 564	79 073 757	-1 977 376	-2.50067	-1 620 193.02	-2.04896

Both the municipal and regression predictions over-predicted for the years 2005/6, 2006/7 and 2007/8. The largest percentage difference of 3.918% was obtained with the regression equation for the year 2005/6. For 2008/9 both predictions under-predicted, with the largest difference being the municipal prediction with 2.5%.

This could possibly be explained by population growth. In the Emfuleni local municipality's IDP for 2009/10, population inflows into the region was in the region of 60 000 people, and population outflows was in the region of 10 000 people. This leads to an overall population growth of roughly 50 000 people. When this is considered against the overall population in the area, it leads to a growth rate of close to 10%. There might be various reasons for this growth, one of which perhaps being the closeness of the Vaal Triangle to Johannesburg, the economic hub of South Africa. Therefore even though the municipality does make provision for population growth in its predictions, 10% is above average growth and most probably explains the under prediction.

5.4 Master plan

In addition to being able to predict future water demand (using any method), it is also important to have a very accurate indication of what infrastructure is currently in place, and what will have to be done to ensure that future demand can be met.

A master plan is a document that a municipality has to compile for every developed area under its jurisdiction, which describes the intentions of the municipality with regards to service delivery specifically. It is typically a document that is compiled during the first few years after a town has been established, and which is then updated on a regular basis. In the master plan areas are classified as being either urban, urban-edge or rural. The urban-edge is usually the area where a town expands, and therefore the urban-edge of a town shifts continuously. The water poverty map itself can be used to keep track of the town boundaries as well as the areas that have been classified according to the three different classifications.

The master plan serves two main purposes. Firstly, it gives a detailed description of what is currently available (in terms of infrastructure, etc.), and secondly what the current demand is and what will be needed to ensure that the demand can be sustainably met.

The result of an investigation into the processes of the local municipality was that the resource component of the water poverty map can be used as part of the master plan to guide development. The resource component will give a very clear indication of how much development is viable given the current maximum carrying capacity, in other words when the maximum level will be reached. The main limiting factor on development (suggested planned development) is resource availability, and one can plan as much as one likes, but water is and will always be a finite resource. Therefore, to ensure the relevance and accuracy of the master plan, one must ensure that it is informed through the use of the most up-to-date information available.

WPM can also play a crucial role in a municipality’s Integrated Development Plan (or IDP). The IDP is similar to the master plan, with the major difference being that the IDP describes all the factors surrounding development for a region over the short to medium term, not only service delivery as is the case with the master plan. The benefits of the WPI and WPM for this document will be similar to that of the master plan.

5.5 Map updates

Depending on the use of the water poverty maps and the required frequency of updates, data sources have to be chosen carefully as various data sources are available. Table 19 is a representation of which data source is appropriate for which component, based on the required frequency of updates. ‘Frequent’ implies on a monthly or two-monthly basis, whereas ‘non-frequent’ implies more on a yearly basis.

Table 19 Data sources for updates

	Updates	
Component	**Frequent**	**Non-frequent**
Resource	Local municipality or service provider representatives	WSAM or service provider figures
Access	Census or local municipality figures	Census figures
Capacity	Census or local municipality figures	Census figures
Use	Local municipality or service provider figures	WSAM
Environment	WSAM	WSAM

The main disadvantage of data sources such as the WSAM and the Census is that, even though they are at a high assurance level, they are not updated frequently enough to make them a viable option for frequent updates of the water poverty maps. If frequent updates are required, the local municipality and service provider will have to ensure that their data is accurate and reliable, and they will have to realise that problems or delays with the data will impact on the water poverty mapping process and the recommendations made from it as well.

The investigation at the local municipality also revealed that water poverty maps and water poverty mapping will reach their full potential if they are updated as regularly as possible. A water poverty map should in actual fact therefore be a living document. In a living document the WPI and the resulting map are updated as soon as new data become available, thereby ensuring that the map is always a true reflection of the reality.

5.6 Conclusion

In this chapter the various applications of water poverty mapping were highlighted. The chapter started with a section on how water poverty mapping can be used to assist with making predictions. It looked at the predictions made by the local municipality, the water services provider and government. This was followed by sections on the regression analysis that was performed and on how water poverty maps and water poverty mapping can form part of a town’s master plan. The chapter concluded with a section that discussed the frequency of map updates and its implications for the water poverty mapping process.

The next chapter discusses the conclusions that have been reached as well as the recommendations based on the work done in this study. Some future research is also suggested that can be done in the field of water poverty mapping.

6 Conclusions and recommendations

6.1 Introduction

According to Frederiksen (2009), the ever-increasing demand for the world's already scarce water resources has the potential to turn disputes among users into serious regional and international security threats. These possible threats unfortunately often do not receive the amount of attention that they deserve, and hence people tend to keep using water in an irresponsible way. Examples of some of these threats, which already exist, include (Frederiksen, 2009):

- Water basins without permanent water-sharing agreements, like the Ganges river.
- Water basins with disputed allocation of resources, like the Nile river basin.
- Water basins with either a dominant user or one who has gained full control through prolonged military actions, like the Euphrates and Tigris rivers with Turkey and Israel.
- Wealthy but water-poor countries that secure long-term agreements for food production outside their borders, like Saudi Arabia, Kuwait and China.

Even though water poverty has numerous social and economic implications, conserving our scarce water resources is important for not only ensuring the long-term survival of all life on earth, but also for ensuring stability and peace, which unfortunately often tend to be overlooked. It is therefore extremely important that water poverty receives sufficient attention within a reasonable amount of time, whatever the scale.

6.2 Methodology and application

This research was an example of mixed methods research. Its three stages (as discussed in section 3.2.1.3) as they were applied in this research can be described as follows:

1. It was an exploratory study rather than a confirmatory study.
2. It used open-ended interviews as the data collection method for its primary data and existing data sources for its secondary data.
3. It used a case study approach to calculate the WPI and to construct the WPM for the demarcated area.

6.2.1 Application

An extensive literature review was presented in which some of the most important aspects with regards to water and water poverty was discussed. The review also highlighted the need for and importance of water poverty mapping as a water poverty alleviation tool.

The three stages of mixed methods research were applied in this research as follows:

1. Unlike with the confirmatory study approach, the exploratory study approach does not test an existing theory. This research took the water poverty mapping concept and applied it to the demarcated area to explore the obtained results, and to document its management applications.
2. Open-ended interviews with representatives from the local municipality and the bulk water service provider were used to obtain the primary data. This data was used specifically for the resource component of the WPI and the management applications of the obtained water poverty map. Existing data sources were used for the secondary data, which in turn was used for the access, capacity, use and environment

components. The use of existing data sources was acceptable, as all of the sources used were at an assurance level of in the high 90%. The sources were Census data, which is available from Statistics South Africa, and the Water Situation Assessment Model (or WSAM), which is available from the Department of Water Affairs (or DWA).

3. The case study approach was followed as it focuses on one instance with a view to provide an in-depth description. In this research the instance was the demarcated area, namely the Vaal Triangle, which consists of Vanderbijlpark, Vereeniging, Sasolburg and their surrounding areas.

6.3 Research findings

The findings of this study are based on the main and secondary research questions formulated in Chapter 1, and will be discussed in the following sections.

6.3.1 Main research question

The main research question for this research was formulated as follows:

How can water poverty mapping be used as a management tool to assist in addressing water poverty?

Findings

This research shows that the WPM and its data can be used for predictions of future water demand, and to form part of the municipal master plan and the IDP as well. Before the WPM is used by management, its relevance and validity should continuously be verified throughout the map construction process. The relevance and validity of this research was verified by representatives of both the local municipality and the bulk water services provider. To accomplish the verification, this research shows that the intended use of the WPM must be clear, the scale at which the map is constructed must be relevant, and the chosen variables for each of the components of the WPI must be representative. Figure 22 shows the WPM that was constructed for the Vaal Triangle area considered in this study.

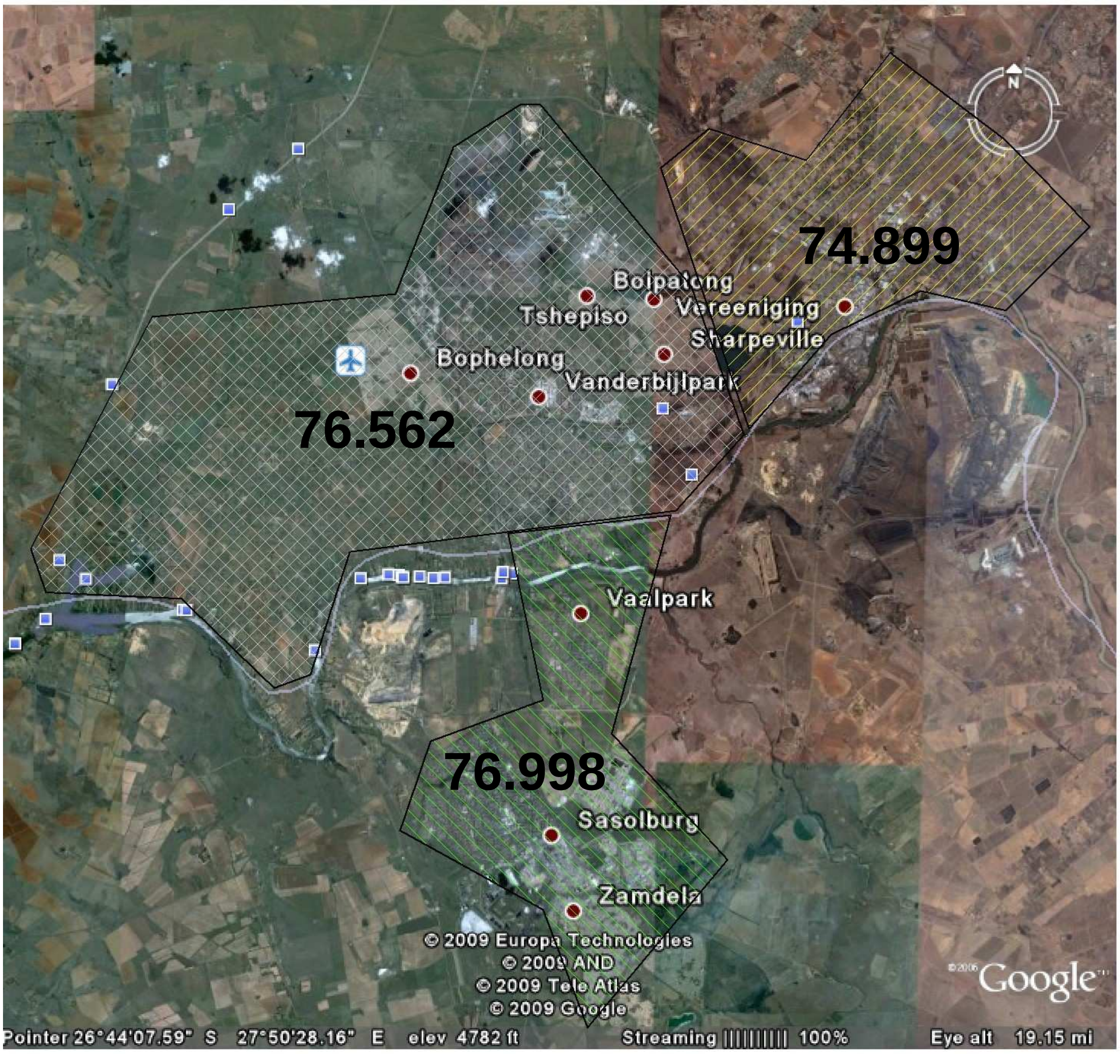

Figure 22 Water poverty map for the Vaal Triangle

This research shows that when it is used for predictions, the WPM can be used as a verification tool to verify the current total water demand prediction.

The current method used by the local municipality to predict total water demand only considers total Kℓ billed and population, and from this a value is produced which is expressed in l/c/d (litres per capita per day). As the data that are used for the WPM and the WPI come from different sources that are at a high assurance level (like Census data and the WSAM which is at the 98% assurance level), they can be used to verify the validity of the municipality's prediction. Alternatively, this data can replace the current method of making water demand predictions. The main problem with the way the local municipality makes their prediction is that their prediction does not consider total water loss due to leakage, faulty meters, etc. Currently the loss factor is estimated to be in the region of 31% of total Kℓ billed. By using the following formula that was developed in Section 5.2.1, the accuracy of the predictions will be improved so that funding can be channelled to where it will have the most impact.

$$Use = \frac{Total\,Kilolitres\,Billed * 1000}{Total\,Population / Days\,in\,Month} * (1 - Loss\,Factor)$$

The master plan and Integrated Development Plan (or IDP) is a document that keeps track of a town's development and its urban, urban-edge and rural area classifications. As these classifications change continuously because development typically occurs at the urban-edge, the WPM and its resource component can contribute to this document by providing a clearer picture of the amount of development that is viable, as well as by helping to keep track of the classification boundaries. The amount of development that is viable depends on the current water supply, current water demand and infrastructure and budgetary constraints, i.e. the maximum carrying capacity. It can also contribute by helping to guide and channel development and funding to the areas that need it the most.

This research shows that water poverty mapping can be used as a management tool to assist in addressing water poverty by ensuring more accurate situational analysis as well as more accurate predictions of future water demand. This will ensure that the already scarce resource is used more efficiently and that the demand for water can be sustainably met. By using the resource more efficiently, more water will be available for distribution to water-poor areas, as indicated by the water poverty map. WPM can also assist with addressing water poverty by forming part of the municipal master plan. In this document the graphical illustration of water poverty indicators will help not only to identify the area with the highest degree of water poverty, but also what type of intervention would be most appropriate.

6.3.2 Secondary research questions

In addition to the main research question, secondary research questions were formulated, and are discussed next.

The first secondary research question was formulated as follows:

- What is the role that water poverty mapping can play in water management?

  Findings

  This research shows that the WPM and the accompanying WPI can have a role to play in assisting management with predicting future total water demand, as well as when planning ahead for town expansion, infrastructure development and maintenance, etc.

  In summary: The role that water poverty mapping can play in water management is to assist management with predictions, by looking at different variables as part of the resource and use components and by compensating for the loss factor, as well as with planning for the future, by forming part of the master plan and the IDP.

The second secondary research question reads as follows:

- What variables define water poverty in terms of domestic water management?

  Findings

  This research shows that the variables (indicators) and weightings that define water poverty in terms of domestic water management, and that were used for each of the components of the WPI, include resource, access, capacity (both income and educational capacity), use, and environment, each of which are discussed below. The values of the weightings have been verified by previous research (as discussed in section 3.5). To calculate the WPI the following formula is used:

  $$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

  The variables in the WPI formula were verified as valid by representatives from both the bulk water services provider and the local municipality surveyed in this research.

  - **Resource.** The resource component indicates the percentage of their allowance that the water services provider is extracting from the system.
  - **Access.** The access component indicates the number of households in the area under investigation with access to a safe water source. A safe water source is defined as the availability of water either inside the dwelling or in the yard.
  - **Capacity.** The capacity component is calculated as the average of education capacity and income capacity. Education capacity indicates the number of people with an education of at least grade 4, as this is the level at which information regarding responsible water usage is disseminated. Income capacity is the number of households with an annual income of at least R26

400, as the average person is not willing to spend more than 5% of disposable income on basic services.

- **Use.** People need clean water on a daily basis. The use component indicates the average daily demand of the population in the area under investigation. This value is expressed in litres/capita/day.
- **Environment.** The value for this variable is obtained directly from the water situation assessment model (WSAM) and expresses the ecological state of the environment as a score from 0 to 5. A 0 indicates a very poor ecological state and a 5 indicates a perfect ecological state.

In summary: This research shows that the variables that define water poverty in terms of domestic water management are water being extracted from the system, number of households with access to a safe water source, number of people with a preset education level, number of households with a preset annual income, average daily demand for water by the population in the area and the ecological state of the environment.

The third secondary research question reads as follows:

- Are data available for the different components of the water poverty index, and if so, how reliable are the data?

Findings

This research shows that various data sources are available for the different components of the WPI and the water poverty mapping process. The data used for this study were obtained from four sources, namely representatives from the local municipality and the water services provider, the Census and the WSAM (version 5.001). The data from the WSAM and the Census are at an assurance level above 95%, and the data obtained from the representatives have been verified by peers in the relevant areas who between them share more than 100 years' experience.

In summary: This research shows that various data sources are available for the different components of the water poverty index and that the data are at an acceptable assurance level.

The fourth and final research question was formulated as follows:

- Is it possible to present a water poverty map?

Findings

Data were collected for each of the components of the WPI and the WPI was calculated for Vanderbijlpark, Vereeniging and Sasolburg (the Vaal Triangle area considered in this study). Map Maker version 3.5, along with Google Earth, was used to construct the final water poverty map which is pictured in figure 22.

In summary: This research shows that it is possible to construct a water poverty map. For the purpose of this research, Google Earth and Map Maker version 3.5 was used, but any of a variety of available software packages can be used. This water poverty map summarises and presents the WPI graphically and can assist with water poverty alleviation.

6.3.3 Summary of findings

This section serves as a summary of the research findings presented in sections 6.3.1 and 6.3.2.

- The WPM and its data can be used for predictions of future water demand, and to form part of the municipal master plan as well as the IDP.

- The role that WPM can play in water management is producing more accurate water demand predictions, as well as with assisting with planning for the future.
- Water poverty in terms of domestic water management is defined by the variables:
    - Water extracted from the system.
    - Households with a safe water source.
    - People with a preset education level and households with a preset income level.
    - Average water demand per person per day.
    - Ecological state of the environment.
- Various data sources are available for the WPI, all of which are at an acceptable assurance level.
- It is possible to construct a water poverty map using any one of a variety of software packages.

6.4 Recommendations

From the findings, as discussed in the previous section, the following recommendations can be made from this study.

- Water poverty mapping should be accepted as a viable water management tool.
    - This research has indicated various advantages and benefits for municipalities and water management authorities, for example the alleviation of water poverty.

- Water poverty mapping should be integrated into the existing tools used to manage water and water affairs.
    - Water poverty mapping and the water poverty index play an important role in producing information about the current state of water affairs, as indicated by this research.
- The variables used to calculate the water poverty index should be carefully selected and motivated for the specific area under consideration.
    - These variables can differ from area to area but great care should be taken to select those variables that produce the most accurate and relevant information for a specific area.
- The data sources used to calculate the water poverty index should be updated as frequently as possible to ensure the most accurate water poverty map.
    - Outdated data will lead to maps that are inaccurate, thereby leading to irrelevant and incorrect decisions being made. Using data that is as up to date as possible will lead to maps that are relevant, which in turn will have the greatest impact on water poverty alleviation efforts.

6.5 Shortcomings

A shortcoming of the water poverty mapping process and the resulting water poverty map is that it is not integrated into the management tools or methods that are currently available to decision makers.

To achieve optimum accuracy and relevance, it should be integrated into and form part of current water management systems and processes. This will, however, only happen once water poverty mapping as a process becomes better known and more widely accepted.

6.6 Future research

Future research into water poverty mapping and its management applications should focus on:

- Integrating the WPM process into water management tools and methods.
- Documenting the uses and successes of WPM, especially in the South African context.
- Methods to ensure that more frequent updates of data are possible, thereby ensuring the relevance of the obtained water poverty map.

6.7 Conclusion

The WPI and WPM have various advantageous applications for local municipalities, bulk water service providers and government, both local and national. The maps can assist with water poverty alleviation, improving the accuracy of predictions of future water demand, and for assisting with planning for the future in terms of infrastructure development and maintenance. As long as the appropriate scale, relevant variables and intended use is clear from the beginning of the process, the obtained indices and map can assist with achieving a variety of goals. As soon as its relevance and importance becomes widely accepted by water practitioners and those in management positions, more efficient use of our already scarce water resources will receive a major boost, thereby ensuring sufficient supply for the future.

7 References

Abrams, L. 1999. *Poverty and water supply and sanitation services.* Paper delivered at the Regional Workshop on Financing Community Water Supply and Sanitation, White River, South Africa.

Ahmad, Q. K. 2003. *Towards poverty alleviation: the water sector perspectives*, Water Resources Development, Vol. 19(2), pp. 263-277.

Allan, J. A. 2002. *Which Water are we Indexing and which Poverty*. Appendix 9.2 to Sullivan, C. A., Meigh, J. R., Fediw, T. S. Derivation and Testing of the Water Poverty Index Phase 1: Final Report. DFID.

Asheesh, M. 2004. *Allocating the gaps of shared water resources (the scarcity index) case study Palestine Israel.* Finnish Institute of Technology, Kotkantie 1, 90100, Oulu, Finland. http://www.ipcri.org/watconf/papers/mohamed.pdf. [11 February 2010]

Asmal, K. 1997. *White paper on a national water policy for South Africa.* Pretoria: Department of Water Affairs and Forestry.

Baker, M. J. 2001. *Selecting a Research Methodology.* The Marketing Review, Vol. 1(3), pp. 373 – 397.

Barker, C. 2007. *Testing the waters: mapping learning networks in Ontario water management.* M.Sc. thesis, Faculty of Graduate Studies, University of Guelph.

Basson, M. S. 1997. *Overview of Water Resource Availability and Utilization in South Africa.* DWAF, Cape Town.

Bateman, C. 2010. *Second report slams crippling neglect of water/sanitation system.* South African Medical Journal, Vol. 100(6), pp. 342 – 344.

Bell, J. & Opie, C. 2002. *Learning from Research.* Open University Press, 325 Chestnut Street, Philadelphia, PA 19106, USA.

Bensimon, E. M., Polkinghorne, D., Bauman, G. & Vallejo, E. 2004. *Doing research that makes a difference.* The Journal of Higher Education, Vol. 75(1), pp. 104 – 126.

Bigman, D. & Fofack, H. 2000. *Geographical Targeting for Poverty Alleviation: An introduction to the Special Issue.* The World Bank Economic Review Vol. 14(1), World Bank.

Bosch, C., Hommann, K., Rubio, G. M., Sadoff, C. & Travers, L. 2001. *Water, Sanitation and Poverty* in Poverty Reduction Strategy Sourcebook, World Bank.

Bouwer, H. 2000. *Integrated water management: emerging issues and challenges.* Agricultural water management, 45(2000), pp. 217 – 228.

Caribbean Water & Waste Association (CBWAW). 2002. Press Release, 20 December 2002. www.cwwacari.net/water.doc [12 January 2003]

Clarke, R. & King, J. 2004. *The Atlas of Water. Mapping the world's most critical resource.* Earthscan, 8 – 12 Camden High Street, London, NW1 0JH, United Kingdom.

Cohen, A. 2007. *An Asian perspective: Water-poverty & rural poverty alleviation in the Karst mountainous regions of Guangxi, China.* Oxford University Press.

Coles, C. 2005. *The World's Water Crisis.* Futurist, Vol. 39(2), p. 14.

Creswell, J. W. 2007. *Qualitative Inquiry and Research Design: Choosing* *among five approaches, 2nd Edition*. Thousand Oaks, California, Sage.

Cullis, J. D. S. 2002. *Targeting the Water Poor through Water Poverty Mapping: A Case study using Census Data and the Water Poverty Index for the Estcourt Municipal District, South Africa*. Unpublished M.Sc. Thesis, Environmental Change Institute, Oxford University Press.

Cullis, J. D. S. 2005. *Water poverty mapping: development and introduction using a case study at the local municipal scale for the Eastern Cape*. Water Research Commission, TT 250/05, August.

Denscombe, M. 2003. *The Good Research Guide, 2nd Edition.* Open University Press, 325 Chestnut Street, Philadelphia, PA 19106, USA.

Department of Health (DOH). 2006. *Social Cluster Briefing: Parliamentary Briefing.* February 2006.

Department of Provincial and Local Government (DPLG). 2005. *Framework for a municipal indigent policy. Executive summary.* September 2005.
http://fbs.dplg.gov.za/fbs/site/docs/DocumentLibrary/IP/Executive.pdf?PHPSESSID=ba2fc5b7d282940898dab7f61abdde5e. [15 February 2010]

Department of Provincial and Local Government (DPLG). 2002. *Free Basic Water Implementation Strategy Version 2.* August 2002.

Department of Provincial and Local Government (DPLG). 2004. *The Municipal Infrastructure Grant Programme: An Introductory Guide*. March 2004.

Department of Water Affairs and Forestry, South Africa (DWAF). 2002. *Proposed First Edition National Water Resource Strategy*. Pretoria.

Department of Water Affairs and Forestry (DWAF). 2005. *Western Cape Reconciliation Strategy.* August 2005.

Department of Water Affairs and Forestry. 2008. *Integrated Sector Support and Improved Sustainability within Water for Growth and Development.* Presentation to the National Water Summit on 17 March 2008.

Department of Water Affairs (DWA). 2011. http://www.dwa.gov.za/Dir_WQM/wqmFrame.htm [8 February 2011].

Desai, M. 1995. *Poverty, Famine and Economic Development*. Edward Elgar, Aldershot.

Desai, N. 2002. Opening address to the World Summit on Sustainable Development, 26 August 2002, Johannesburg.

Dlamini, D. J., Schulze, R. E. & Jewitt, G. P. W. 2003. *Applicability of the Water Poverty Index at Mesocatchment Scale*. Poster presented at the International Young Scientists Conference in Italy, November, 2003.

Doolan, D. M. & Froelicher, E. S. 2009. *Using an Existing Data Set to Answer New Research Questions: A Methodological Review.* Research and Theory for Nursing Practice: An International Journal, Vol. 23(3), pp. 203 – 215.

Doran, P. 2002. *World Summit on Sustainable Development (Johannesburg) – An assessment for IISD.* International Institute for Sustainable Development.

Du Toit De Villiers, G., Schmitz, P. M. U. & Booysen, H. J. 1996. *South Africa's Water Resources and the Lesotho Highlands Water Scheme: A Partial Solution to the Country's Water Problems.* Water Resources Development, Vol. 12(1), pp. 65 – 77.

Emfuleni Local Municipality (ELM). 2007. *Integrated Development Plan 2007 – 2012.*

Emfuleni Local Municipality (ELM). 2010. *Integrated Development Plan 2009/10.*

FAO. 2000. New Dimensions in Water: Water, Society and Ecosystem Services in the 21st century, United Nations, Rome.

Fotheringham, S. 1997. *Trends in Quantitative Methods 1: Stressing the Local Progress in Human Geography,* 21(1), pp. 88-96.

Frederiksen, H. D. 2009. *The world water crisis and international security.* Middle East Policy, Vol. 16(4), p. 76 – 89.

Fuggle, R. F. & Rabie, M. A. 2009. *Environmental Management in South Africa, 2nd Edition.* Juta Law, 7 Mercury Crescent, Hillstar, Wetton, 7780, Cape Town.

Galliers, R. D. & Land, F. F. 1987. *Choosing Appropriate Information Systems Research Methodologies.* Communications of the ACM, Vol. 30(11), pp. 900 – 902.

Gibson, C. C., Ostrom, E. & Ahm, T. K. 2000. *The Concept of Scale and the Human Dimensions of Global Change: A Survey.* Ecological Economics Vol. 32 pp. 217–239.

Gleick, P. 2002. *The world's water, The biennial report on freshwater resources, 2002 – 2003.* Island Press, 1718 Connecticut Avenue, N.W., Suite 300, Washington, DC 20009.

Global Water Partnership. 2000. *Towards water security: a framework for action*, Stockholm, Global Water Partnership.

Gomez-lobo, A., Foster, V. & Halpern, J. 2000. *Information and modeling issues in designing water and sanitation subsidy schemes.* University of Chile.

Grigg, N. S. 2008. *Total water management: Practices for a sustainable future.* American Water Works Association, 6666W Quincy Avenue, Denver, Colorado, 80235.

Henninger, N. 1998. *Mapping and Geographic Analysis of Human Welfare and Poverty*; Review and Assessment. World Resources Institute, Washington DC.

Hemson, D., Kulindwa, K., Lein, H. & Mascarenhas, A. 2008. *Poverty and Water. Explorations of the reciprocal relationship*. Zed Books Ltd, 7 Cynthia Street, London, N1 9JF, United Kingdom.

Holland, A. S. 2005. *The water business. Corporations versus people.* Zed Books Ltd, 7 Cynthia Street, London, NI 9JF, United Kingdom.

Jolly, Sir R. 2003. *Assessment of progress towards the WSSD goal for sanitation*. Water Supply and Sanitation Collaborative Council. http://www.wwssc.org/load.cfm?edit_id=217. [5 June 2009]

Langford, M. 2005. *The United Nations concept of water as a human right: a new paradigm for old problems?* Water Resources Development, 21(2), pp. 273 – 282.

Lawrence, P., Meigh, J. & Sullivan, C. 2002. *The water poverty index: an international comparison*. Keel Economics Research Papers, KERP 2002/19, October, 2002.

Maliki, S. & Benhabib, A. 2008. *Measuring water-poverty relationship in Algeria using ROC curves.* Economic Research Forum, working paper no. 423.

Melville, S. & Goddard, W. 1996. *Research Methodology.* Juta & Co Limited, P.O. Box 14373, Kenwyn, 7790.

Meyer, W. N. 2007. *The economics of water, water for life; sanitation for dignity.* Van Schaik Publishers, 1064 Arcadia Street, Hatfield Pretoria.

Miles, M. B. & Huberman, A. M. 1994. *Qualitative data analysis: An expanded sourcebook, 2nd Edition*. Thousand Oaks, California, Sage.

Miller, S. M. 1996. *The Great Train of Poverty Explanations in Poverty: A Global Review*. Handbook of International Poverty Research. Oyen, E., Miller, S. M. and Abdus, S. (eds), Scandinavian University Press and UNESCO Publishing, Oslo.

Municipal Infrastructure Task Team (MITT). 2004. *Policy Framework for the Municipal Infrastructure Grant.*

Naess, P. & Saglie, I. 2000. *Surviving Between the Trenches: Planning Research, Methodology and Theory of Science.* European Planning Studies, Vol. 8(6), pp. 729 – 750.

Newson, M. 2009. *Land, Water and Development. Sustainable and adaptive management of rivers, 3rd Edition.* Routledge, 2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN.

O’Hare, G. 2000. *Hurricane 07B in the Godavari Delta, Andhra Pradesh, India: vulnerability, mitigation and the spatial impact.* The Geographical Journal, 167(1), pp. 23 – 38.

Ohlsson, L. & Turton, A.R. 1999. *The turning of a screw: social resource scarcity as a bottle-neck in adaptation to water scarcity.* Proceedings of the Stockholm Water Symposium, Stockholm, Sweden.

Onwuegbuzie, A. J. & Leech, N. L. 2005. *On Becoming a Pragmatic*

Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies. International Journal of Social Research Methodology, Vol. 8(5), pp. 375 – 387.

Oyen, E., Miller, S. M. & Samad, S. A. 1996. *Poverty: A global review. Handbook on international poverty research.* Scandinavian University Press, P.O. Box 2959, Toyen, N-0608, Oslo, Norway.

Pallett, J. 1997. *Sharing water in Southern Africa.* Desert Research Foundation of Namibia, PO Box 20232, Windhoek, Namibia.

Perveen, S. & James, L. A. 2011. *Scale invariance of water stress and scarcity indicators: Facilitating cross-scale comparisons of water resources vulnerability.* Applied Geography, 31(2011), pp. 321 – 328.

Polit, D. F. & Beck, C. T. 2010. *Generalization in quantitative and qualitative research: Myths and strategies.* International Journal of Nursing Studies, Vol. 47(11), pp. 1451 – 1458.

Putcha, C. 2008. *Mathematical formulation of poverty index.* European Journal of Scientific Research, 20(2), pp. 291 – 296.

Rainharvest. 2010. Government Must Respond to Acid Mine Water*. http://www.rainharvest.co.za/2011/02/04/government-must-respond-to-acid-mine-water.* [21 February 2011]

Ramontja, T. 2010. *Report to the inter-ministerial committee on acid mine drainage. Mine water management in the Witwatersrand gold fields with special emphasis on acid mine drainage (unpublished). Pp. 1 – 145.*

Rand Water. 2008. http://www.wisa.org.za/patrons/randwater/index2.html [2 October 2008].

Rijsberman, F. R. 2005. *Water scarcity: Fact or fiction?* Agricultural water management, 80(2006), pp. 5 – 22.

Schulze, R. E. & Dlamini, D. J. M. 2002. *Mesoscale Indicators of Water Poverty in the Thukela Catchment, South Africa, under baseline land cover conditions.* Appendix 9.14 to Sullivan, C. A., Meigh, J. R., Fediw, T. S. Derivation and Testing of the Water Poverty Index Phase 1: Final Report. DFID.

Sen, A. 1981. *Poor, Relatively Speaking*. Oxford Economic Papers, No. 35.

Sen, A. 1985. *Commodities and Capabilities.* North Holland, Amsterdam.

Sen, A. 1999. *Development as Freedom.* Oxford University Press.

Sharma, S. K. & Vairavamoorthy, K. 2009. *Urban water demand management: prospects and challenges for the developing countries.* Water & Environment Journal, Vol. 23(3), pp. 210 – 218.

Shiklomanov, I. A. 1997. *Assessment of Water Resources and Water Availability in the World*. Report prepared for the Comprehensive Assessment of Freshwater Resources of the World. United Nations: St. Petersburg.

Soussan, J. 2003. *Poverty, water security and household use of water*. Paper presented at the International Symposium on water, poverty and productive uses of water at household levels. 21–23 January, Muldersdrift, South Africa.

SouthAfrica.info. 2008. *South Africa's weather and climate.* http://www.southafrica.info/travel/advice/climate.htm. [8 June 2009]

Stephen, L. & Downing, T. 2001. *Getting the Scale Right: A comparison of Analytical Methods for Vulnerability Assessment and Household-level Targeting*. Disasters, Vol. 25(2), pp. 113 – 135.

Sullivan, C. A., Meigh, J. R. & Fediw, T. S. 2002. *Derivation and Testing of the Water Poverty Index Phase 1*: Final Report. DFID.

Sullivan, C. A. 2002. *Calculating a Water Poverty Index*. World Development Vol. 30(7), pp. 1195 – 1210.

Sullivan, C. A, Meigh, J. R. & Lawrence, P. 2005. *Application of the Water Poverty Index at different scales: a cautionary tale*. Water International, Vol. 31(3), pp. 412 – 426.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., Mlote, S., Hutton, C., Allan, J. A., Schulze, R. E., Dlamini, D. J. M., Cosgrove, W., Delli Priscoli, J., Gleick, P., Smout, I., Cobbing, J., Calow, R., Hunt, C., Hussain, A., Acreman, M. C., King, J., Malomo, S., Tate, E. L., O'Regan, D. P., Milner, S. & Steyl, I. 2003. *The Water Poverty Index: Development and application at the community scale*. Natural Resources Forum, 27, pp. 1–11.

Swanson, R. A. & Holton, E. F. 3rd. 2005. *Research in organizations: Foundations and methods of inquiry.* San Francisco, Berrett-Koehler.

Swatuk, L. A. 2008. *A political economy of water in Southern Africa*. Water Alternatives, 1(1), pp. 24 – 47.

Swatuk, L. A. 2010. *The State and Water Resources Development through the Lens of History: A South African Case Study.* Water Alternatives, Vol. 3(3), pp.521 – 536.

Voorsluys, W., Araujo, E., Cirne, W., Galvao, C. O., Souza, E. P. & Cavalcanti, E. P. 2007. *Fostering collaboration to better manage water resources.* Concurrency and computation: Practice and experience, Vol. 19, pp. 1609 – 1620.

Walmsley, J., Carden, M., Revenga, C., Sagona, F., & Smith, M. 2001. *Indictors of sustainable development for catchment management in South Africa – Review of indicators from around the world* in Water SA Vol. 27 No. 4 pp. 539 – 550.

Warfield, D. 2010. *IS/IT Research: A Research Methodologies Review.* Journal of Theoretical and Applied Information Technology, Vol. 13(1/2), pp. 28 – 35.

Waterlovers. 2010. *Acidic Mine Water Crisis.* http://www.waterlovers.co.za/2010/09/28/acidic-mine-water-crisis. [21 February 2011]

Weiner, R. 2007. *World water, a crisis of global governance?* New England Journal of Public Policy, Vol. 21(2), pp. 128 – 134.

Winde, F. & Stoch, E. J. 2010. *Threats and opportunities for post-closure development in dolomitic gold mining areas of the West Rand and Far West Rand (South Africa) – a hydraulic view Part 1: Mining legacy and future threats.* Water SA, Vol. 36(1), pp. 69 – 74.

World Bank. 2001. *World Development Report 2001/2002: Attacking Poverty,* Oxford University Press.

World Water Forum. 2003. *Water Poverty Index Yields Surprising Results.* 3rd World Water Forum press release.

Appendix A

As mentioned earlier, this research has been published as part of the 15th IBIMA conference proceedings and has been accepted for publication in the "Communications of the IBIMA" journal. The accepted paper is presented in this appendix for the interest of the reader.

Water Poverty Mapping and its role in Assisting Water Management

Charles van der Vyver, North-West University, Vaal Triangle Campus, PO Box 1174,
Vanderbijlpark, 1900, South Africa. Charles.vandervyver@nwu.ac.za

Dawid B Jordaan, North-West University, Vaal Triangle Campus, PO Box 1174,
Vanderbijlpark, 1900, South Africa. Dawid.jordaan@nwu.ac.za

Abstract

Water scarcity occurs when the ways in which we use and distribute water cannot fully meet the demand from the environment, industry, farms and households. On a worldwide scale, the World Bank estimates that roughly 166 million people in 18 countries are affected by water scarcity and another 270 million people in 11 countries are water stressed (Hemson *et al.*, 2008). Given these figures, it is easy to see why we can refer to the existence of a so-called global water crisis.

The purpose of this paper is to document how water poverty mapping can assist the water management in three towns in South Africa. It should assist with as many as possible of the following aspects: the collection and analysis of all relevant information regarding the availability of water, its various uses, current supply status, future prospects, current water allocation details and the state and processes of water deprivation, and dissemination of information and messages arising from the analysis thereof to all concerned. It recommends that water poverty mapping be used as a managing tool by governments, water service providers and local municipalities. It can also form part of a local municipality's master plan, which in turn, guides town expansion and infrastructure development. All three entities can use water poverty mapping as part of their water management strategy to replace, supplement or validate their water demand predictions so that future supply can be guaranteed.

Keywords: Water Poverty Mapping, Water Management, Water Poverty Index.

1 Introduction

South Africa, being a water-stressed country, with less than 1700 m^3 of water for each person per year (Rand Water, 2008), has limited fresh water resources and budgets for the supply of basic infrastructure services. Currently over 6 million people in South Africa are without access to even a basic level of water supply or have a very limited level of access (Cullis, 2005). The norm has been to think of water poverty merely in terms of a lack of the actual resource, whereas Sullivan *et al.* (2003) and Sullivan (2005) have shown that water poverty should be expressed in terms of resource, access, capacity, use and environment. These five components are contained in the Water Poverty Index (or WPI), as developed by Sullivan *et al.* (2002), and refined by researchers at the Centre for Ecology and Hydrology in Wallingford, UK. Graphical representations of the WPI are a very effective and understandable way of communicating information as no knowledge of the underlying data and its transformation is required. These graphical representations of the WPI are known as water poverty maps.

2 Water Management

During recent years the two major shortcomings of water management that have been widely recognized are, firstly, very little or no pollution control, and secondly inefficient utilization. According to Pallett (1997), the aim of water management should be to supply people with essential water supplies whilst ensuring that water continues to be shared amongst all the components of the human and the natural environment in a river basin. Water and poverty interface in more than one way (Ahmad, 2003), and the management of water resources is, therefore, a vital process element of sustainable human development. If we continue to use our water resources as we currently do, the world will be facing a severe water shortage as early as 2025 (Clarke *et al.*, 2004). This will lead to reduced food production, which in turn will lead to malnutrition and disease, and also to increased ecological damage.

3 The Water Poverty Index

The conventional methods to assess water management were purely deterministic relying on the availability of large-scale data. A method that was easy to calculate, cost effective to implement, based mostly on existing data, and that uses a transparent process (i.e. easy to understand), was needed. This motivated Sullivan *et al* (2002) to design the Water Poverty Index (WPI). The WPI has the following advantages over conventional methods:

- It provides a better understanding of the relationship between the physical availability of water, its ease of abstraction, and the level of welfare;
- It is a mechanism to prioritize water needs;
- It is a tool for monitoring progress in the water sector;
- The WPI is mainly designed to help improve the situation for people facing poor water endowments and poor adaptive capacity.

The WPI allows the use of different scales to be applied for different needs and defines water poverty according to five components. These components are:

- **Resources**. The availability of water, taking into account the variations in seasonal and inter-annual fluctuations and water quality.
- **Access**. The accessibility of water for human use.
- **Capacity**. Capacity is interpreted in the sense of income to allow purchase of improved water, and education and health, which interact with income and indicate a capacity to lobby for and manage a water supply (Cullis, 2005; Lawrence *et al.*, 2002).
- **Use**. Captures the actual amount of water being used and extracted from the system.
- **Environment**. This variable captures the environmental impact of water management (Lawrence *et al.* 2002).

Each of the five components consists of a number of sub-components and a weighting (see section 8) can be applied to each component to indicate the component's importance. The components are standardized to fall in the range 0 to 100, resulting in a final WPI value between 0 and 100. The highest value 100 is taken to be the best situation and 0 being the worst.

The five key components are combined together in a general expression:

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

Where

WPI = Water Poverty Index score of a particular location

R = Resources component
A = Access component
C = Capacity component
U = Use component
E = Environment component
w = weighting factor for each component

The WPI was the preferred indicator for this study, although other indicators like the Water Stress Index (Gleick, 2002), the Water Scarcity Index (Asheesh, 2004), etc. were considered. However these indicators did not provide sufficient detail, especially when working on a smaller scale. A high level of detail is required to allow targeting of resources to address specific problems.

4 The South African Context

South Africa's water resources are limited and in global terms are scarce (Hemson *et al.*, 2008), and has been rated as one of the 20 most water-deficient countries in the world (Meyer, 2007). South Africa also has a high unemployment rate, which means that many people simply cannot afford to pay for basic water and sanitation (Holland, 2005), and many people who can afford to pay simply don't pay for public services because they consider it a right.

The free basic supply of water regulation was introduced in 2001. According to the World Health Organization, a person requires roughly 25 liters of water per day to promote healthy living. Under the assumption of 8 people per household, the standard was set at 6000 liters of free water per household per month (Hemson *et al.*, 2008). Unfortunately, many municipalities experienced difficulties in implementing the free basic water supply regulation and by 2002 only 57% of the population was receiving their free basic water supply (Holland, 2005).

In 2005 the Department of Provincial and Local Government (or DPLG) created a policy that provides a basis for the provision of free basic services to the indigent. These basic services include free basic water and sanitation, free basic electricity, and the property rates act, which provides for a zero rating of low value properties (DPLG, 2005). According to this policy, an indigent is someone who "*lacks the necessities of life".* In a broad sense, these necessities include, amongst others:

- Sufficient water.
- Basic sanitation.

Under this policy, people that have been classified as being indigent and that have undergone a successful registration process will receive their basic services free of charge. Instead of the local municipality carrying this financial burden, they will be reimbursed by the state. In the region of 21 000 indigents were registered at one of the major local municipalities in the area under consideration on 30 June 2009 (the end of their financial year).

5 Water Poverty Mapping

Water poverty mapping is used to identify areas of high levels of water poverty with the aim to assist in the targeting of water related policies. This ensures the most efficient use of resources to meet the development objectives of the country. The strengths of the Water Poverty Index (WPI), poverty mapping and geographic targeting are combined in water poverty mapping (Cullis, 2005). The concept of water poverty mapping was introduced by Cullis in 2002 when he constructed a water poverty map for the town of Escort in the Kwazulu-Natal province of South Africa. In 2005. Cullis expanded the concept by constructing the water poverty map for the Eastern Cape Province in South Africa.

6 Data Sources

The data for this study was obtained from three sources. The first source is an analysis that was done into the current operations of the local municipality and the local water services provider. The second source is the Census data from 2001, which can be accessed through the website of Statistics SA (http://www.statssa.gov.za). The third source is the Water Situation Assessment Model (or WSAM) version 5.001, which was released on 1 October 2008 and is available from the Department of Water Affairs and Forestry (DWAF). All the data in the WSAM is at the 98% assurance level. Table 1 lists the WPI components and the respective data source.

Table 1 WPI component data sources

Component	Source
Resource	Analysis
Access	Census
Capacity	Census
Use	WSAM
Environment	WSAM

7 Component Calculation

The following sections will discuss the calculation method for each of the component values, its benchmark level, and the calculation of the final score that will be used to calculate the WPI. The indicators to be used for the various components as well as the benchmark levels have been selected according to the guidelines developed by Cullis (2005).

7.1 Resource

After an analysis of the operations of the local municipality and the local water services provider, it was identified that looking at the total resource availability in an area in terms of groundwater and surface water availability is an irrelevant method for the Vaal Triangle (collective term for Vanderbijlpark, Vereeniging and Sasolburg) area that is under consideration in this study. The method suggested by the analysis is motivated firstly by the fact that it is the method currently used by management when looking at total resource availability, and secondly because it is a method that supports prediction. It recommends that the resources of the area should be expressed in terms of the percentage of water that the service provider actually extracts from the water system in comparison to the amount of water that may be extracted.

Due to the sensitive nature of the actual figures, the input for this component will be the percentage of the allowance that is actually extracted. The minimum benchmark level for this component is 0 and the maximum benchmark level is 100. The value of the optimum extraction rate has been set at 90%, as this is the current extraction rate that satisfies the total demand. A resource component score of 100 indicates an optimum extraction rate of 90%. Any value above or below this optimum level is adjusted so that it reflects consumption in terms of a percentage of the optimum level. Table 2 lists the resource component score for each of the three towns in the study.

The values for the three towns under consideration are the same because all three towns receive their water from the same water system.

Table 2 Resource component calculation

	Value **(Extraction rate %)**	**Score** **(%)**
Vanderbijlpark	90	100
Vereeniging	90	100
Sasolburg	90	100

7.2 Access

The access component value is calculated as

$$A=\frac{\text{Households with access to secure water source}}{\text{Total households}}$$

A secure water source is defined as being piped water either inside the dwelling or inside the yard. This study is limited to these two sources of water as there are too many factors influencing access to a communal water source such as certain community factions monopolizing the facility, etc. The minimum benchmark level for Access is 0% and the maximum level is 100%. Table 3 lists the access component score for each of the three towns in the study.

Table 3 Access component calculation

	Households With Safe Water Source	**Total Households**	**Value** **(Proportion)**	**Score (%)**
Vanderbijlpark	25 422	26 602	0.955	95.564
Vereeniging	21 103	22 884	0.922	92.217
Sasolburg	7 456	7 644	0.975	97.541

7.3 Capacity

The capacity component consists of Educational Capacity as well as Income Capacity. The Educational Capacity value is calculated as

$$EC=\frac{\text{People with education greater than grade 4}}{\text{Urban population}}$$

and the Income Capacity value is calculated as

$$IC=\frac{\text{Households with income greater than R26400 per annum}}{\text{Total households}}$$

Grade four is the educational level at which information regarding responsible water use is disseminated to learners (Cullis, 2005). As the same education plan is still in place, grade 4 was used as the threshold level for educational capacity. According to the WSDP (water service development plan which is available from DWAF), the average person is willing to spend roughly 5% of their disposable income on services. After an analysis at the local municipality, it was determined that a basic suite of services costs approximately R110 per household per month, or R1 320 per household per year. If R1 320 equals 5% of disposable income, 100% will equate to R26 400, the threshold level for income capacity.

The two sub-components used for the capacity component have been assigned equal importance (Cullis, 2002; 2005). The capacity component value is therefore merely the average of the two sub-components and is calculated as

$$C=\frac{EC+IC}{2}$$

The minimum benchmark level for capacity is 0% and the maximum level is 100%. Table 4 lists the capacity component score for each of the three towns in the study.

Table 4 Capacity component calculation

	People With Education > Grade 4	Total Population	Education Capacity (%)	Households With Income > R26 400	Total Households	Income Capacity (%)	Score (%)
Vanderbijlpark	63 529	474 081	13.4	18 432	26 602	69.288	41.344
Vereeniging	58 649	497 600	11.786	15 135	22 884	66.14	38.963
Sasolburg	19 906	141 000	14.118	6 220	7 644	81.371	47.745

7.4 Use

The use component value is calculated as

$$U=\frac{\text{Direct requirement urban}}{\text{Urban population}}*\frac{10^9}{365}$$ l/c/d (liters/capita/day).

The minimum benchmark levels for the use component are 0 l/c/d and 320 l/c/d (as an optimum level is used) and according to Cullis (2005), the maximum (optimum) level for use in the South African environment is 160 l/c/d. A use component score of 100 indicates an optimum consumption level of 160 l/c/d. Any value above or below this optimum level is adjusted so that it reflects consumption in terms of a percentage of the optimum level.

As this study and water poverty mapping generally focus on residential water poverty alleviation, it is important to differentiate between residential and non-residential water use. The local municipality indicated that, on a month-to-month basis, residential water use tends to fluctuate between 50% and 55% of the total water use and non-residential between 45% and 50% of the total water use. Therefore, a figure of 52% will be used for residential use, and 48% for non-residential use.

From the three towns under consideration, Vanderbijlpark was the only town where the use component value was not adjusted, as the major non-residential water consumer in the town obtains their water directly from the local water services provider, and not from the local municipality. This is however not the case for Vereeniging and Sasolburg, as both these towns have major non-residential water consumers that obtain their water from the local municipality, and including these two towns in the usage figures corrupts the use component score. Table 5 lists the use component score for each of the three towns in the study.

Table 5 Use component calculation

	Direct Requirement Urban	Population	Value (l/c/d)	Score (%)
Vanderbijlpark	22.26	474 081	128.641	80.401
Vereeniging	25.896	497 600	142.58	89.113
Sasolburg	10.598	141 000	205.926	71.296

7.5 Environment

The environment component value is obtained directly from the WSAM and no calculation is required to determine the component value. The minimum benchmark level for Environment is 0 and the maximum level is 5, as it is the exact measurement scale used by DWAF to express the present ecological class in the WSAM. The environment component score is then calculated by multiplying the component value with 20, as this expresses the component as a score out of 100, and therefore, as a percentage. It has a range of 0 to 5, with 0 indicating a "very poor" ecological state and 5 a perfect ecological state. Table 6 lists the environment component score for each of the three towns in the study.

Table 6 Environment component calculation

	Index (Rating)	Score (%)
Vanderbijlpark	4.086	81.72
Vereeniging	3.641	72.82
Sasolburg	3.856	77.12

8 Component Weighting

The option of adding different weightings to the components has been included in the WPI to compensate for different priorities and circumstances. When deciding which weightings to use for the calculation of the WPI, the hydrological and economic conditions, as well as the national/regional, priorities of the specific area need to be considered. Table 7 contains the various weighting groupings as compiled by Sullivan *et al.* (2002).

The second combination of weightings will be used as it has been proven to be effective in previous studies on a similar scale (Cullis, 2005), i.e. 1 for resource, 2 for access, 2 for capacity, 1 for use and 1 for environment. The descriptors that are related to the chosen weightings are also the closest match to the conditions found in the area under consideration.

Table 7 Weighting options for the WPI

Local condition descriptors			Component weights				
Hydrological condition	Economic condition	National priorities	Resource	Access	Capacity	Use	Environment
Very good	Unknown	Agriculture, Industry & Social	1	2	2	3	1
Average	Average	Social	1	2	2	1	1
Very good	Good	Environment & Social	1	2	2	1	2
Unknown	Unknown	Industry & Agriculture	1	2	2	2	1

9 Index Calculation

After calculating each of the individual component scores, the weightings have to be used to calculate the final WPI for each town. The formula to be used for the final calculation of the WPI is given below.

$$WPI = \frac{w_r R + w_a A + w_c C + w_u U + w_e E}{w_r + w_a + w_c + w_u + w_e}$$

Table 8 summarizes the component scores and final WPI scores for each of the towns in the study.

Table 8 WPI calculation

	Resource **(Weighting=1)**	**Access** **(Weighting=2)**	**Capacity** **(Weighting=2)**	**Use** **(Weighting=1)**	**Environment** **(Weighting=1)**	**WPI**
Vanderbijlpark	100	95.564	41.344	80.401	81.72	76.562
Vereeniging	100	92.217	38.963	89.113	72.82	74.899
Sasolburg	100	97.541	47.745	71.296	77.12	76.998

When working with water poverty mapping and the water poverty index as mentioned earlier, the contributions of each of the components to the final index value is just as important as the final index value itself. Figure 1 is a graphical representation of the component contributions and water poverty indexes of the three towns in the Vaal Triangle.

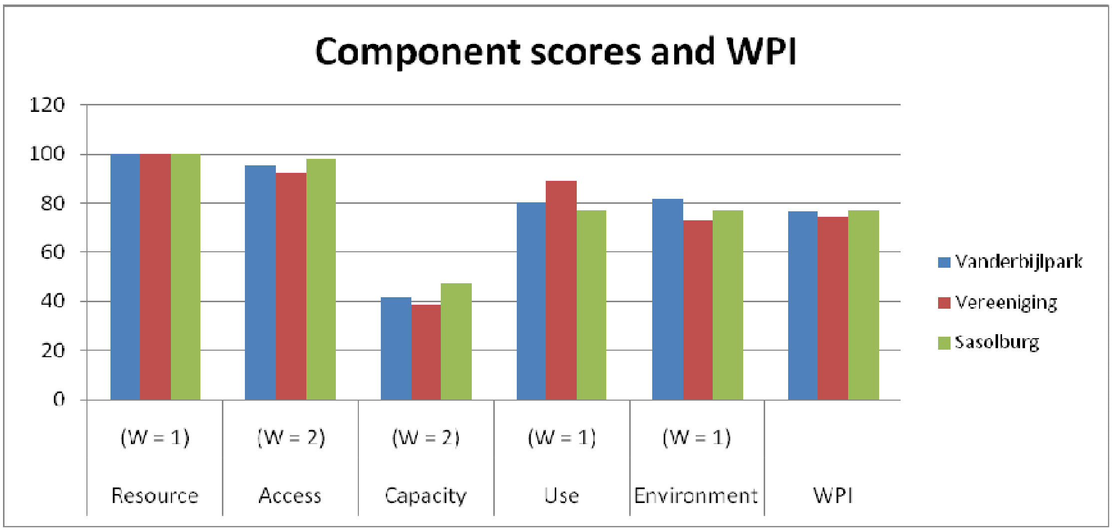

Figure 1 Graphical representation of component scores and WPI

A WPI of 100 indicates that there are no water related problems in an area. The worst WPI that an area or region can have is 0, which indicates that there are numerous water related problems and that a lot of time and money will have to be spent in an effort to rectify the situation. The three towns in this study all have a WPI value in the high seventies, which is relatively high seeing that the entire country had a WPI of only 52. The capacity component score was the lowest, therefore, improving educational and income capacity in each of the towns could be a key factor for improving the water poverty in the region.

10 Map Construction

After calculating the various water poverty indexes, the next step in the process is to construct the water poverty map. For the purpose of this study, the image of the area under consideration was obtained using Google Earth, and the mapping was done using Map Maker version 3.5. Figure 2 represents the WPM that was constructed for this study.

On the map the various colors indicate the boundaries of the three towns, namely Vanderbijlpark in white, Vereeniging in yellow, and Sasolburg in green. The three numbers on the map represent the water poverty indexes for each of the towns.

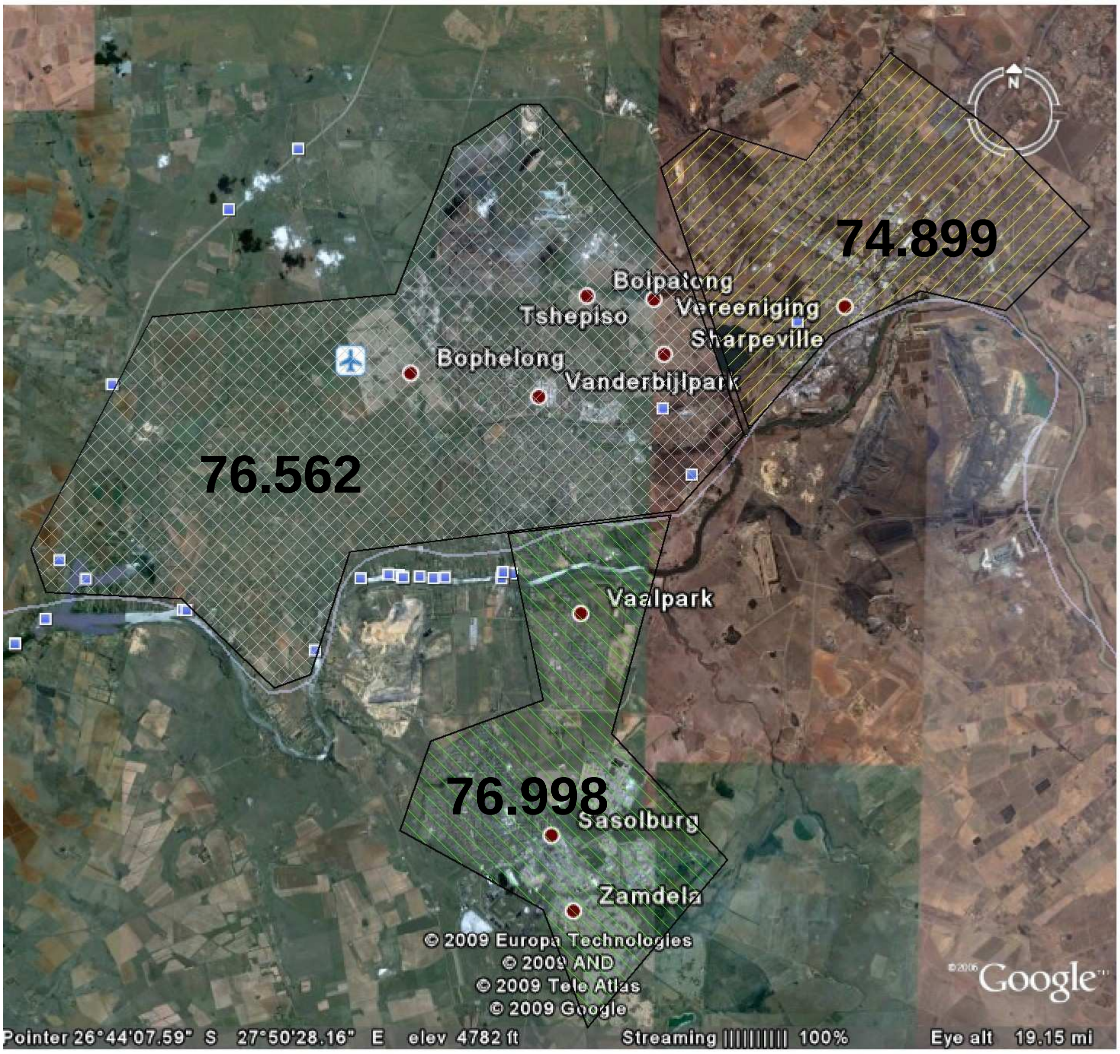

Figure 2 Water poverty map for the Vaal Triangle

11 Recommendations

When planning for the future, local municipalities, water service providers and governments have to ensure that they can keep up with the rate of growth and development. This is particularly important when it comes to water and the demand for water, as it is an extremely valuable but also very limited resource. The following recommendations are aimed towards various water management entities.

11.1 Recommendation to Local Municipality

A local municipality has to predict its future water requirements on a regular basis. These predictions are given to the water services provider so that they can ensure that they can meet the demand for water.

Currently these predictions are based on two measurements, the trend of demand for water as well as the population growth rate. The demand and the growth figures are available on a month-to-month basis, and when determining the value for the prediction, the average of the two measurements is used. These demand predictions are also used when determining the relevant tariff that the end user will be charged. In the long-term, these predictions are used to plan ahead for projects like infrastructure improvement, maintenance, expansion, etc.

The result of an analysis of the processes of the local municipality was that the Use component of the WPI and the water poverty map can immediately form part of their predictions, and that if water poverty maps can be constructed on regular intervals they even have the potential to completely replace the current prediction-system. Currently, when determining overall demand, the municipality looks at the total number of kiloliters that was supplied to them by the water service provider. Unfortunately, this total also contains the water that has been lost, for example through leaking pipes, and this affects the accuracy of the information. By taking the usage (measured in l/c/d) and multiplying it with the population size, it can be used as a more accurate measure of overall demand, or it can be used to confirm whether the earlier obtained overall demand is reasonably accurate or not. It was also highlighted that if water poverty maps were to be constructed on a relatively regular basis, using the most recent data, the maps could become the sole basis of their predictions. With a series of regularly constructed maps, it will become much easier to measure the impacts of development, and it will also provide users with a relevant and up to date overall picture, considering not only the resource, but also the factors influencing its responsible usage.

The WPM can also be included in a municipality's master plan. A master plan is a document that a municipality has to compile for every developed area under its jurisdiction. It is typically a document that is set up during the first few years after a town has been established, which is then updated on a regular basis. In the master plan, areas are classified as being either urban, urban-edge or rural. The urban-edge is usually the area where a town expands. Therefore, the urban-edge of a town shifts continuously. The water poverty map itself can be used to keep track of the town boundaries as well as the areas that have been classified according to the three different classifications. The master plan serves two main purposes. It provides a detailed description of what is currently available (in terms of infrastructure, etc.), and what the current demand is and what will be needed to ensure that the demand can be sustainably met. An analysis of the current processes of the local municipality highlighted that the resource component of the water poverty map can be used as part of the master plan to guide development. The Resource component will give a very clear indication of how much development is viable given the current maximum carrying capacity, in other words, when will the maximum level be reached. The main limiting factor on development (suggested planned development) is resource availability because water is and will always remain a finite resource.

11.2 Recommendation to Water Service Provider

The water service provider needs to consider all the predictions from the municipalities they serve when preparing their prediction for government. Although they annually predict the demand for the next year, every five years they have to predict the demand for the next five years when they apply for their permit from DWAF. The permit they obtain from DWAF gives them permission to extract water from the system and states how much water they are allowed to extract. The advantages of the use of water poverty maps by the water service provider are similar to those that will be experienced by local municipalities. The only difference will be the scale on which the water poverty map is constructed.

11.3 Recommendation to Government

The advantages of more accurate predictions are tenfold for government and DWAF. Government has to ensure that it can meet the water demand of its inhabitants, and to enable this accurate predictions of future demand are needed so that they can have a clear idea of when the demand is going to overtake the supply. The sooner they know when this is likely to happen, the more time they have to prepare for alternatives.

On a provincial government level, the results obtained from water poverty maps on a municipal level can be used to identify the municipalities or districts most in need of an intervention. This information can then be used when assigning resources to ensure that the water poverty is addressed efficiently. On a national level, the benefits of water poverty mapping are similar. The maps can be constructed on a provincial level to identify the province with the highest water poverty. Once the province has been identified, a map on a smaller scale can be used to identify the worst district in that province, and from there a map on an even smaller scale can be used to identify the worst municipality in that district.

12 Conclusion

A water poverty map that has been constructed on a sufficient scale and with the correct sub-components can be very helpful for the management of our scarce water resources. They not only act as a quick reference point for various water related information, but can also assist the various management levels to obtain more accurate water demand predictions, and to do better town planning through the master plan. The fact that they can be constructed on any scale and with any components, means that they are not limited in terms of their scope and usefulness.

13 Acknowledgements

The work in this paper is based on a poster presented at the IWA – Young Water Professionals Conference that was held in Sydney Australia during July 2010.

References

Ahmad, Q. K. 2003. *Towards poverty alleviation: the water sector perspectives*, Water Resources Development, Vol. 19(2), pp. 263-277.

Asheesh, M. 2004. *Allocating the gaps of shared water resources (the scarcity index) case study Palestine Israel.* Finnish Institute of Technology, Kotkantie 1, 90100, Oulu, Finland. http://www.ipcri.org/watconf/papers/mohamed.pdf. [11 February 2010]

Clarke, R. & King, J. 2004. *The Atlas of Water. Mapping the world's most critical resource.* Earthscan, 8 – 12 Camden High Street, London, NW1 0JH, United Kingdom.

Cullis, J. D. S. 2002. *Targeting the Water Poor through Water Poverty Mapping: A Case study using Census Data and the Water Poverty Index for the Estcourt Municipal District, South Africa*. Unpublished M.Sc. Thesis, Environmental Change Institute, Oxford University.

Cullis, J. D. S. 2005. *Water poverty mapping: development and introduction using a case study at the local municipal scale for the Eastern Cape*. Water Research Commission, TT 250/05.

Department of Provincial and Local Government (DPLG). 2005. *Framework for a municipal indigent policy. Executive summary.*
http://fbs.dplg.gov.za/fbs/site/docs/DocumentLibrary/IP/Executive.pdf?PHPSESSID=ba2fc5b7d282940898dab7f61abdde5e. [15 February 2010]

Gleick, P. 2002. *The world's water, The biennial report on freshwater resources, 2002 – 2003.* Island Press, 1718 Connecticut Avenue, N.W., Suite 300, Washington, DC 20009.

Hemson, D, Kulindwa, K, Lein, H & Mascarenhas, A. 2008. *Poverty and Water. Explorations* *of the reciprocal relationship*. Zed Books Ltd, 7 Cynthia Street, London, N1 9JF, United Kingdom.

Holland, A.S. 2005. *The water business. Corporations versus people.* Zed Books Ltd, 7 Cynthia Street, London, NI 9JF, United Kingdom.

Lawrence, P., Meigh, J. & Sullivan, C. 2002. *The water poverty index: an international comparison*. Keel Economics Research Papers, KERP 2002/19.

Meyer, W. N. 2007. *The economics of water, water for life; sanitation for dignity.* Van Schaik Publishers, 1064 Arcadia Street, Hatfield Pretoria.

Newson, M. 2009. *Land, Water and Development. Sustainable and adaptive management of rivers, 3rd Edition.* Routledge, 2 Park Square, Milton Park, Abingdon, Oxon, OX14 4RN.

Pallett, J. 1997. *Sharing water in Southern Africa.* Desert Research Foundation of Namibia, PO Box 20232, Windhoek, Namibia.

Rand Water. 2008. http://www.wisa.org.za/patrons/randwater/index2.html [2 October 2008].

Sullivan, C. A, Meigh, J. R., Fediw, T. S. 2002. *Derivation and Testing of the Water Poverty Index Phase 1*: Final Report. DFID.

Sullivan, C. A. 2002. *Calculating a Water Poverty Index*. World Development, Vol. 30(7), pp. 1195 – 1210.

Sullivan, C. A, Meigh, J.R & Lawrence, P. 2005. *Application of the Water Poverty Index at different scales: a cautionary tale*. Water International, Vol. 31(3), pp. 412 – 426.

Sullivan, C. A., Meigh, J. R., Giacomello, A. M., Fediw, T., Lawrence, P., Samad, M., Mlote, S., Hutton, C., Allan, J. A., Schulze, R. E., Dlamini, D. J. M., Cosgrove, W., Delli Priscoli, J., Gleick, P., Smout, I., Cobbing, J., Calow, R., Hunt, C., Hussain, A., Acreman, M. C., King, J., Malomo, S., Tate, E. L., O'Regan, D. P., Milner, S. & Steyl, I. 2003. *The Water Poverty Index: Development and application at the community scale*. Natural Resources Forum, 27, pp. 189 – 199.