Measurement & Modelling of Households' Demand & Access to Basic Water in Relation to the Rapidly Increasing Household Numbers in South Africa

by

Nnadozie Remigius Chidozie

Submitted in fulfilment of the academic requirement
for the degree of Doctor of Philosophy in the
School of Mathematical Sciences
University of KwaZulu-Natal
Durban

March 2010

As the candidate's supervisor I have approved this thesis for submission.

Signed:
Supervisor: Professor PGL Leach
Date: 31 : 03 : 2010

Measurement & Modelling of Households' Demand & Access to Basic Water in Relation to the Rapidly Increasing Household Numbers in South Africa

Nnadozie Remigius Chidozie

Measurement & Modelling of Households' Demand & Access to Basic Water in Relation to the Rapidly Increasing Household Numbers in South Africa

by

Nnadozie Remigius Chidozie

Submitted in fulfilment of the academic requirement
for the degree of Doctor of Philosophy in the
School of Mathematical Sciences
University of KwaZulu-Natal
Durban

March 2010

As the candidate's supervisor I have approved this thesis for submission.

Signed:
Supervisor: Professor PGL Leach
Date:

Abstract

Service delivery in post-apartheid South Africa has become a topical issue both in the academia and the political arena . The rise of social movements, the xenophobic tensions of May 2008 and protest actions could be noted as the major traits of post-apartheid South Africa. Though there are divergent views on the underlying causes of these protests, lack of service delivery has most significantly been at the centre stage. In this thesis we investigate the relationship between household/population changes and the demand for piped-water connection in South Africa. There is an ample, albeit at times of questionable accuracy, supply of statistics from official and other sources. These statistics are both the source of inspiration of particular societal measures to be investigated and a gauge of the accuracy of the mathematical/statistical modelling which is the central feature of this project.

We construct mathematical/statistical models which take into account demographic constituents of the problem using differential equations for modelling household dynamics and we also investigate the interaction of demographic parameters and the demand for piped-water connection using multivariate statistical techniques.

The results show that with a boost in delivery the rich provinces seem to be in better standing of meeting targets and that the increasing demand in household-based services could be most significantly attributed to the fragmentation of households against other demographic processes like natural increase in population and net migration. The results imply that in as much as service delivery policies and programmes should focus on formerly disadvantaged poor communities, adequate provisions for increasing service demands in urban centres should also be a priority in view of the increasing in-migration from rural areas as households fragment. Most of the findings/results are in tabular and graphical forms for easy understanding of the reader.

Declaration 1: Plagiarism

I *Nnadozie Remigius Chidozie* declare that:

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being obtained from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being obtained from other researchers. In writing this thesis where other written sources have been quoted, then: (a). Their words have been rewritten, but the general information attributed to them has been cited (b). Also, where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and cited.
5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the References.

Signed:

March 2010

Declaration 2: Publications & Presentations

The following publications form part and / or include research presented in this Dissertation:

- Nnadozie RC (2009). *Modeling Demand for Basic Services in South Africa: the Case of Household Dynamics and Water Connection*, (Paper presented at the 57^{th} Session of the International Statistical Institute, August 2009 Durban).

- Nnadozie RC (2008). *On the Theoretical Number of Service Units in South Africa*, (Paper presented at the 51^{st} congress of South Africa Mathematical Society, November 2008 Durban).

- Hemson D and Nnadozie R (2006). *Pipe Dream for the Province's Poor*, statistical review of basic water backlogs in KwaZulu-Natal in the (The Mail & Guardian Newspapers, 28 April 2006).

- Nnadozie RC and Hemson D (2005). *Transforming Rural Areas? Service Delivery and Rural Development*, (Paper Presented at the HSRC winter conference 2005 Johannesburg).

- Nnadozie RC (...). *Sociodemographic Influences on Demand for Household-based Services in South Africa*, (Draft Article to be submitted to the **Southern Africa Journal of Demography**).

- Nnadozie RC (...). *Measuring Provincial Advances in Delivery and Access to Basic Water in South Africa: A Phase-Based Approach*, (Draft article to be submitted to the journal: **Water SA**).

Signed:

March 2010

Dedication

To every little infant/child in the world that is fed without basic portable water.

To the loving memories of Mama and Papa (Mr & Mrs Alfred Nnadozie Nwokocha)

To Sam Duh...for all the dreams and fighting spirit we shared. The spirit lives.

Acknowledgments

I shall ever remain most grateful to my supervisor, Professor PGL Leach. I most confess that he is one of the persons who have most positively influenced my life, not only with regards to academic but general perceptions and attitude towards life. Professor Leach has bestowed in me the psychological impetus that has entirely reshaped my perception of my abilities.

I am very grateful to the staff and students of the School of Mathematical Sciences, Professor John Swart who initially motivated me to do research in the modelling of biological systems, to the secretaries and to all for their cheerfulness and the friendly environment.

My sincere gratitude also goes to the staff and management of the University's libraries, the staff and students of the Population Studies Unit, where I experienced wonderful exposure to the social and demographic aspects of population dynamics and of course the entire community of the University for making me feel like home away from home. I am grateful to the Human Sciences Research Council for the opportunity to serve as an intern. I learnt a lot from the HSRC by working with my research director, Dr David Hemson.

I thank my wife, family and friends for their support. All praise and glory to God!

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Motivation for the Study

The rise of social movements and protest actions could be noted as one of the major traits of the present era in South Africa. Though there are divergent views on the underlying causes of these protests, lack of service delivery has most significantly been at the centre stage. Evidently service delivery has a high profile in South Africa's post-apartheid government. Then again there is a high expectation of a better life of the populace in the post-apartheid era.

In the water-delivery sector for instance from the foundation of the Reconstruction and Development Programme (RDP) there has been the anticipation that the goals set out in the national water and sanitation programme to provide all households with a clean, safe supply of 25 litres per capita per day within 200 metres and improved sanitation facilities would be achieved. Although the RDP now exists as a historical landmark, the subsequent developmental targets, including the provision of all households in South Africa with basic water by 2008, are built on expectations of speedy delivery.

The monitoring and evaluation of progress towards meeting targets require consistent datasets of different levels of service from provincial to district municipality levels. The yearly national household surveys, i.e. the October Household Surveys and the General Household Surveys (OHS/GHS) from Statistics South Africa, remain the main source of such data. The common practice in most countries emphasizes on individual population, data at household level especially in developing countries has not received due attention [102], this is evident in South Africa where the mid-year population estimates is published annually by Statistics South Africa without the household estimates. Although the preference of unit for demographic analysis depends upon the problem to be solved, for forecasts of total population, of the future labor force, of pension weight, of social grants etc it is satisfactory to work with the level of individuals. However, this does not tell us much about how the population fits into for instance the housing supply, water/sanitation demand and supply etc. It tells nothing about the social networks among which communal support takes place [89]. This information can mainly be obtained with data at the household level.

The October Household Surveys (OHS) 1995 to 1999 were reweighted and benchmarked with midyear population statistics based on the Census 1996 results. Individual population in 5-year age intervals and sex per province has over the years received more attention over household numbers in the midyear demographic estimates calculated by Statistics South Africa.

Figure 1.1: Household Trend in South Africa

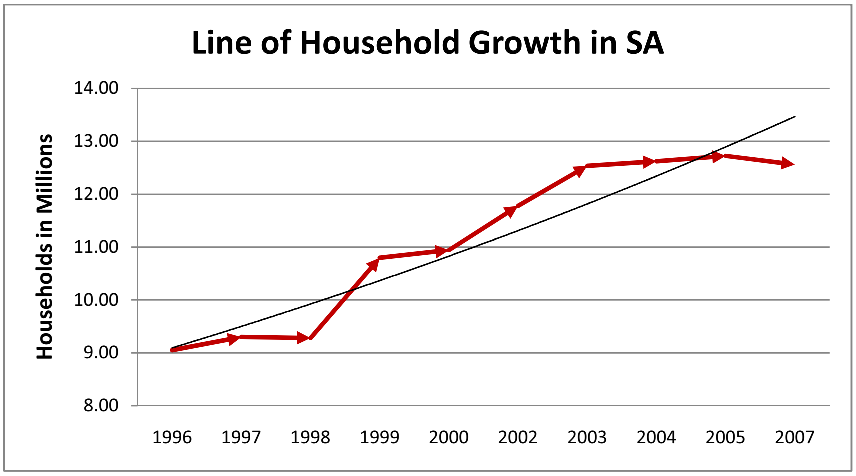
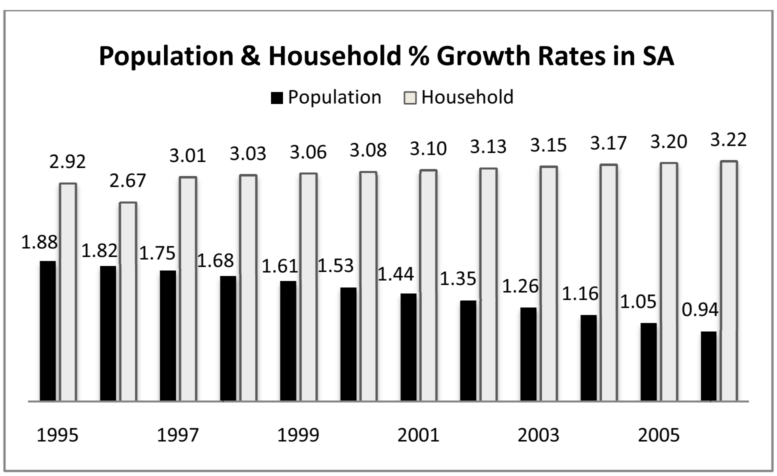


Figure 1.1 is a plot of total household numbers as obtained from the national surveys from Statistics South Africa 1994 to 2007. Even though the general trend in Figure 1.1 shows almost an exponential pattern, a very irregular growth pattern could be noted over time especially when analyzed on a year by year basis. The individual population however have comparatively been been growing almost at a steadily decreasing growth rate as shown in Figure 1.2.

Figure 1.2: Population Versus Household Growth Rates in South Africa



The general trends in Figures 1.1 and 1.2 suggest a rapid increase in household numbers, though it could be argued that the phenomenon of rapid growth could not be real in view of the high poverty rate where from an African point of view household members would naturally depend upon the breadwinners. Moreso recent demographic data from most other African countries show that age at first marriage has increased quite substantially [102]. Figure 1.1 implies that between 1994 and 1996 total household rose in the two year interval by about 0.4 million, between 1996 and 1998 households rose by 0.15 million, but between 1998 and 2000 there was a surprising increase of 1.74 million households. This illustrates clearly the problem of computation involving household numbers.

The problem is not that households are increasing but the manner of increase in relation with the base population. Household numbers are bound to increase especially for a growing economy like South Africa where householders are increasingly getting empowered to leave home. Even in these instances exponential and erratic growth pattern as official data suggested is questionable. For measuring service delivery even at levels of particular service, for instance computing on a year by year basis changes in household with piped water to dwelling or yard, one encounters very irregular changes of the number of households within levels of service. The surveys evidently carry the hazard of inconsistent data. This is a risk which is partially hidden in the use of percentage changes in most research reports involving service delivery especially at household level while the use of numbers may expose inconsistencies such as dramatic and inconsistent changes in the number of households year by year, between provinces and between levels of service.

1.2 Overall Aims, Objectives & Hypothesis of the Project

1.2.1 Generic Aims

The major aims of this study are to:

- Review of the trend in households access and demand for piped water connection in South Africa against governmental and institutional targets based upon official data.
- To investigate the rapidly increasing trend household numbers in South Africa against population of individuals.
- Using a multidisciplinary approach to investigate the interaction of demographic parameters and their impact on demand for piped water connection in South Africa.
- A review of the challenges with Region and South Africa fixed fresh water resource-base in the light of increasing human demand for fresh water and climate change.

1.2.2 Explicit Objectives

The more precise objectives of this thesis are to:

- Use official statistics without modification to review the trend in households' access and demand for piped water connection.
- Build a complementary dynamic mathematical model for household projection in South Africa and compare results obtained by demographic methods.
- Do an analysis of the interacting of selected parameters and their impact on demand for water connection using the method of least squares.

In order to achieve the set aims and objectives of this project we examine and test the following hypothesis.

1.2.3 Hypotheses

- The increasing demand for water connection is as a result of the main drivers of population change, i.e changes in fertility, mortality and migration.
- The lower levels of additional access to basic water are in those provinces with the lowest existing level of service or lowest initial (1994) conditions.
- The trend in water delivery in the provinces has remained consistent over the period (post-apartheid era).

The problems above form the motivation for this research in which we seek a multidisciplinary approach towards the problem and also to present a consistent numerical representation of social parameters over time. From a mathematical perspective models of the dynamical evolution of a population are normally constructed with time-dependent parameters; the actual analysis is invariably made with assumptions such that the time dependence is removed. In the usual approach to such models using the methods of dynamical systems this is necessary unless an artificial variable is introduced. This introduction is not invariably satisfactory. However, realistic populations of moderate biological complexity invariably contain parameters that vary in time, for example birth and death rates, in this case household formation and dissolution. In this thesis we examine some comparatively simple models of population drawn from the areas of population and household projections in which the parameters are specifically time-dependent. This examination could lead to insights as to the effect of variation of parameters in time on the evolution of the population/number of households in South Africa. The ultimate aim is to implement a realistic and complementary mathematical model for household projection in South Africa especially in relation to the planning of service delivery. A particular area of potential application is in the study of interaction of sociodemographic parameters and demand of household-basic services.

1.3 Methodology

1.3.1 Scientific Approach

In developing this thesis, due to the nature of research, we adopted a multidisciplinary approach. The main subject of the study (Changes in Households) is demographic especially when studied in the social context in this case demand for basic services. On the other hand changes in household numbers in itself entail processes of growth and decay which could be studied analytically using quantitative or mathematical tools.

This study is a secondary research in which we use the desk research methodology. We collected historical quantitative and qualitative data from different sources and synthesized them to establish trends and patterns of events and make projections into the future.

Exploring the data-sets we used SPSS frequency tabulations, cross-tabulations and descriptive statistics. For the household projection model we used the method of partial differential equation and numerically approximated the solution to obtain the numerical results that we compared with the household projection model obtained using demographic methods. For investigation of the interaction of selected social and demographic parameters and impact on demand for piped water we used the method of least squares through the SPSS multiple regression analysis and SPSS logistic regression for the evaluation of access profile/likelihoold.

1.3.2 Data-sets and Data Sources

The bulk of data used for this study are from the South African national household surveys by Statistics South Africa, which have been accessed through the national data archive. The surveys basically collected household-based data on the following themes; demographics, household services, income, expenditure, land access and use and general perceptions of household dwellers. The surveys include the October Household Surveys from 1994 to 1999, the General Household Surveys from 2002 to 2005, the Community Surveys of 2006 and 2007, the South African National Censuses of 1996 and 2001.

Useful information was also obtained from some local and interactional research bodies and institutions. These include the population projections from the Actuarial Society of South Africa, population and household projection data from the Bureau for Marketing Research at the University of South Africa, demographic data from the Population Reference Bureau and the United States Census Bureau.

1.4 The Outline of the Thesis

In Chapter One we present the motivation and overview of the research problem highlighting the aims and objectives of the project.

In Chapter Two we present the reasons for a quantitative study of water delivery, supply and access in South Africa. These are presented within the context of different themes such as impact of climate change on fresh water resources, the correlation of lack of access to portable water and human poverty, basic access to basic water as a basic human right and access to basic water as one of the targets of millennium development goals of the united nations. The Chapter also presents the setting of water service delivery in South Africa.

Chapter Three provides a review of literature on some of the studies involving quantitative evaluation of service delivery in South Africa in the post-apartheid era. The Chapter draws attention to the issues around various service delivery promises to the people of South Africa and some attempts/methodologies by scholars towards evaluating progress on the promises. The Chapter indicates the data constraints of such studies and the contribution of this study towards filling gaps that are observed. Chapter Two also reflects on the state of official statistics in the developing world in general and in South Africa in particular and gives a brief historiography of census and official data in South Africa.

Chapter Four presents an overview of household structure in South Africa and provides the scientific defining of a 'Household'. The Chapter also makes the case for more studies on quantitative evaluation of the trend in household formation and dissolution in South Africa within the context of the relationship towards household-based services.

Chapter Five presents the benefits of the mathematical approach to the problem of estimating and projecting population and household numbers, and the mathematical foundation for the study through a review of classical mathematical theories of population-growth processes. The Chapter also compares results of model of South African population.

In Chapter Six we implement a dynamic household model for South Africa based on a partial differential equation. We numerically integrate the solution using it to estimate and project South African household numbers. We use the result as imputation data for least squares interaction model.

In Chapter Seven we present a comprehensive review of the current scenario of water service access and demand with a thorough review of official data from the national household survey data from 1995 to 2006 and the 1996 and 2001 census data. The case of access of water in South African households is the major indicator. Here we also highlight the position of South Africa in its ability to meet the millennium development goals and even at the local level the presidential targets in the water sector. We also highlight some instances of shortcomings of the data sets.

Chapter Eight presents an investigation of interaction of demographic parameters and their impact on increasing household demand for piped water connection in South Africa using SPSS regression analysis. The Chapter also reflects upon the profile of access of households on the basis of odds in favour or against households of being served using SPSS logistic regression analysis.

In Chapter Nine we present the summary of results of the different chapters and the general remarks or conclusions of the projects. The Chapter also highlights limitations of the study and makes the necessary recommendations for further study.

Chapter 2

Justification for the Study: Water in South Africa

2.1 Why Water

Although our focus on this study is the quantitative review of the dynamics of household demand and access to household-based services in South Africa based on official statistics, the critical question is, why the choice of water amongst other household-based services? This section provides the justification for the focus on water arguing in consideration of the state of water fresh water resources from regional level to national level in the light of increasing demand on a static resource base, the impact of climate change and the vital life sustaining role of water to humanity.

Water is a chemical compound defined in elementary chemistry classes as H_20 meaning two parts of hydrogen and part of oxygen combining to form water. This compound water is the one of the most essential elements for human survival. Water is very essential for the mechanics of the human body and the largest component of the human body. The body cannot work without water, just as a mechanical engine cannot operate without oil. In fact the entire anatomy and physiology of the human depend upon water for functioning. Water makes up more than two thirds of the weight of the human body and, without it, humans would die in a few days. The human brain is made up of 95% of water, blood is 82% and lungs 90%. As little as 2% shortage of the human body requirement for water could trigger symptoms of dehydration. The importance of water as an element of human nutrition, prevention of diseases, sanitation and the maintenance of the ecological balance cannot be over emphasized. Therefore this vital element should not be denied of any human being.

Even with water making up 70% of the earth's surface, fresh water availability out of this value is about 3%. Even though the available fresh water is relatively small 75% of the Earth's fresh water is locked into ice caps and glaciers in the difficult to access Polar Regions [30, 101]. Interestingly the world's rising demand for fresh water resource is not matched by the rather fixed availability of global fresh water supply. The implication is a critical challenge as humanity faces a looming shortage of fresh water. At present more than half the world's accessible fresh water is in regular use and the proportion is increasing [30]. About 75% will be in use by 2025 [30, 101]. Presently over 1.5 billion persons lack ready access to drinking water and, if the consumption trend continues, at least 3.5 billion people, i.e., nearly half the world's projected population will live in water-stressed river basins in just 20 years to come [30, 101].

2.1.1 The National/Regional Fresh Water Challenges

Subsaharan Africa, as a member of the global community, is faced with serious water challenges. As at year 2000 an estimated 250 million people in Africa (mainly in Subsaharan Africa) were living in water-stressed countries and about 150 million in countries with water scarcity. With high fertility and rapid population growth in the region it is expected that this problem will even get worse over the next few decades. It is projected that by the year 2025 as many as 1.1 billion people, about two thirds of the region's projected population, will live under conditions of water scarcity [30]. Already many Subsaharan Africans get less than 20 litres of water a day and two-thirds have no proper toilets. In contrast the average Briton uses 150 litres a day while Americans are the world's most wasteful users of water at an average of 600 litres daily per capita [30].

It is projected that by 2030 the population of Southern Africa (Botswana, Lesotho, Namibia, South Africa and Swaziland) will be 69.9 million [84] and, as populations increase, available water will diminish [30]. The potential for regional conflicts to erupt over water resources is a possible reality given that Southern Africa has 15 transboundary river basins and 70% of water resources in the region are shared by two or more countries. With the global situation noted it is critical that the African and in particular Southern African situation be appreciated and put into context for remedial planning. While climate change is caused primarily by developed countries, Africa suffers the effect most given that the resources to adapt as rich countries do are lacking [30].

South Africa is known to be rich in many natural resources. South Africa is a main exporter of gold, diamonds and platinum, but the one natural resource that the country is not rich in is water. In fact South Africa is rated one of the 30 driest countries in the world [93]. South Africa is classified as a semi-arid country with average annual rainfall of 500 millimetres a year. This is relatively low in comparison with the world average of about 860 millimetres [93]. Even with the scarce rain fall, the fact is that rain fall is not evenly distributed with most rain falls in the narrow belt along the eastern and southern coasts of South Africa. South Africa is also observed to have a low runoff rate. It is estimated that on average only some 9% of rainfall gets to the rivers as runoff [93]. South Africa's scarce rainfall and low ratio of runoff, which affects the reliability and variability of river flow, has necessitated the building of many dams built to store water, protect areas from floods and redistribute water resources [93].

South Africa relies mainly on rivers, dams and underground water for the supply of water although there are a few natural lakes. It is observed that about 75% of the water flowing from South Africa into the sea occurs along the eastern and southern seaboards [93]. Flowing from East to West is the largest river in the country, the Orange River which is shared with Lesotho, Botswana and Namibia [93]. It is estimated that South Africa's rivers receive about 50 billion cubic metres of water a year, with another six billion cubic metres stored underground [93]. In a nutshell South Africa's existing water resource availability comprises 77% surface, 9% groundwater and 14% reuse of return flows [98]. In South Africa water is mostly used for agriculture and irrigation (52%), forestry (4%), industry (4%), domestic use (10%) and (20%) of water is protected for the survival of the environment [93].

2.1.2 Water as a Basic Human Right

Access to water is basic to life itself and is recognized as a fundamental human right. Human life and health demands sufficient, safe, water. In South African law and policy basic water supply must be sufficient, safe, accessible and affordable. Basic water must be provided continuously with a minimum flow rate [28]. Each of these requirements is described below:

Accessible: There are many levels of improved access at different levels: multitap; yard connections; communal taps; or unimproved sources such as rivers, springs and water holes. The minimum standard is access to a communal tap within 200 metres of a household. In rural areas many households are either further than 200 metres or do not have access to piped water [28].

Sufficient: Sufficient water is to be provided to each citizen. The law, however, does not define how much water this is, but it can be understood as enough water to maintain an individual and household in health and wellbeing [28].

Basic Water: Basic water is at least 25 litres per person per day (one container) when citizens use communal taps or 6 kilolitres per household per month when citizens use yard or household connections. For large families this may not be sufficient. However, most people in the rural areas do not even have access to 25 litres per person per day [28].

Safe: Municipalities must test the water according to national standards to ensure it is safe. Although all water in urban areas and much water in rural areas is treated, any untreated water is likely to be unsafe. People should be informed if there is a risk from unsafe water, but often this is not the case [28].

Affordable: The basic water policy promises each household 6 kilolitres of free water per month. The poorest are also meant to be guaranteed access to sufficient water through the indigency policy which provides subsidies to these families. The law states that households are to receive free basic water even if bills are not paid. Municipalities are not to disconnect households from the service and are to treat persons with compassion [28].

Minimum Flow Rate: There should be a flow of water of not less than 10 litres per minute; in many areas the flow rate is observed to be less than this. The restrictions used to limit supply where bills are not paid provide less than this rate.

Continuous: Municipalities are required to provide water services efficiently and effectively with a minimum of interruptions. There should be a continuous flow of water at any time of day or night. The law says that people should not experience interruptions of more than 48 hours at any one time and not more than 15 days all together in the year. In many rural areas interruptions are frequent and long. If water supply is interrupted for more than 24 hours, the law says that at least 10 litres of water per person per day must be provided [28].

Good Service: Municipalities and Water Service Providers must provide prompt replies to complaints, explaining what is happening and when repairs will be made. Once a leak is reported, it must be repaired within 48 hours [28, 80].

2.1.3 Water and Poverty

Poverty within this context is the situation of lack of the basic needs for survival as broadly measured using the Human Poverty Index (HPI) of the United Nations Development Programme (UNDP) Human Development Report for 2006. These indices are:

- Percentage of population not expected to survive to age 40
- Percentage of adult illiteracy (Deprivation in Education and Knowledge)
- Deprivation in economic provisioning

- Percentage of population without access to safe water
- Percentage of population without access to health services
- Percentage of underweight in the population of children.

However, it is important to note that among the poverty indices water is the main utility that directly affects families and individuals almost on daily basis. Acute shortage of safe water has direct impact on the overall wellbeing of the society. This situation therefore has the potential of sustaining or reproducing poverty as observed by a recent study (International Water Management Institute) which measures the association between access to safe water and incidence of poverty in African countries using the Human Poverty Index (HPI) for 2004 [85].

Table 2.1: Water Access and HPI in Selected African Countries

Country	**% Without Water**	**HPI**
DRC	54	40.9
Nigeria	52	40.6
Zambia	42	45.6
Kenya	39	35.5
Tanzania	38	36.3
Cameroon	34	35.6
Ghana	25	33.1
Algeria	15	21.5
Namibia	13	32.5
South Africa	12	30.9

Source: UNDP, The Human Development Report 2000 - 2006

In Table 2.1 the countries are ranked by the percentage of population without access to a source of safe water and Human Poverty Index (HPI) in 2004 . The data indicate that a higher proportion of the population without access to safe water (2002 and 2004) is generally associated with a higher Human Poverty Index (2004). The two extremes of high and low levels of population without access to safe water are taken as the basis for illustrating the association (Spearman's correlation coefficient = 0.891). The DRC and Nigeria have 54 percent and 52 percent of the population without access to safe water respectively and also correspondingly among the highest HPI figures. At the other extreme South Africa has 12 percent of the population without access to safe water and a relatively lower level of HPI. Although access to safe water is a subcomponent in the estimation of HPI, the observed trend is a pointer to its magnitude and its relative importance in the aggravation of poverty [84].

2.1.4 Water and the Millennium Development Goals

During the 2000 millennium summit of the United Nations member countries of the world body recognised developmental targets to be reached by 2015 in order to emancipate the world, especially developing countries, from plaguing poverty and under-development. Prominent among the eight goals in the declaration of The Millennium Development Goals is the declaration to reduce by half the proportion of people without access to adequate water by 2015 [86]. The following list shows selected UN development goals and targets.

United Nations Millennium Development Goals and Targets

- (Goal 1) **Eradicate extreme poverty and hunger**

  Target 1: Halve, between 1990 and 2015, the proportion of people whose income is less than 1 dollar a day.

  Target 2: Halve, between 1990 and 2015, the proportion of people who suffer from hunger.

- (Goal 2) **Achieve universal primary education**

  Target 3: Ensure that by 2015 children everywhere, boys and girls alike, will be able to complete a full course of primary schooling.

- (Goal 3) **Promote gender equality and empower women**

  Target 4: Eliminate gender disparity in primary and secondary education, preferably by 2005, and in all levels of education no later than 2015.

- (Goal 4) **Reduce child mortality**

  Target 5: Reduce by two-thirds, between 1990 and 2015, the under-five mortality rate.

- (Goal 5) **Improve maternal health**

  Target 6: Reduce by three-quarters, between 1990 and 2015, the maternal mortality ratio.

- (Goal 6) **Combat HIV/AIDS, malaria and other diseases**

  Target 7: Have halted by 2015 and begun to reverse the spread of HIV/AIDS.

  Target 8: Have halted by 2015 and begun to reverse the incidence of malaria and other major diseases.

- (Goal 7) **Ensure environmental sustainability**

  Target 9: Integrate the principles of sustainable development into policies of countries and programs and reverse the loss of environmental resources

  Target 10: ***Halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation***

Target 11: Have achieved by 2020 a significant improvement in the lives of at least 100 million slum dwellers

- (Goal 8) **Develop a global partnership for development**

On the global level the water target of the UN requires that globally 125,000 people per day get access to safe water [86]. For South Africa, with the backlog around 2000 at about 2.5 million representing about 22 percent of total households, reducing the proportion by half to 11 percent in 2015 requires yearly additional connection of about 100,000 households assuming that the backlog was static. The figure of 100,000 seems quite an easy task and in that sense there are claims in some quarters that South Africa had already achieved the MDG in the water delivery sector. However, given the unevenness of capacity and delivery/access base in different provinces, the true situation might be that South Africa at national levels might have or will achieve the water target in the millennial development goals, but a comparative analysis at say rural/urban or even provincial level could reveal wide differences which shows that the targets might not be achieved on those bases.

2.2 The Water Services Delivery Setting in South Africa

South Africa is the fourth largest country in Subsaharan Africa by population size; the country has a surface area of about 1,2 million square kilometers. The average rainfall is about 500mm per year. The rainfall can vary quite significantly between the West Coast and the East Coast.

The apartheid system with its disjointed institutional infrastructure did not provide for one dedicated department taking responsibility for universal supply of water and sanitation services. Water service infrastructures were run by different homeland governments. In poorer black rural areas these were run by uncoordinated homeland government structures that were almost completely dependent on the South African government for funding [98]. Consequently in 1994 it was estimated that 30% of the South African population lacked access to adequate water supply services and that 50% were without adequate sanitation [24].

The post-apartheid government instituted The Reconstruction and Development Programme (RDP) as the policy foundation stone of the new government. The RDP mandated the Department of Water Affairs and Forestry (DWAF) with the responsibility of ensuring that universal access to basic water services to all South Africans. Subsequently the White Paper on Water and Sanitation was released in 1994, with emphasis on speedy delivery of water and sanitation services to ensure that all South African have access to basic water supply. However, Basic Water Supply was defined as a standpipe supplying 25 litres per capita per day within 200m of household and with a fast rate of flow [24].

In realization of the need to update the 1994 White Paper to align with current realities, a strategic framework for Water Services was drafted and approved by cabinet in September 2003. The main strategy of the new framework was to decentralize further the sector, phasing out the involvement of the national government in service provision and limiting the role of the Department of Water Affairs and Forestry to policy and regulation. The strategic framework set the following targets:

- An end to the bucket system of sanitation by 2006
- An end to the water supply backlog by 2008

- All assets of water-service schemes transferred to municipalities by 2008

- An end to the sanitation backlog by 2010. [24]

With the introduction of the strategic framework the water and sanitation service sector in South Africa is organized into three different tiers. They are

- **Municipalities**: The Municipalities provide most retail services and also own some of the bulk supply infrastructure. This implies that the 52 district municipalities of South Africa have the immediate responsibility of direct delivery of services to consumers. The national government can also assign responsibility for service provision to the 231 local municipalities in South Africa [98].

- **Water Boards**: The Water Boards primarily provide bulk water, but also some retail services and operate some waste water treatment plants, in addition to playing a role in the management of water resources. The three largest of the 15 Water Boards are Rand Water, Umgeni Water and Overberg Water and serve about 10 million, 4 million and 2 million people respectively [98].

- **The National Government**: As was stated above, the national government, represented by the Department of Water Affairs and Forestry (DWAF), is a policy setter [97].

It is also worthy to mention that private and professional institutions like the banks, private operators, the professional association Water Institute of Southern Africa (WISA), the Water Research Commission and nongovernmental organisations (NGOs) also play important roles in the water-service sector. The Mvula Trust is a remarkable water supply and sanitation NGO in South Africa. Mvula Trust has disbursed over R300 million to water services programmes and projects and has provided services to over a million South Africans who previously did not have access to either water or sanitation services. It is specialised in implementing and supporting the delivery of water services in rural and periurban areas through community management, the establishment of community-based providers of water services and supporting local authorities to create an enabling environment for sustainability. There are also many other smaller NGOs that together play an important role in the sector [98].

The National Strategic Framework brought about improvement in national water delivery, but it came with a price as the government has relied on cost recovery and various forms of privatisation and corporatization to deliver water [24]. As a result of these policies, millions of predominantly low-income households have had their access to water cut for nonpayment of services [97], typically because they cannot afford to pay the increased prices associated with cost recovery. Around the same time a three-year cholera epidemic affecting over 100,000 people broke out in 2002, in part because of the introduction of cost recovery and user fees in the water sector which forced many rural homesteads to use contaminated surface water [27]. Consequently the same year the government embarked on a project that was designed to provide free water for people. This program provides six kilolitres of water to each household per month, but is widely criticized for being inadequate for large low-income households and for not addressing high costs after the free allocation [96].

The statistical results from the 2006 Community Survey of Statistics South Africa show that between the 2001 census and the 2006 survey the percentage of households with access to piped water has increased in all nine provinces. Western Cape is the province with highest percentage, 98.9%, of households with access to piped water, followed by Gauteng and Free State with 97.9% and 97.5% respectively. The percentage scores of households that have access to piped water in Eastern Cape, KwaZulu-Natal and Limpopo are below the national average of 88.6% in 2006 [58]. A more detailed analysis of the delivery and access dynamics is presented in Chapter Seven.

The highlights in this Chapter reflect that as much as access to basic water is essential for human existence, proper management of the resource base remains vital for the future generations and the maintenance of ecological balance. It is reasonable to infer that proper management and conservation of the resource base is almost unfeasible without adequate measurement and projection of human demand and access to water resources. The measurement dimension of the problem is the aspect that this study is intended to contribute towards within the context of household demand and access in South Africa in the post-apartheid era.

Chapter 3

A review of Literature On Measurement of Access to Basic Services in Post-apartheid South Africa

In this Chapter we present a review of selected studies on measurement or assessment of progress towards government and institutional service delivery targets in the post-apartheid South Africa. The review will focus on highlighting methodology and data constrains to the studies and possible gaps that this study could contribute towards filling.

With much of the populace in the post-apartheid South Africa in conditions of large-scale unemployment and poverty the provision of free basic services in housing, water, electricity and sanitation feature importantly in government priorities.

3.1 Post Apartheid South Africa: An Era of Promises

Freedom has come with promises by the government of the African National Congress of job creation, water and sanitation for all, improved delivery of housing, and expanded welfare. Apart from the Millennium Development Goals, the minimum of social objectives to be met by the poorest countries by 2015, fairly far-reaching promises on these fronts have been made by the Presidency such as halving unemployment by 2014 [51, 52].

Exactly ten years into the democratic South Africa president Mbeki in one of the most remarkable State of the Nation addresses made various time-bound promises on the key issues around household services, education, health care, security etc. The following list provides a summary of some of the promises [51].

Household services

- To intensify the housing programme...in the next three years we will spend $R14.2$ billion to help our people to have access to basic shelter.
- Within the next five years all households will have access to clean running water.
- During the current year more than 300 000 households will be provided with basic sanitation.
- Within the next eight years ensure that each household has access to electricity [51].

Health care

- Reduce malaria cases by 10% each year.

- Implementation of our Comprehensive Plan on HIV and AIDS. 113 health facilities will be fully operational by March 2005 and 53 000 people will be on treatment at that time [51].

Education

- By the end of this financial year we shall ensure that there is no learner or student learning under a tree, mud school or any dangerous conditions that expose learners or teachers to the elements.
- By the end of the current financial year we expect all schools to have access to clean water and sanitation [51].

Security

- By 2006 there we be 152 000 officers on active duty in the SAPS.
- In the current year establish at least two community courts in each province.
- In the next three months we will set up special joint teams to target and focus on serious crime with an immediate objective of apprehending the top 200 criminals in the country [51].

The critical issue is to ascertain where South Africa stands in terms of delivery of these services at any point in time. There are three difficulties in solving this problem; firstly data, secondly household growth (for household-based services) and thirdly somewhat different sets of commitments.

Firstly the appropriate statistics are not always to hand. People are interested in the actual houses delivered rather than for instance the monetary figures of housing budgets. The mass actions and protests show an increasing concern about the quality as well as the quantity of delivery; about size of houses as well as their number, about the quality of water as well as piped water being available.

Secondly one of the greatest controversies relates to the growth of households which are increasing at a faster pace than population. This is not a small matter as a rising number of households puts extra demand on the level of household-based service delivery not least with housing and water connection.

Thirdly commitments are made in different documents: the Reconstruction and Development Program, the State of the Nation and the Millennium Development Goals (MDG). These are variously phrased, have different deadlines and are not always directly comparable.

3.2 Measuring Progress on Promises: The Data Challenge

The Development Policy Research Unit at the University of Cape Town among others has undertaken a number of studies on measuring changes in the access to basic services by the people of South Africa in the post-apartheid era [9, 10, 11, 12]. These studies, including also those by the Human Sciences Research Council [27, 29, 58], have acknowledged the lack of reliable historical data on changes in conditions basic services as a major challenge. Ideally data from national household surveys are normally most suitable to provide information for studies relating to conditions of basic services. They often provide the latest information in the most detailed manner than the census. They are also based on a representative sample of the population usually designed with the most recent population census as the sampling frame.

The two main issues pertaining to the difficulty of working with historical survey data in South Africa are the issues of fluctuating population base from which the surveys are sampled and benchmarking especially for household-based parameters:

Population Base

- The October Household Surveys done after the 1996 census used 1996 population census as a base while the earlier surveys used the 1991 census as the base. The 1991 census did not include Transkei, Venda, Bophuthatswana and Ciskei (the so-called TBVC states) and hence their size had to be estimated and added later. Therefore it is reasonable to infer that the pre-census 1996 and post-census 1996 survey data are not strictly comparable in the series.

With these controversies around demographic data in South Africa, demographic models were found as complementary solution for estimating trends in demographic variables in South Africa. During much of the 1980s to 1990s the demographic projections model by Sadie [26] was majorly acclaimed as the one of the reliable point of reference in terms of demographic information for South Africa. In Sadie's demographic models the population processes of Whites, Indians and Coloureds were built on data gathered during the 1980s, while the estimate of the dominant African population was based on the 1970 Census as later data proved to be less reliable [26]. To this Haarmann [26] observed that for the largest proportion of the population, the models were built over the older and the possibly least reliable data. Therefore most of the surveys around that time including the censuses up to 1996 suffered from this defect as they were adjusted according to Sadie's demographic model [26]. In the recent years demographers Van Aardt, Dorrington and Udjo [3, 84, 88] among others have independently factored in the impact of HIV AIDS in their models of demographic variables and population projection in South Africa producing results that are not too divergent from each other.

Benchmarking

- Survey estimates are benchmarked to mid-year population projections and equivalent data are not reliably available to benchmark households and of course it is obvious that reliable household estimates are the prelude towards reliable measure of household-based services.

In light of the above problems researchers perhaps consider the use of proportions rather than absolute figures when estimating the number of households and other household-based parameters like levels of sanitation, water connection etc as this might help reduce observed fluctuations. This is observable in most studies [9, 10, 11, 10, 79] which have concentrated on percentage changes; this provides useful information, but it does not provide the numbers essential to the dimension of progress or problems of data for assessment, planning and practical budgeting and implementation. A more elaborate discussion on the state of official statistics in South Africa is presented in Section 3.3.

Bhorat *et al* in their studies on 'Shift in Non-Income Welfare in South Africa' reveal that an overview of the focus of the government welfare services in the post apartheid era has been pro-poor. Households at the bottom of the expenditure decile (poorest of the poor) were found to have benefited more from government services. However, even though delivery seem to have been pro-poor, a significant amount of backlogs were noted in these studies among the poor households especially on issues of housing, sanitation and piped water [11, 12].

Much of the above studies employed the method of factor analysis where the historical analyses of levels of warfare services are done in which various variables reflecting conditions of services are aggregated into an asset index . These studies did well qualitatively in the assessment of income dynamics and access to basic services. In this sense the use of factor analysis could be reasonable. Factor analysis is statistical technique to reduce large data sets to the smallest number of 'factors' required to explain the pattern of relationships in the data. In this manner inconsistencies in the data are not severely damaging and notable. Supporters see it as neutral and scientific while critics argue that it generates statistical abstractions, which have little explanatory value. These studies gave little or no insight into the trend lines of households's demand and accesses to basic services in terms of absolute numbers. The absolute number values as much as rates of change in time remain quite critical for policy driven studies on basic services demand and access. As stated earlier, without good information of the trends in terms of numbers it becomes quite cumbersome to measure progress on targets, prepare dynamic budgets and forecasts for the future.

This gap is partly what we intend to fill in this project in which we provide a numerically based approach providing most results in absolute numbers geared towards the purposes of practical planning.

3.3 Data and Social Parameters of Development in South Africa

In Subsaharan African countries, like South Africa, barriers to implementation of developmental policy are commonly phenomenal, though historically they do not share common antecedents. The wide gap in social development between the urban and rural areas for instance is commonly notable. A major impediment towards planning of development in Africa remains a lack of reliable vital statistics. The United

Nations population and vital statistics report for 2005 reveals that out of 15 countries worldwide that have not taken a census since 1990 seven are African countries as listed in Table 3.1. Ongoing political and religious conflicts and instability remain the main reason for this, but in some instances it is because of lack of resources.

Table 3.1: Year of Last Census for Selected African Countries

Country	**Last Census**
Angola	1970
Burundi	1990
DRC	1984
Eritrea	1984
Liberia	1984
Somalia	1984
Togo	1981

Source: Population Reference Bureau 2006 [61]

Analysts stress that the importance of census is not only for the update of national parameters but also for the development of a frame for other vital studies. According to Carl Haub, a senior demographer at the Population Reference Bureau,

> *Census taking doesn't just provide an update of many national parameters such as total population, fertility, age, and sex. In the case of developing countries, it provides an up-to-date sampling frame for badly needed demographic surveys* [62].

3.3.1 Official Statistics in South Africa

South Africa witnessed a level of European settlement much higher than most Subsaharan African states, largely because the Cape sea route and mineral wealth of South Africa. The fear of domination between the white minority and the black majority later led to the institution of the apartheid system. This had significant impact on the collection and management of vital statistics in the country. In South Africa the first formal census after the formation of the Union of South Africa in 1910 was in 1911 [38]. Before the end of apartheid in 1994 there were census exercises in 1921, 1936, 1946, 1951, 1960, 1970, 1980 and 1991 [38, 59]. A common limitation of these censuses is that they were incomplete in terms of equitable coverage of all racial groups. Technical limitations in data collection, processing and management were also common features [38, 59].

The apartheid legislation restricted South African blacks to less than 15 percent of the land area, called 'the homelands'. This societal segregation and unrest consequently caused the black populace to be aggrieved and thus their interest in vital civic activities like the census was greatly reduced because of the injustice. The 1980 census count witnessed remarkable improvement. Although the initial figure of 23.8 million was far from being accurate, the improvement here was that there was acknowledged report of undercounting especially of the black populace on the part of the authorities for the first time, ushering in hope for future remedy of injustice of undercounts in subsequent census counts [38, 59]. The 1991 census was not much different from the previous ones with regards to under-enumeration. The authorities employed sample survey methods and aerial photography to count violence-prone areas. At the end of the exercise the population was put at about 30.9 million [38, 59].

The end of apartheid and the all-race elections in 1994 marked a turning point of the socioeconomic and political situations in South Africa. This led way to activities that strive towards revealing the true demographic composition of South Africa. The 1996 census count was the first door-to-door count in all eleven official languages of South Africa. Efforts were made for the three-week exercise to be all-inclusive; most of the home dwellers, squatters and the homeless were counted to this some observers believe the 1996 census was a success though with a lot to improve on [29, 37]. The distinct phases and procedure of census; preenumeration, enumeration, postenumeration and data processing were observed without bias for the first time [38, 31]. The census exercise put the South African population to about 40 million with revelations of the country's poverty and levels of inequality. For example it was revealed that 50 percent of the country's 40 million people did not have access to potable water supplies in their homes, one quarter of the population had an income of less than USD100 a month with most poverty among the black populace.

The 2001 census witnessed various strategies of improvement especially from the perspective of project management for better preenumeration and postenumeration exercises building from the lessons learnt from 1996 census [31]. However, these strategies did not to a great extent translate to significant improvement in coverage and reduction of undercount. Therefore with improved management practice in place there is the hope that the next census in 2011 would see remarkable improvement in the most vital aspects of coverage and reduction of undercount.

From 1994 there have been annual household surveys, formerly called October Household Surveys and now called General Household Surveys. These surveys are intended to provide a yearly update of vital information especially with regards to the conditions of living of South African households. The weighting of these surveys is normally based on estimates derived from the preceding population census. As stated earlier the previous censuses apart from those of 1996 and 2001 have been criticised for lack of accuracy. These probably have affected the outputs of these national surveys and a result the data from these surveys are remarkably irregular in terms of social indicators like total household numbers and conditions of living in these households over time. With this it becomes difficult to extrapolate trend lines and rates of change in time of these parameters.

The case of access and demand of water services is only but one of such services which the death of reliable household level data limits their monitoring and evaluation. Better understanding of the household dynamics and structure is a prelude to any systematic enquiry on the dynamics and evaluation of households access to any household-based service such as piped water connection. In the next Chapter we present an overview of households in South Africa within the context of access to basic services.

Chapter 4

The Household as a Unit of Service Delivery

A deeper understanding of the dynamics of household formation in South Africa remains vital and should be given due cognizance by appropriate authorities. This is quite crucial for effective monitoring and evaluation of demand and delivery of services and the millennial development goals on a progressive year by year basis especially during the inter censual periods.

4.1 What is a Household?

For most purposes of population study there is little need to consider any unit intermediate between the individual and the larger group consisting of all the individuals included within some area, state, province, country or nation. Recognition of only two units, population and individual, permits the construction of models that are readily expounded and understood. Demographers, following in the footsteps of Lotka and other predecessors, have worked hard to simplify this much-too-complex material [89].

As was stated above, the choice of unit for demographic analysis depends upon the problem to be solved. For forecasts of total population, of the future labor force, of pension burden etc it has seemed sufficient to work with the individual level factoring in fertility, mortality and migration. One supposes that individuals give rise to other individuals over the course of time in a renewal process, irrespective of marriage or coresidence; individuals are discrete from birth; they live their separate lives, reproduce and die [36].

For some purposes the recognition of an intermediate unit is unavoidable. Individual demography can tell us little about how the population fits into for instance the housing stock, water/sanitation demand and supply etc. It tells nothing about the kin networks among which mutual aid and protection take place. It falls short of explaining fertility change, insofar as the couple rather than the individual is the decision-making unit. Children are not born to couples independently at random, but couples take account of the number of children already born to them and of other aspects of their family situation at any moment. When family constitution was stable, it attracted less attention from scholars and lay people. Enormous changes in family and residential arrangements since World War II have aroused the current interest in the demography of the family.

The family generally consists of father, mother and children in terms of primary or nuclear family but, in terms of extended family could consist of a broader range of relatives. The standard definition of the family need not have all of these components for a family could suitably be a couple without children or a widow/widower with or without children [63].

Household includes all the persons who occupy a housing unit. A housing unit is a house, an apartment, a mobile home, a group of rooms or a single room that is occupied (or, if vacant, is intended for occupancy) as separate living quarters. Separate living quarters are those in which the occupants live and eat separately from any other persons in the building and which have direct access from the outside of the building or through a common hall. The occupants may be a single family, one person living alone, two or more families living together or any other group of related or unrelated persons who share living arrangements.

Defining in an explicit manner the family and household are conceptually distinctive terms especially for a multicultural society like South Africa in which the different components of the society subscribe to different value systems, family system and kinship systems [4]. However, for the purpose of this study we use the terms interchangeably adopting the working definition of a household for the census and surveys by Statistics South Africa:

> *A household is a group of persons who live together and provide themselves jointly with food and/or other essentials for living, or a single person who lives alone* [67-77].

Apart from bringing people together sharing meals and house-keeping, Bongaarts [13] observes that the household is the most fundamental socioeconomic institution in any economy providing the base upon which the larger economy is built. Therefore an understanding of the trend in the dynamics of the household is very vital not only for service delivery and consumption-based reviews but also broader economic enquiries.

4.2 Changing Household Structure in South Africa

In most of Subsaharan Africa during the precolonial era the family formation patterns is observed to be linked to the main activities of livelihood of the different ethnic groups. Among the pastoral groups, mostly in the Eastern block, the family system was mostly nuclear, while for the agricultural groups of the Western and Southern blocks the extended family system was more prominent [4].

Colonialism came into Subsaharan Africa and induced urbanization, industrialization and capitalist orientations which to a great extent affected household and family formation. In South Africa for instance the subsequent apartheid-imposed restrictions for the dominant African population meant limitations on geographical mobility and access to land. This to a great extent changed the precolonial family and household formation system in South Africa. To this Amaoteng [4] argues that the situation necessitated urban-rural homesteads and internal circular migration as a survival strategy especially for the migrant mine workers who were predominantly males. This created a deficit of males in the rural areas and thus marriage was either delayed or avoided. In the cases where there was marriage, the man often left the wife and children behind. The situation led to household/family patterns as female-headed households, out-of-wedlock births leading to unstable households among the dominant African population [4].

Empirical evidences from the works of Amoateng [4] and Van Aardt [88] show that in the post-apartheid era the proportion of one-person households has increased between the intercensusal period 1996-2001 from 15% to 16% respectively over the period. This increase is believed to have reached a high of almost 18% in 2007 [88]. Conversely while this remarkable increase is noted for single-person household, the proportion of couple-based households decreased from about 42% in 1996 to about 36% in 2001 [88].

Table 4.1 shows the distribution of the percentage proportion of South African households by type over the period 1996 to 2006.

Table 4.1: % Distribution of Households by Type in SA

Household Type	**1996**	**2001**	**2006**
One-person	15.0	16.2	17.6
Couple	9.6	8.7	7.1
Couple and Children	24.2	21.3	17.7
Couple, Children & Relatives	8.6	10.7	11.2
Single-parent	12.8	11.7	10.2
Single-parent & Relatives	11.5	15.6	17.3
Nonrelated-persons	1.5	3.3	4.6
Head & Relatives	7.6	10.4	12.1
Couple & Relatives	2.5	2.3	2.1
Other	6.9	-	-
Total	100	100	100

Source: Van Aardt CJ (2007) [88]

The general impression in Table 4.1 is that households are getting smaller in size over time with one-person type of household on the increase. This implies that households in South Africa could be fragmenting as we have seen in Chapter 1 the remarkably greater annual growth rates in household when compared to the individual population.

Table 4.2: Household Growth Rates in SA by Race 2001-2005

Population Group	**% Growth Rate**
African	3.5
Asian	3.9
Coloured	3.4
White	0.8

Source: Van Aardt CJ (2007) [88]

An enquiry into the contribution of the different population groups to this trend shows in Table 4.2 that the African population group with by far the greatest individual population base is the largest contributor to the fragmentation trend with an average annual household growth rate of about 3.5%, even though the growth rates for the Asian population group is the greatest at 3.9%. The growth rate for the white population group is at below 1%. Van Aardt [88] opines that this could be expected in view of the historical low fertility rates among this group coupled with the higher level of emigration among the White population.

On provincial bases Van Aardt [88] observes that different factors are the main drivers of household growth dynamics for the different provinces. These factors include high/low population growth rates, in/out-migration, declining household sizes and the impact of HIV-AIDS. To this the Easter Cape, Limpopo and Mpumalanga are seen as higher household growth areas with higher population growth rate as the main driver also with in-migration making an impact in Limpopo and Mpumalanga. KwaZulu-Natal for instance is seen as a lower household growth area as a result of the impact of HIV-AIDS. Provinces in the zone of lower household growth where lower population growth is the driver are found to be Western Cape, Gauteng and Northern Cape according to the observations of Van Aardt [88].

The declining household size and faster growth of households in South Africa is in conformity with the global trend. According to Bongaarts [13] household structures in both the developed and developing world have seen much of transformation during the past century. Household size declined from an average of 4.7 in 1900 to 2.5 in 2000 for the developed countries, while the decline for the developing countries is about 6.0 in 1900 to 4.3 in 2000 [13]. For South Africa the end of apartheid induced increased movement and the gradual economic empowerment of the dominant African population with more and more people being able to afford to make choices of smaller-sized household type and also with more young adults getting empowered to leave home and form new households. These contribute to a large extent to the rapid increase in household numbers in South Africa.

In order to estimate or project quantitatively the households of any geographical region like South Africa as erratic official data necessitates, there is the need to first have good understanding of the the estimates and projections of population base. Because it is from the population base that demographic estimates needed for the household model like headships rates etc are made. From a mathematical perspective these (population and household dynamics) involve growth and decay process which is studied building from the classical mathematical models of populations. Therefore in the next Chapter we present the mathematical and theoretical tools for the study of population dynamics starting with the art of mathematical modelling.

Chapter 5

Mathematical Modelling of Growth & Decay Processes

5.1 Mathematical Modelling

Here we present a theoretical base for modelling South African household growth in relation to demand and access of basic water. We provide a brief introduction to the art of mathematical modelling and the classical mathematical theories of population dynamics.

Mathematical modelling is the entire process of representing our observations and/or experimental results in the form of mathematical concepts to represent real situations to help understand physical or other phenomena by translating problems from an area of application into tractable mathematical formulations the theoretical and numerical analysis of which provide insight, answers and guidance useful for the originating application [8, 15, 25]. A mathematical model usually depicts a system by the use of variables. The values attached to the variables can be anything real or integral numbers etc, depending upon the objectives of the model . The variables represent some properties of the system while the actual model is the solution of the acquired system of equations or relationships, which is usually the set of functions that depicts the relations among the different variables [15, 25].

The mathematical process provides a convenient manner to describe relationships between numbers and other quantifiable quantities. Mathematics is one of the oldest most continuously pursued speciality of human thought. However, unlike philosophy and social enquiry, comparatively little of the mathematics that has ever been created has been discarded [25]. Mathematics has recorded collective development through different civilisations and could be seen as the natural home of both abstract thought and the laws of nature [8]. The beauty of Mathematics allows it to be studied solely for its aesthetic beauty, not undermining numerous useful applications of mathematics in almost all aspects of human endeavour [8, 25].

The application of mathematical models received the highest relevance ever starting from the 17^{th} century with the development of the calculus by Isaac Newton and Gottfried Wilhelm Leibniz. Rigorous mathematical analysis became a sine qua non for the development of mathematical models used by physicists, chemists and engineers. For instance in 1905 Albert Einstein showed that light could also behave as a particle. Einstein mathematically demonstrated the equivalence of mass and energy as shown by the famous equation $E = mc^2$ in his Theory of Relativity. These developments coupled with inquiries into the wavelike nature of matter enhanced the creation of complex mathematical models that demonstrated physical laws [25].

There is no doubt that Mathematics is truly the universal language of science and allows scientists to communicate ideas through mathematical models with universally accepted terminology. The benefit from mathematical models cannot be overemphasized as they play vital roles in most of the systems upon which our daily lives depend such as telephone systems, computers, automobiles etc. Interestingly mathematical models have also helped policy makers in useful policy formulations as regards the people's welfare, for instance mathematical models of population and epidemiological dynamics have contributed in providing understanding about the dynamics of human and animal populations and the spread of infectious diseases. Useful information provided by mathematical models has contributed to the formulation of population control and disease control policies, even though these have not narrowed the interactive divide between policy makers and practitioners who are mostly social science inclined and model builders. To this Mark Smith observed that,

> *much as in any aspect of social science, mathematical modelling has its enthusiasts and its sceptics. The enthusiasts accuse the sceptics of not understanding the models, and the sceptics in turn accuse the enthusiasts of not understanding the reality [65].*

This project is partly a contribution towards narrowing such divide thereby building practical and policy-relevant models of social systems and working through the intricacy of the presentation of such models and their results in a manner that could be comprehendible and acceptable by both parties.

5.2 Development in Classical Models of Population Dynamics

In the next subsection we present a brief review of the theory of the classical differential equations that have been of great importance in modeling of population. Our emphases are on ordinary differential equations in the Bernoulli and Riccati form for we have used such equations below to describe populations in which periodic variation of population parameters is considered.

Differential equations evolved in Newton's effort to describe the motion of particles. Today differential equations are found to be useful tools for the description of systems in almost every sphere of human endeavour. Differential equations are so popular in their use that they could be considered as one of the most successful tools for modeling of phenomena that are dynamical in nature. Therefore differential equations have been found to be very useful for modeling the growth and decay processes of populations.

5.2.1 Differential Equations in Modeling Population Dynamics

Definition 5.1 *Differential equations are basically equations that contain the derivatives or differentials of one or more dependent variables with respect to one or more independent variables [14,15].*

This implies that these are equations for unknown functions of one or several variables that relate the values of the functions themselves and of their derivatives of various orders. Many dynamical processes including population processes are described by equations involving rates of change, velocities, slopes, gradients etc, all of which are derivatives [14].

The two main classes of differential equations that are most commonly used for description of population processes are ordinary differential equations and partial differential equations. Other classes of differential equation such as delay differential equations and stochastic differential equations are also gradually gaining popularity and use in the modeling of population dynamics.

Definition 5.2 *An ordinary differential equation is a differential equa-*

tion in which the unknown function is a function of a single independent variable, conversely a partial differential equation is a differential equation in which the unknown function is a function of multiple independent variables [14].

Another important characteristic of a differential equation is the order of the differential equation and this we define below.

Definition 5.3 *The order of a differential equation is the order of the highest derivative appearing in the equation.*

It therefore follows that a differential equation of order 1 is called a first-order differential equation, order 2 a second-order differential equation, etc. A differential equation is linear if the dependent variable and all its derivatives appear to the first power and there are no products or functions of the dependent variable and/or its derivatives. Otherwise the differential equation is nonlinear. In a formal manner we establish whether a differential equation is linear or not with the following definition.

Definition 5.4 *A an ordinary differential equation of order n is linear if it is of the form*

$$a_n(x)\frac{d^n y}{dx^n} + a_{n-1}(x)\frac{d^{n-1}y}{dx^{n-1}} + \cdots + a_2(x)\frac{d^2y}{dx^2} + a_1(x)\frac{dy}{dx} + a_0(x)y = f(x),$$

where the functions $a_i(x), i = 0, 1, \cdots, n,$ and $f(x)$ are given and $a_n(x)$ is not the zero function.

A simple illustration of this definition is given in example (5.5) below.

Example 5.5 *If $u^{'}$ denotes the first derivative of the function u, the equation $u^{'} = u$ is linear while the equation $u^{'} = u^2$ is nonlinear.*

The solutions of differential equations are functions that make the equation hold true. Only the simplest differential equations admit solutions given by explicit formulas, few differential equations also admit solutions in closed form. Many properties of solutions of a given differential equation may be determined without finding their exact form. If a self-contained formula for the solution is not available, the solution may be numerically approximated. The theory of dynamical systems puts emphasis on the qualitative analysis of systems described by differential equations, while many numerical methods have been developed to determine solutions with a given degree of accuracy [96].

Definition 5.6 *A solution of the* n^{th}*-order ordinary differential equation* $F(x, y, y', y'', \cdots, y^{(n)}) = 0$ *on the interval* $a < x < b$ *is a function* $\phi(x)$ *that is continuous on* $a < x < b$ *and has all the derivatives present in the differential equation such that* $F(x, \phi, \phi', \phi'', \cdots, \phi^{(n)}) = 0$ *on* $a < x < b$ *[1, 96].*

The theorem of vanishing derivative provides a basic platform for many techniques of solution for differential equations.

Theorem 5.7 (Vanishing Derivative) *Every solution of* $dy/dt = 0$, $a < t < b$, *has the form* $y(t) = C$, $a < t < b$, *where* C *is a constant. If the function* f *is continuous on an interval* I, *then all solutions of* $y' = f(t)$ *on* I *have the form* $y(t) = F(t) + C$, *where* F *is any antiderivative of* f *and* C *is an arbitrary constant.*

Proof: *The above theorem follows the idea of the constant of integration in integral calculus. The first assertion of the theorem is proven through the Mean Value Theorem, the second assertion only requires the observation that* $F' = f$ *and that the equation* $y' = f$ *can be written as* $(y - F)' = 0$ *[14, 96].*

In many practical problems involving modeling of populations the task does not only require solving the evolving differential equation but also establishing whether the solution satisfies one or more important conditions. This leads to the concept of 'initial value problem'. An initial value problem is an ordinary differential equation together with a specified value, called the initial condition, of the unknown function at a given point in the domain of the solution [96].

Definition 3.8 *An initial-value problem is a differential equation*
$y'(t) = f[t, y(t)]$ *with* $f : \mathbb{R} \times \mathbb{R} \to \mathbb{R}$
together with a point in the domain of f*,* $(t_0, y_0) \in R \times \mathbb{R}$*, called the initial condition* [1].

The differential equation is an evolution equation specifying how, given the initial conditions, the system evolves with time. Therefore the solution to an initial-value problem is a function $y(t)$ that is a solution to the differential equation and satisfies, $y(t_0) = y_0$ [96].

In practical situations of modeling dynamical systems with differential equations there are basic questions regarding the use of the solution of the differential equation arising. These questions are around the existence of a solution to the differential equation, the uniqueness of the solution, solvability of the differential equation and the sensitivity of the solution of the differential equation [14].

The uniqueness and existence theorem provides provides most of the answers to the questions raised above.

Theorem 3.9 (Existence and Uniqueness) *Consider the initial-value problem*

$$\begin{cases} \dfrac{dy}{dx} = f(x, y) \\ y(x_0) = y_0. \end{cases}$$

If the functions f and df/dy are continuous on a region R of the xy-plane and if (x_0, y_0) *is an interior point of R, the initial value problem has a unique solution y(t) on an interval I containing* x_0 *in its interior.*
In fact, if the functions f and df/dy are well-behaved (no discontinuities etc), the theorem guarantees the existence of a unique solution for $x \epsilon R$. However, the statement still only applies to initial value problems.

Special First-Order Ordinary Differential Equations

A Bernoulli differential equation has the form

$$\frac{dy}{dx} + P(x)y = Q(x)y^n. \tag{5.1}$$

Clearly for $n = 0$ and $n = 1$ (5.1) is linear. For other values of n it is nonlinear. However, changing the dependent variable by $z = y^{1-n}$ converts it into the linear equation

$$\frac{dz}{dx} + (1-n)P(x)z = (1-n)Q(x). \tag{5.2}$$

A Riccati differential equation has the form

$$\frac{dy}{dx} = P(x)y^2 + Q(x)y + R(x). \tag{5.3}$$

If $R(x) = 0$, (5.3) becomes a Bernoulli equation. If $R(x) \neq 0$, however, a general solution can be found whenever one specific solution $y = u(x)$ is known. Then the substitution $y = u + z^{-1}$ transforms (5.3) into a linear first-order equation in z. This can be demonstrated in the following manner.

By hypothesis, if $u(x)$ is a particular solution of the Riccati differential equation (5.3), then

$$\frac{du}{dx} = P(x)u^2 + Q(x)u + R(x). \tag{5.4}$$

By using the substitution $y = u + z^{-1}$, we obtain

$$\frac{dy}{dx} = \frac{d}{dx}\left(u + \frac{1}{z}\right) = \frac{du}{dx} - \frac{1}{z^2}\frac{dz}{dx}. \tag{5.5}$$

Substituting (5.5) into the Riccati equation (5.3) we obtain

$$\begin{aligned}\frac{du}{dx} - \frac{1}{z^2}\frac{dz}{dx} &= P(x)\left(u + \frac{1}{z}\right)^2 + Q(x)\left(u + \frac{1}{z}\right) + R(x)\\ &= \left(P(x)u^2 + Q(x)u + R(x)\right) + \left(\frac{2u}{z}P(x) + \frac{1}{z^2}P(x) + \frac{1}{z}Q(x)\right).\end{aligned}$$

We can therefore simplify (5.4) into

$$-\frac{1}{z^2}\frac{dz}{dx} = \frac{2u}{z}P(x) + \frac{1}{z^2}P(x) + \frac{1}{z}Q(x)$$
$$\Rightarrow \frac{dz}{dx} = -2uzP(x) - P(x) - zQ(x).$$

It therefore follows that we obtain the following linear first-order differential equation in z.

$$\frac{dz}{dx} - \left(2uP(x) + Q(x)\right)z = -P(x). \tag{5.6}$$

Ordinary differential equations of the Bernuolli-Riccati form have a wide range of applications one of which is shown below in modeling populations with time-dependent considerations.

5.2.2 The Malthusian Model

The model of Daniel Bernoulli in 1760 in which he described the effects of vaccination could be described as one of the earliest attempts towards mathematical modelling of populations [48] though the classical Malthusian theory of exponential population growth based on the essay 'The Principle of Population' by Thomas R Malthus in 1798 received a more popular attention due to the implication of a catastrophic future for mankind. Thomas Robert Malthus was born in 1766 at Dorking in the south of London. Malthus explicated in fundamental and straightforward terms his theories of human population growth and the connection between over-population and misery. One of the fundamental concepts that he introduced is that of unlimited population growth.

The mathematical model based on this idea is that the population size for one generation depends upon the size of the previous generation and it is a multiple. This is expressed mathematically by the following equation [48]

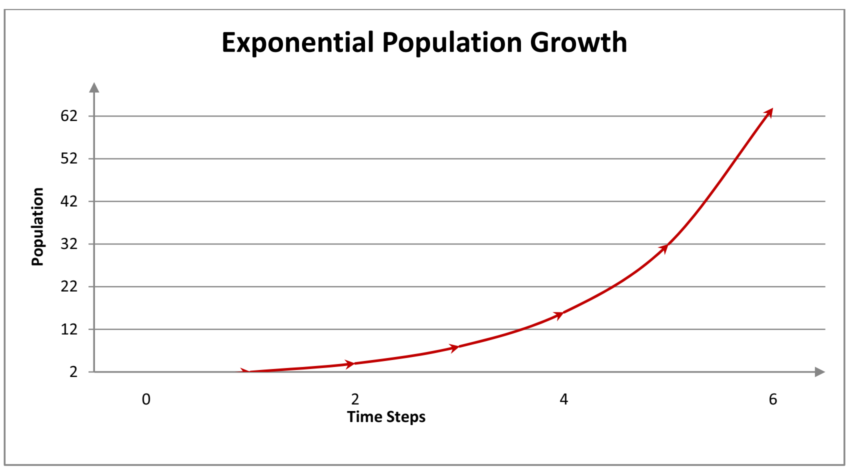
$$\frac{dP}{dt} = rP, \qquad (5.7)$$

where P is the population and r represents the rate of population growth. Equation (5.7) has the solution

$$P(t) = P_0 e^{rt}, \qquad (5.8)$$

where P_0 is the initial population and t is time. Following equation (5.8) the value r is the determinant of whether the population increases, decreases or remains constant for positive, negative and zero values of r respectively [47]. Figure 5.1 is a graphical representation of the exponential growth phenomenon.

Figure 5.1: Exponential Growth



The population model predicts either population growth without bound or inevitable extinction. The difference is based on whether the growth rate r is positive or negative. Neither case is typically observed in genuine biological communities. What is often observed instead is that small populations often (though not always) increase in number while very large populations tend to decline in number. In both cases a steady state is often reached after which significant changes in population are not observed unless a significant environmental change is encountered. A good population model must therefore reproduce this behavior [55].

From a biological point of view the missing feature of Malthus's model is the idea of carrying capacity. As a population increases in size, the environment's ability to support the population decreases. As the population increases, the availability of food per capita decreases, waste products may accumulate and birth rates tend to decline while death rates tend to increase. It seems reasonable to consider a mathematical model which explicitly incorporates the idea of carrying capacity [91].

5.2.3 The Logistic Population Model

The logistic model is a slight adjustment of Malthus' model developed by the Belgian mathematician, Pierre Verhulst (1838) [91], who suggested that the rate of population increase may be limited. As with Malthus model the logistic model includes a growth rate, r. This parameter represents the rate at which the population would grow if it were uncumbered by environmental degradation. A second parameter, K, represents the carrying capacity of the system being studied. Carrying capacity is the population level at which the birth and death rates of a species precisely match, resulting in a stable population over time [91]. The logistic model is given by

$$\frac{dP}{dt} = rP(1 - P/K), \tag{5.9}$$

where K and r are positive constants. The population-dependent per capita birth rate is $r(1 - P/K)$. The carrying capacity of the environment, K, is naturally determined by resources available to sustain population.

Figure 5.2: The Logistic Growth

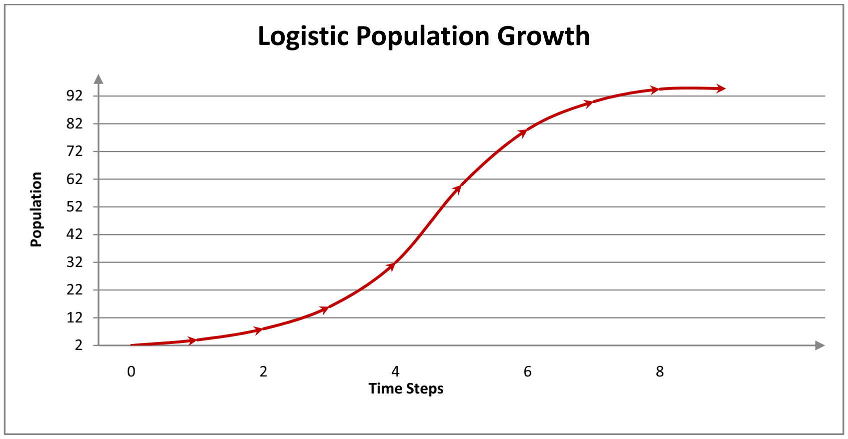


Figure 5.2 is a graphical depiction of the system. There exist two steady states or equilibrium points for (5.9), namely $P = K$ and $P = 0$, that is where $dP/dt = 0$. The equilibrium point, $K = P$, is stable. When we linearise about it, we obtain $d(P - K)/dt \approx -r(P - K)$ and so $P \to K$ as $t \to \infty$. The other equilibruim point $P = 0$ is unstable, linearisation about it gives $dP/dt \approx rP$ and so P grows exponentially from any small initial value. The carrying capacity, K, determines the size of the stable steady-state population, while r is an indicator of the rate at which the carrying capacity is attained. The measure of the dynamics, r, could be incorporated into the time by a transformation from t to rt. Hence $1/r$ can be regarded as a representative timescale of the response of the model to any change in the population [91]. The solution of (5.9) is

$$P(t) = \frac{P(0)K\exp(rt)}{[K + P(0)(\exp(rt) - 1)]} \quad \to \quad K \quad \text{as} \quad t \to \infty. \tag{5.10}$$

From (5.10), if $P(0) > K$, $P(t)$ decreases monotonically to K. Conversely, if $P(0) < K$, $P(t)$ increases monotonically to K. When $P(0) > K$, it implies that the per capita birth rate is negative. The practical meaning of this is that in the logistic equation births plus immigration are less than deaths plus emigration. The point about (5.10) is that it is more like a metaphor for a class of population models with density-dependent regulatory mechanisms, a kind of compensating effect of overcrowding and must not be taken too literally as the equation governing the dynamics of the population [61].

The Bilogistic Population Model

The standard form of the logistic growth model as above describes one period or 'pulse' of growth as the system proceeds from rapid exponential growth to slow growth as the carrying capacity, K, is approached. Meyer and Ausubel [54] examined the case of a system with two well-defined serial logistic growth pulses. It is possible to split the time-series data set into two and model each set with a separate logistic function. We call such a system with two logistic growth pulses, growing at the same time or sequentially, 'bilogistic' where t_1 and t_2 ($t_1 \leq t_2$) represent the time intervals of the two growth pulsations within the entire time t and A, B represent the first and second pulsations respectively.

$$P(t) = \begin{cases} 0, t < t_1 \\ A, t_1 < t < t_2 \\ A + B, t > t_2, \end{cases}$$

where,

$$A = \left[\frac{P(0)K\exp(rt_1)}{[K + P(0)(\exp(rt_1) - 1)]}\right]$$

$$B = \left[\frac{P(1)K\exp(rt_2)}{[K + P(1)(\exp(rt_2) - 1)]}\right] \tag{5.11}$$

where $P(1)$ is the value of the function $P(t)$ for the value of its argument 1.

This could be applicable to the household dynamics in South Africa. Immediately after apartheid 'freedom-induced' urbanization saw the fragmentation of mostly rural households leading to a rapid rise in household numbers. However, the freedom-induced rapid urbanization reached the peak as some of the urban migrants started returning as a result of a lack of sustainable livelihood in the urban centres [54]. The second phase of the household fragmentation leading to rapid household growth could be attributed to the economic empowerment of the Black populace 'BEE Induced'. This could be the current situation therein households fragment as a result of householders' economic liberation.

However, this method is limited because it is often unclear exactly where to split the data set. Cases rarely appear for which one process ends entirely before the second begins. Problems arise in assigning values from the 'overlap' period to the first or second pulse [54].

5.2.4 Considering Age Distribution in Population Models

The above population models have the deficiency of not considering other demographic factors that could influence the human population change process apart from birth and death rates. These factors include proximate factors like age structure and postpartum amenorrhea, contraceptive practice and indirect factors like level of education, income, cultural/religious beliefs etc. These factors in practical situations can influence the size of the population and the pattern of growth of the population [55, 56]. For simplicity we present a linear model considering one of these factors (age structure).

Let $n(t, a)$ be the population density at any time t in the age range a to $a + da$. Let $b(a)$ and $u(a)$ be the birth and death rates respectively which are functions of age a such that in a small increment of time dt

the number of the population of age a that dies is $u(a)n(t,a)dt$. The conservation law for the population would be [55],

$$dn(t,a) = \frac{\partial n}{\partial t}dt + \frac{\partial n}{\partial a}da = -\mu(a)n(t,a)dt. \tag{5.12}$$

The $(\partial n/\partial a)da$ term is the contribution to the change in $n(t,a)$ from individuals getting older. Dividing (5.12) by δt (noting that $\lim_{\delta \to 0}$, $\delta t \to dt$ & $\delta a \to da$, also noting that $da/dt = 1$ since a is chronological age, $n(t,a)$) satisfies the linear partial differential equation

$$\frac{\partial n}{\partial t} + \frac{\partial n}{\partial a} = -\mu(a)n, \tag{5.13}$$

holding for $t > 0$ and $a > 0$ [55]. If $\mu = 0$ for instance, (5.13) reduces to a conservation equation which simply implies that the time rate of change of the population at time t and age a, $\partial n/\partial t$, simply changes by the rate at which the population gets older, i.e. $\partial n/\partial a$ [55].

A Numerical Scheme for Age Structured Population

In most practical instances use of population models involves the implementation of numerical approximation schemes for the differential equation arising in most cases nonlinear in nature. Here we consider the numerical scheme for the approximation of age structured initial-boundary value problem for the nonlinear hyperbolic integrodifferential equation

$$u_t + u_x = -\mu(x, I_\mu(t))u, \qquad 0 \le x \le A, \qquad 0 \le t \le T, \tag{5.14}$$

$$u(0,t) = \int_0^A \beta(x, I_\beta(t))u(x,t)dx, \qquad 0 \le t \le T, \tag{5.15}$$

$$u(x,0) = \phi(x), \qquad 0 \le x \le A, \tag{5.16}$$

where $I_\mu(t)$ and $I_\beta(t)$ denote

$$I_\mu(t) = \int_0^A \gamma_\mu(x)u(x,t)dx, \qquad I_\beta(t) = \int_0^A \gamma_\beta(x)u(x,t)dx, \tag{5.17}$$

respectively. The independent variables x and t denote age and time, respectively, and $u(x,t)$ represents the age-specific density of individuals of age x and time t. The nonnegative functions μ and β represent the mortality and fertility rates respectively with the assumption that they depend upon the age x and some weighted averages of the density function, $I_\mu(t)$ and $I_\beta(t)$ as in (5.17).

One of the most used and convenient techniques to integrate numerically the situation in (5.14) and (5.15) is the finite-difference method along the characteristics [2, 54]. The characteristic curves of (5.14) are lines $x - t = c$, where c is constant and along those characteristics the solution $u(x,t)$ satisfies

$$\frac{du}{dt} = -\mu(x, I_\mu(t))u. \tag{5.18}$$

Integrating along characteristics, we obtain that solution of the hyperbolic integrodifferential equation (5.14), for each x_0 with $0 < x_0 < A$ and such that $a + h < A$. Thus

$$u(x_0 + h, t_0 + h) = u(x_0, t_0) \exp\left(-\int_0^h u(x_0 + \tau, I_\mu(t_0 + \tau))d\tau\right), \tag{5.19}$$

where $t_0 > 0$ [2, 54]. The effort here is geared towards a numerical approximation to the values of the theoretical solution u of (5.14) - (5.16) in the time interval $[0, T]$ by discretizing the identity (5.19). Given a positive integer J, if $h = A/J$, and $N = [T/h]$, we introduce the grid points $x_j = jh$, $j = 0,...,J$, and time levels $t_n = nh$, $0 \le n \le N$, implying $(x_{j+1}, t_{n+1}) = (x_j + h, t_n + h)$, $0 \le J \le j-1$, $0 \le n \le N-1$. Thus we obtain

$$u(x_{j+1}, t_{n+1}) = u(x_j, t_n) \exp\left(-\int_0^h u(x_j + \tau, I_\mu(t_n + \tau))d\tau\right) \tag{5.20}$$

[2,54].

Discretising (5.19) we obtain

$$U_{j+1}^{n+1} = \left(-\frac{h}{2}(\mu(x_j, I_\mu^h(U^n)) + \mu(x_{j+1}, I_\mu^h(U^{n+1})))\right), \tag{5.21}$$

$0 \le j, \le -1$, $0 \le n \le N-1$, with initial condition $U^0 = (U_0^0, ..., U_,^0)$ and boundary condition [2,54]

$$U_o^{n+1} = \sum_{j=0}^{J} h\beta(x_j, I_\beta^h(U^{n+1}))U_j^{n+1}, \qquad 0 \le n \le N-1. \tag{5.22}$$

In (5.21) the integral inside the exponential in (5.19) has been approximated using the trapezoidal rule [2,54].

Example 5.8 *Choosing the age-specific fertility and mortality moduli as*

$\mu(x, z, t) = z$ *and*

$\beta(x, z, t) = \dfrac{4xze^{-x}(2 - 2e^{-A} + e^{-t})^2}{(1+z)^2(1-e^{-A})(1-(1+2A)e^{-2A})(1-e^{-A}+e^{-t})}$,

weight functions $\gamma_\mu \equiv \gamma_\beta \equiv 1$ *and considering the initial age-specific density to be*

$$u_0(x) = \frac{\exp(-x)}{2 - \exp(-A)}, \tag{5.23}$$

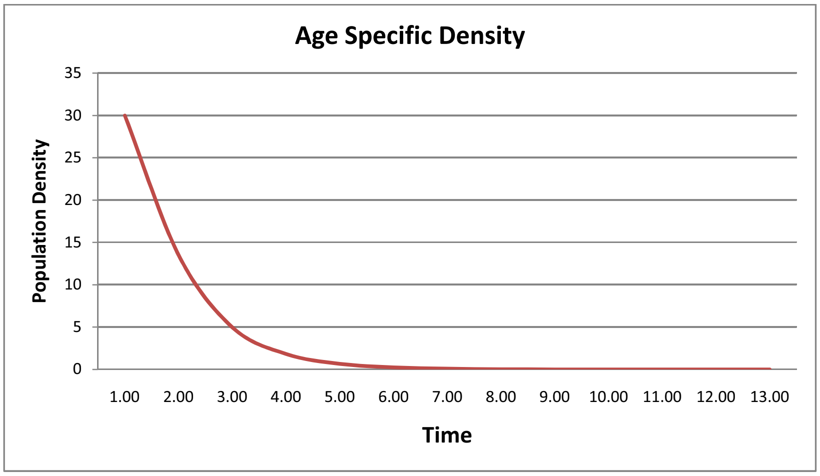
the solution of (5.14) - (5.16) is given by

$$u(x,t) = \frac{\exp(-x)}{1 - \exp(-A) + \exp(-t)} \tag{5.24}$$

[2,54].

The behavior of the age distribution of (5.24) is shown in Figure 5.3.

Figure 5.3: Population Density Pattern of Particular Age Cohort



In the age-structured population distribution as shown in Figure 5.3, the contribution of a particular age cohort to the population density diminishes with time. For human population the rate of diminishin could be determined by the general standard of living. In the developing world in which standards of living and health care are still poor for the eradication of diseases and elongation of life expectancy at birth, a more rapid diminishing effect could be noted for such populations than for developed and more advanced countries.

The shortcoming of the model and numerical approximation for the age-structure model that we have considered is the non inclusion of migration as a major component of population change especially for the population of humans. For instance there are certain cities or geographic areas that are known to be preferred retirement areas. Such cities like Florida in the United Sates may be observed to witness huge in-migration of retirees into particular older age cohort such that the diminishing effect of time on the contribution such age cohorts to the population density could be greatly reduced.

5.2.5 Time-Dependent Population Models

Mathematical models in general have the deficiency of inaccurate depiction of the population over long period of time (say from 10 years for human populations) especially when used and interpreted literally without any modifying assumptions tailored towards the particular problem at hand, for this demographers prefer using cohort component method among others for projecting human population over long period. This common defect is easily notable in the Malthusian and Verhulst models for their insistence that the population parameters such as birth and death rates are constant over a long period of time thereby implying that the solution remains finite for all t as observed by Leach and Andriopoulos [43]. In reality, however, birth and death rates are not constant except for stable populations but then for a limited time. Moreover the Verhulst model which has been acclaimed to be a better depiction of reality than the Malthusian has as a major criticism the fact that it did not consider variation in time of the upper limit. Momentary variations in the upper limit of populations have been observed to be a real fact for different living organisms including human populations. For instance the continual ability of technology to increase human economic throughput and food supply, such as the expansion of food production during the 'green revolution', is an evidence of the ability of man to vary the carrying capacity of human population and even some eventual catastrophes, like wars and epidemics, provide major setbacks for the Verhulst model which assumes constant carrying capacity for populations.

The consideration of time dependency is relevant for the population dynamics of a system where due to some natural causes as the case of periodic seasonal changes of population parameters as result issues like changes in climatic conditions etc. It could also be applied to situations where artificial influences cause fluctuation of population parameters as in controlled births or deaths due to periodic fluctuations in demand for animals in animal husbandry. In these instances time variations in the population parameters are considered. An extension of this could provide an insight into the evolution of populations of human and other animal species where time variation in the parameters remains a reality.

Assuming that in this system births or increase in animals are generally concentrated in two peak periods in the year like in the case of animal husbandry particularly to sheep farming where the farmer strategically concentrates production on two peak periods due to market forces. Outside these peak periods there are no births. A birth-rate parameter, which starts from zero, rises to a peak, falls back to zero and rises again for the second peak of the year, is needed to mimic the birth dynamics of the population. Writing (5.9) as a nonhomogeneous linear first-order differential equation in Bernoulli form we obtain [43]

$$\frac{d}{dt}\left(\frac{K}{P}\right) + r\left(\frac{K}{P}\right) = r. \tag{5.25}$$

The integrating factor for (5.25) is $\exp[\int r dt]$. Following Leach and Andriopoulos [43] for time dependency we assume that $r = r(t)$ and $K = K(t)$. The solution of (5.25) is

$$\frac{1}{P} = \frac{1}{K}\exp\left[-\int_0^t r dt'\right]\left(A + \int_0^t P\exp[r]dt'\right) \tag{5.26}$$

Thus the population function becomes

$$P(t) = \frac{K\exp[\int_0^t r]}{\dfrac{K}{P_0} + \int_0^t r\exp[\int_0^{t'} r]} = \frac{P_0 K\exp[\int_0^t r]}{K + P_0\int_0^t r\exp[\int_0^{t'} r]}. \tag{5.27}$$

To mimic the pattern of the population and take cognisance of the time dependence of the birth rate and mortality parameters, r and K, we write the birth variable, r, as

$$r(t) = b\sin^4(2\pi t). \tag{5.28}$$

Figure 5.4 is a plot of the above sine function (using Mathematica)

Figure 5.4: Two Peaks Occurring During One Time Step

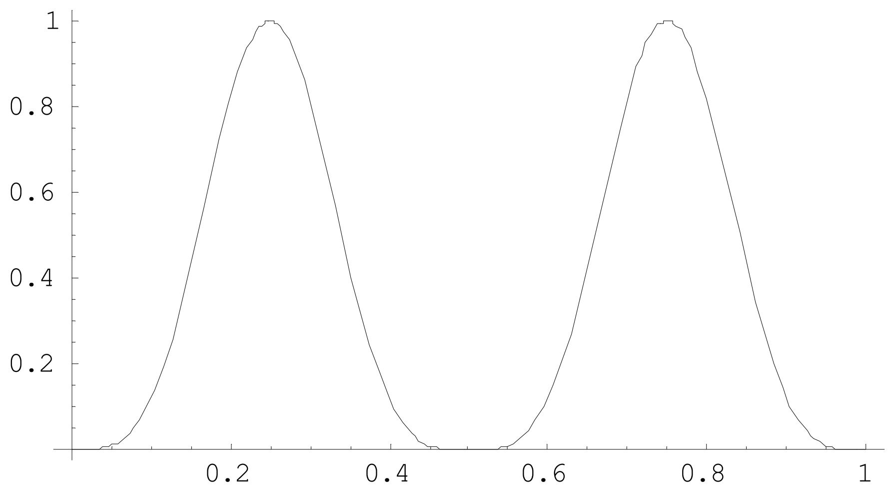
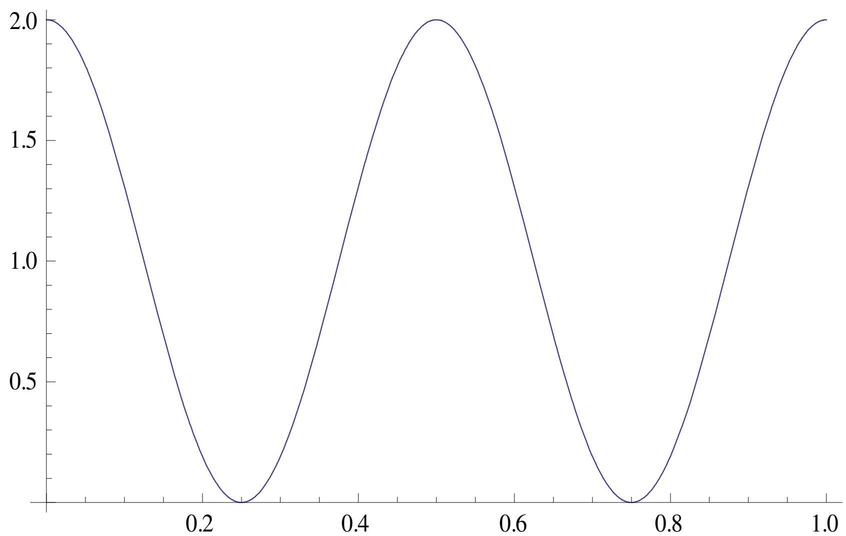


Figure 5.4 represents the birth pattern showing the two peak periods of birth in the year.

However, deaths follow a different pattern which could be imagined as a periodic variation about a nonzero value with the rate being always nonnegative. We write the death parameter using a cosine function as [57],

$$K = [k + a\cos 2\pi t]. \tag{5.29}$$

Figure 5.5: Two Peaks of Decay/Death During One Time Step



In Figure 5.5 parameter allowance has also been made for two peak periods in a year that are considered to occur about the same periods as the drops (births) in the year. The resulting pattern of population dynamics $P(t)$ is oscillating given by the following function.

$$\int_0^t (\sin 2\pi t)^4 dt - \int_0^t 0.38[1 + \cos(2\pi t)]dt$$
$$= \left[\frac{24\pi t - 8\sin(4\pi t) + \sin(8\pi t)}{64\pi} - 0.38\left(t + \frac{\sin(2\pi t)}{2\pi}\right)\right]. \tag{5.30}$$

In order to have a pictorial representation of the above function we make a plot of the function firstly over a period of a year with a hypothetical initial number of the animal population P_0=100.

$$Plot[100{*}\exp\left[\frac{24\pi t - 8\sin[4\pi t] + \sin[8\pi t]}{64\pi} - 0.38\left(t + \frac{\sin[2\pi t]}{2\pi}\right)\right], t, 0, 1]$$

Figure 5.6: The Population Dynamics Over One Time Step

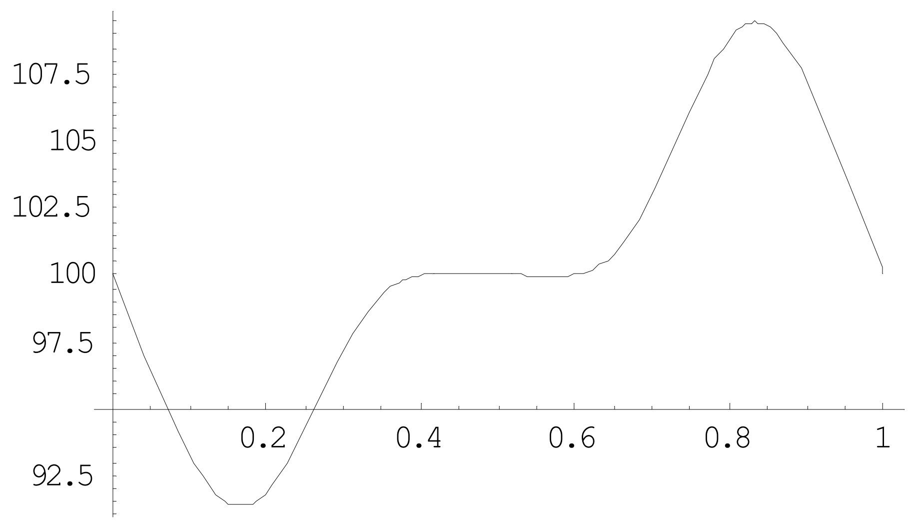
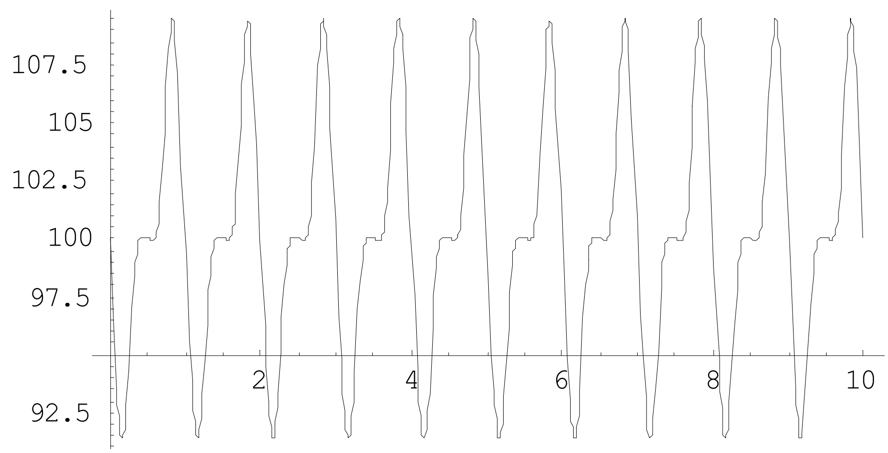


Figure 5.6 is a graphical illustration of the behavour of the solution (5.27).In Figure 5.6 the first peak of births for the animal population would be noticed to be around March while the second maximum would be around September. An interesting enquiry would be to know the behaviour of the population at the end and beginning of each year.

$$Plot[100{*}\exp\left[\frac{24\pi t - 8\sin[4\pi t] + \sin[8\pi t]}{64\pi} - 0.38\left(t + \frac{\sin[2\pi t]}{2\pi}\right)\right], t, 0, 10]$$

A plot of the function over a ten-year interval in Figure 5.7 shows an oscillating population movement.

Figure 5.7: The Population Dynamics Over Ten Time Steps



5.3 Human Demography & Population Models

Changes in the size of human populations are as the result of three demographic processes, i.e. birth, death and migration. These three variables are the components of population change as shown in the population component balancing equation (5.31) below [32, 34, 36],

$$P_t = P_{t-1} + B_{t-1,t} - D_{t-1,t} + M_{t-1,t} - E_{t-1,t}, \tag{5.31}$$

where

P_t = the size of the population at the current year

P_{t-1} = the size of the population at time $t-1$

$B_{t-1,t}$ = total births in the time interval $t-1, t$

$D_{t-1,t}$ = total deaths in the time interval $t-1, t$

$M_{t-1,t}$ = the total Immigrants in the time interval $t-1, t$

$E_{t-1,t}$ = the total Emigrants in the time interval $t-1, t$.

The difference between births and deaths constitutes natural increase, in the same manner the difference between total immigrants and emigrants in a closed population constitutes net-migration. Therefore the population component balancing equation simply reduces to (5.32)

$$P_t = P_{t-1} + NI_{t-1,t} + NM_{t-1,t}, \tag{5.32}$$

where

$NI_{t-1,t}$ = natural increase in the time interval $t-1, t$,

$NM_{t-1,t}$ = net migration in the time interval $t-1, t$.

It becomes clear that two main factors control the dynamics of human population, i.e the rate of natural increase and net migration. The effect of these two factors is well reflected in the parameter r (for rate of growth) in the exponential function describing the Malthusian growth model (5.7, 5.8) as well as r in the logistic model (5.9). However, as stated earlier, the major limitation of the exponential model is the insistence that r remains for stable for a long period of time especially for human populations. In the case of biological species like some bacterial colonies, where growth of the population is fast and the life span of the species short, the exponential model describes such populations better than human populations where the components of the human population fertility, mortality and migration are really factors that are more of human choices and natural phenomena that are heavily time-dependent. The logistic model which is acclaimed to be a better depiction of reality has as a major limitation the problem of establishing what constitutes the carrying capacity or upper limit for human populations. Again for some biological species the logistic model makes sense for instance in the case of animal husbandry where the farmer knows the geographic bounds of his farm and of course his limits of food supply. However, with sound assumptions from experienced demographers and a bit of caution these mathematical models could yield fairly good results for estimates of human populations within reasonable time frames. The main beauty of these models lies in their ease of implementation and moderate data requirements.

With the above limitations of the Malthusian and Logistic models in sight, to forecast practically the total human population size, one of the most popular demographic method is the cohort component method. In the cohort component method the number of males and females of the population are grouped into age groups of usually 5-years. Within the cohorts probability (life-table) functions are used to find the number of people who survive or are expected to be alive in a time frame. The survived population within all the components including the number of births that take place and the number of net migrants are all added up to produce the total estimate of the population. The cohort component method could be described as in the equation (5.33)

$$P_t(a) = P_{t-1}(a) + NI_{t-1,t}(a) + NM_{t-1,t}(a). \tag{5.33}$$

Here a denotes age as of the last birthday. This method is based on similar logic as in (5.31 and 5.32) for individual age groups. The source population for a given age group is the population at time $t-1$ in the adjacent younger age group [32, 36]. The main difference here is that each of the terms in equation (5.33), whether defined as a population or a number of events, relates to people born in a particular year called the 'birth cohort' from $t-a-1$ to $t-a$ [32, 36]. The cohort component method has very heavy data requirements as it disaggregates total population into various components like age, gender and in some cases race etc. Further the different drivers of population change, i.e. births, deaths, and migration, are individually taken into account and past figures for these components are applied to the current age and sex cohorts [32, 36]. This could be problematic for its implementation in developing countries where reliable and timely vital statistics are hard to obtain. More so for South Africa as the main economic centre of the Southern African region coupled with the porous borders migration as a component of population change is a complex issue. It is both difficult to capture and to interpret. One key reason for the difficulty of interpretation is to distinguish between migrants and moves, a migrant (a person) can experience many migratory moves (events) as time passes. Therefore it is even more difficult to obtain reliable migration data for South Africa than to obtain the fertility and mortality components of the population. Thus in as much as the component cohort method seems to be a comprehensive population estimation and projection tool, it should be used with care for developing countries in which reliable vital statistics are hard to obtain. Well constructed mathematical models in view of their light data requirement could play a supplementary role to appropriate demographic models in the developing world. More so in South Africa where the apartheid legacy left of history of a noninclusive process of the collection vital statistics.

Figure 5.8: Population Projection of South Africa with Different Models

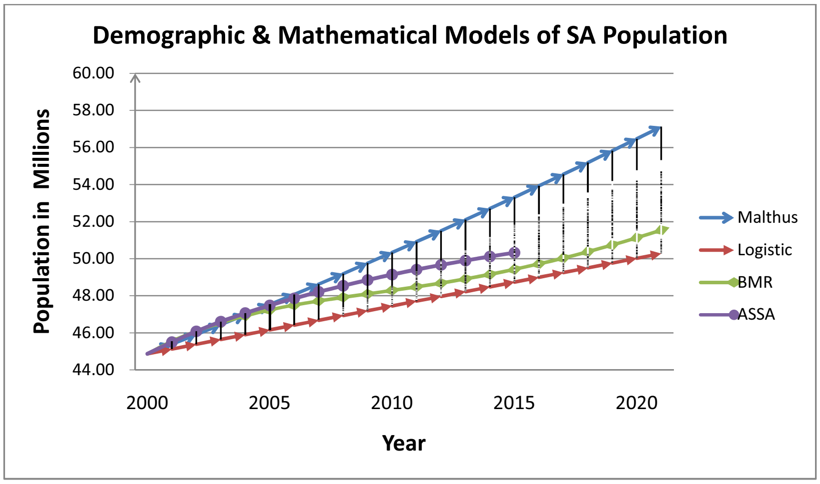


Figure 5.8 is a plot of the trend and projections of the population of South Africa using the classical Malthusian and Logistic models and comparing them with results obtained by demographic methods built by the Actuarial Society of South Africa (ASSA) and the Bureau for Marketing Research at the University of South Africa (BMR)[3, 88].

The Malthusian and Logistic models in Figure 5.7 are built with an average population growth rate of 1.15% per annum as computed using mid-year population estimates from Statistic South Africa between 2001 and 2008 and also assuming 65 million as the upper limit for the Logistic model based on human judgement. A close look at Figure 5.7 shows that the Malthusian model seem to be the most unrealistic replica of the population on long term basis and the divergence with the other models widens with increase in time, this in line with the perception of demographers regarding the use of mathematical models for long term projections exceeding 10 years [84]. The BMR, ASSA and Malthusian models show very little divergence especially during the early period 2000 to 2008. It is also notable that the Logistic model concurs to a reasonable extent with the BMR model during the period

2010 to about 2018.

We have shown that realistic models of biological systems should contain parameters that vary with time. This does not exclude the human species for which variations of drivers of the dynamics of human population (births, deaths and migration) are even very noticeable through the spread of epidemics, civil conflicts, terrorism, starvation, changing lifestyles, contraceptive practice, postpartum amenorrhea, value systems etc. On the other hand improvements in science, technology, medicine and agriculture have also brought variations in these population parameters over time. These variations in parameters could be factored towards more realistic population models as we have demonstrated with the case of animal husbandry, the aim being to give an insight into the possibility of being explored in the more complex situation population of humans.

In the next Chapter we present the special case of modelling the growth or decay process where the subject of investigation is human households applied specifically with the case of the South African society in the context of household access to basic services.

Chapter 6

Modelling the Number of Service Units/Households in South Africa: Demographic & Mathematical Approaches

There are several demographic methods for estimating and projecting the number of households in a state; these models are broadly categorized as Static Household Models and Dynamic Household Models. The static models generally have the weakness of not being able to capture the dynamics of household formation and dissolution. Under the static category the headship rate method in its primordial form is one of the most common methods. Being purely demographic models they extrapolate proportions of household heads in population categories using independent projection of the population broken down by the same categories [89].

6.1 Static Household Models

Basically the headship rate method gives an estimate of the number of heads of households over the projection period. As each household is assumed to have just one head, the number of household heads in a state equals the number of households [63]. The proportion of people who head a household is calculated for each age, sex and marital status group, as a proportion of all persons in that group. This is known as the headship rate. A major shortcoming of this method is inherent bias towards the older male population, the headship model is driven primarily by changes in the older male population who are usually selected as household heads and is therefore less sensitive to changes in the rest of the population. The rate can only be in the range 0 to 1 and is often expressed in percentage terms. Therefore calculating headship rate implies that

$$HeadshipRate = \frac{HouseholdHeads}{Population} \tag{6.1}$$

and so total household would be

$$TotalHouseholds = (HeadshipRate) \times (Population). \tag{6.2}$$

The main advantage of the headship rate model is that it is a simple and computationally efficient model with minimal data requirements. Although most household projections are made using the headship rate method, being a static model the headship model has weakness of being prone to underestimate the actual numbers of households. The main problem with the headship rate approach is that it is based only on an extrapolation of past trends and is also time independent. There are no causal or truly predictive elements. The rate of household formation is dependent upon a number of interrelated factors such that the formation of new household depends upon choices, often shaped by changing social attitudes and on the ability of potential households to obtain their choices, dependent upon factors such as income. The headship rate method is not able to capture the range of factors influencing household formation and is essentially demographically driven [89].

6.2 Dynamic Household Model

On the other hand dynamic household models tend to capture the process of household formation and dissolution through a number of life events. They strive to factor in such questions as, if a child would leave home a few years later, how would this affect household structures. We therefore build on the recent work of O'Neill B and Jiang L [60] and present a dynamical model which captures some of the these factors.

Let $H_s(a,t)$ be the number of households of size s, with householder aged a, at time t; Let F be the number of households formed and D the number dissolved. Then

$$\frac{\partial H_s(a,t)}{\partial t} = -\frac{\partial H_s(a,t)}{\partial a} + F_s(a,t) - D_s(a,t). \tag{6.3}$$

Equation (6.3) implies that the time rate of change in the number of households within a given age category of householders is equal to the divergence of the householder age structure plus the net formation rate of households of a particular size due to fertility, mortality by other factors, HIV induced mortality, migration, marriage, leaving home, divorce, black economic freedom etc. We can derive an expression for size- and age-specific headship rates by writing the number of households as the product of population size (P) and the headship rate (h), $H_s(a,t) = h_s(a,t)P(a,t)$, substituting this expression for H into equation (6.3), taking the indicated derivatives and rearranging terms [60] to obtain

$$\frac{\partial h_s(a,t)}{\partial t} = -\frac{\partial h_s(a,t)}{\partial a} - \frac{h_s(a,t)\left(\frac{\partial P(a,t)}{\partial t} + \frac{\partial P(a,t)}{\partial a}\right)}{P(a,t)} + \frac{f_s(a,t)}{P(a,t)}. \tag{6.4}$$

In (6.4) $f_s(a,t)$ is the net rate of household formation, i.e $[F_s(a,t) - D_s(a,t)]$, the equation expresses the time rate of change in headship rates as being composed of three terms. The first two terms represent the change in headship rates due to the effect of the age structure of either householders or population. The first term indicates the effect on headship rates of the tendency for the number of households in a given age (and size) group to change as householders' age (with population size held constant); the second term indicates the effect on headship rates of the tendency for the population size to change as cohorts age (with numbers of householders held constant). The third term represents the net effect of all demographic processes leading to either formation or dissolution of households as listed; fertility, mortality by other factors, HIV induced mortality, migration, marriage, leaving home, divorce and the net formation and dissolution of households being increasingly positive given that the black populace which is the by far the larger group is gaining economic freedom [4, 24, 88].

Realistic use of this model (equation 6.4) would entail specifying $f_s(a,t)$ as a function of demographic events and estimating parameters. However, the critical issue for consideration is the realistic estimation of demographic events given the generally poor state of reliable demographic data in South Africa.

To solve equation (6.4) we proceed as follows;

$$\underbrace{\frac{dt}{1} = \frac{da}{1}} = \frac{dh}{-h\dfrac{\left(\dfrac{\partial P}{\partial t} + \dfrac{\partial p}{\partial a}\right)}{P} + \dfrac{f}{P}}, \tag{6.5}$$

Take the first and second terms in (6.5).

$$\mu = t - a \qquad\qquad\qquad a = t - \mu.$$

Taking the first and third terms with $a = t - \mu$

$$\frac{dt}{1} = \frac{dh}{\dfrac{-h\dfrac{dd(\mu,t)}{dt}}{d(\mu,t)} + b(\mu,t)}, \tag{6.6}$$

where

$$b(\mu,t) = \frac{f(t-\mu,t)}{P(t-\mu,t)}.$$

$$\frac{dd}{dt}/d = \frac{\left(\dfrac{\partial P}{\partial t} + \dfrac{\partial P}{\partial a}\right)}{P}|_{a=\mu-t}. \tag{6.7}$$

Thus (6.6) becomes

$$0 = \frac{dh}{dt}d + h\frac{dd}{dt} - bd \Longrightarrow \frac{d}{dt}(hd) - bd. \tag{6.8}$$

$$w = hd - \textstyle\int bddt$$

$$h = \frac{1}{d}\left\{\int bddt + K(\mu)\right\} = \frac{1}{d}\left\{\int bddt + K(t-a)\right\}, \tag{6.9}$$

where K is an arbitrary function of the argument.

At $t = 0$

$$h(a,0) = \frac{1}{d(a,0)}\{0 + K(-a)\}, \tag{6.10}$$

where

$$K(-a) = h(a,0) \times d(a,0) = Q(a).$$

Hence

$$K(t-a) = Q(a-t),$$

where Q is some given function coinciding with K at the value a.

The numerical results for headship rates h, (6.4), is presented in Table 8.1. The estimated total households $H_s(a,t) = h_s(a,t)P(a,t)$, i.e. the product of the h and the total population is computed using the mid-year population estimates from Statistics South Africa (1996 to 2008) in combination with mid-year estimates of the population of South Africa from the US Bureau of Census (2009 to 2015). The results are presented in Figure 6.1.

6.2.1 Comparing Demographic and Mathematical Results

In projecting the South African households for the period 2001 to 2021 van Aardt [88] implemented the demographic protocol for modelling household growth developed by the US Census Bureau, in which the numbers of future households are modeled as a function of future population growth, future age composition of the population and future household headship rates, i.e $FH = f(P, A, H)$. However, apparently as a result of dearth of data Van Aardt revised the model from the US Census Bureau substituting future household headship rates with current average household size and produced a simplified model for households as [88],

$$H_{t+1} = \frac{P_{t+1}}{\bar{X}_{t+1}}, \tag{6.11}$$

where

H_{t+1} = Current number of households

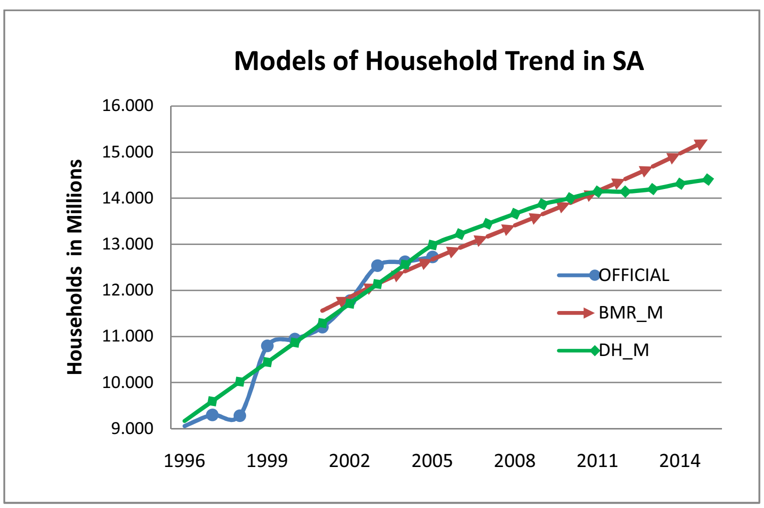
P_{t+1} = Current population size

$\bar{X}_{t+1}$ = Current average household size.

The major advantage of this model is that it has very modest data requirements and that it is very easy to implement. However, for assuming a static average household size over the 20 years period, this model would not reflect possible variational changes in demographic variables that control household size over the period. This is a major shortcoming of the model, due to this the model would be more appropriate for stable populations.

In Figure 6.1 we present the numerical results of the demographic model (BMR_M) by van Aardt [88], the numerical results of the dynamic headship (DH_M) model from the partial differential equation and official data.

Figure 6.1: Comparison of Models of Households in South Africa



In Figure 6.1 the trend in both models of South African households and official data suggest rapid increasing household numbers from the early years of freedom from 1996. This could be inferred as being consistent with the turn of events in that period where many new households are formed as people surged into the urban centres in search for jobs and better prospects [41]. Even though the official data are erratic, the overall trend has maintained a rapid increasing tendency from the official trend line. The BMR model seem almost exponential and has maintained the exponential tendency through the projecting period, some good degree of agreement could, however, be observed between the BMR model and the dynamic headship model for the period between 2002 and 2005. Remarkable discrepancies between the BMR model and the dynamic headship model with the dynamic headship model projecting a little above the BMR model could be noted from about 2006 till 2010 before the intersecting agreement in 2011. While the BMR model continues on the exponential trend the dynamic headship model shows a decrease in growth rates from 2012, it is hoped that this slowdown in the growth would continue into the near future. It is reasonable to infer that household numbers would seemingly not continue to grow in an exponential manner in South Africa over a long period of time. Unskilled economic in-migrants into the urban centres are continually coming to terms with the reality of the situation that jobs are not easy to get in the urban centres [41]. More so the base population from most projections [3, 83, 87, 88] show a continued slowed growth over the next few decades in the light of HIV-AIDS induced mortality which is projected to high of about 420,000 per annum in 2015 even though there is projected marginal decrease in the incidence rates, the cumulative impact of disease would still be significant into the foreseeable future [3]. On the other hand total fertility rates in South Africa for all the population groups have been observed to be on the decline with estimates of 2.9 births per woman in 2001 declining to about 2.5 births per woman in 2007, the highest rate is observed for the African population group at about 2.7 while that of the White population group is about 1.4 births per woman [79]. Total fertility projections for Southern Africa into the near decades indicate that the decline in fertility could get to below replacement rates over the next decade [84]. The aggregate effects of these is that that natural increase in the population of South Africa is declining as shown in Table 8.1, therefore the trend of rapid growth in households would be expected to slow in the near future.

In the next Chapter we present a review of access and delivery of piped water to households in South Africa highlighting provincial differences. The main motive is to present official statistics as they appear without modification working around the presentation of the statistics in manner that the erratic jumps in the data do not to a large extend influence the inferential outcomes.

Chapter 7

Household Demand/Access to Piped Water in South Africa

In this Chapter we investigate the trend in household demand and access to basic water in South Africa as manifested by the data-sets from Statistics South Africa, the impact of the rapidly increasing household trend on demand/access to basic services and the differences among the provinces, considering the fact that Figure 1.2 in Chapter 1 reflects rapidly growing household numbers against the population. The population to household ratio decreased from about 5:1 in 1994/5 to 3:1 for 2006/7. The ultimate aim is to provide the basis for building a realistic framework for South African household modeling and projection in relation to provision of basic services with the realisation that households remain the unit of provision of most social services.

The analysis of data in the Chapter is made with the underlying assumption that the newly formed households need state assistance for water connection. This assumption we believe would not be far from reality as most of the fragmenting households are African households representing by a wide margin the majority of populace and within them the higher proportion is poor [4, 10, 27].

In analyzing the official data-sets inconsistent outliers are occasional encountered. These anomalies do not imply that the data-sets are wrong or right but apparently as a result of the continuous efforts of Statistics South Africa towards adjusting the weighting scheme of the national surveys as new information becomes available as necessitated by the history of noninclusive vital data collection in South Africa as we saw in Chapter Two. However the objective of this Chapter is to present official data as they appear and to see what information or inference that could be drawn from them in light of the controversial nature of arguments around service delivery issues in South Africa.

7.1 Household Access to Piped Water: Evidence from Official Statistics

Here we present an historical account of household access to basic water based on official statistics from Statistics South Africa with little or no alteration. Even though there is evidence of inconsistency at certain levels in data from the household surveys, Statistics South Africa still remains the official and main provider of socioeconomic and welfare statistics in South Africa as prescribed by the Statistics Act of 1999 [81]. It is interesting to note that efforts are made towards improving the data output of Statistics South Africa in time.

The following list shows the metadata (definition of levels of water access) of different levels of water access as captured by the survey questionnaire from Statistics South Africa for the question of the source of water for households. Although there are small variations of the definition of access levels from the earlier October Household Surveys to the recent General Household Surveys, the variations do not make any significant difference.

Question: What is the Household Main Source of Water ?

- Piped (tap) Water in Dwelling
- Piped (tab) Water on Site
- Neighbour's Tap
- Borehole on Site
- Rainwater Tank on Site
- Public Tap
- Watercarrier/Tanker
- Borehole off-Site/Communal
- Flowing Water/Stream/River
- Dam/Pool/Stagnant Water
- Well
- Spring
- Other, Specify

For simplicity we proceed by summarizing the levels of household access/demand based on two broad categories of water sources, that is households that met the minimum basic regulatory standard (Households with access to piped water not more than 200 metres away from their dwelling) of water access and those that do not. Households under the first category 'Piped Households' or 'Basic Access' are those with running tap-water in the dwelling, running tap-water on site and households with access to public taps. Households accessing from neighbours' tap, even though it is a tap system are, not included for most times the neighbours' tap are found to be more than 200 metres away [27]. All other sources of water are considered not to be to regulatory standards and therefore are referred to as 'Backlog' or 'No Access'.

The computations are presented in tables involving the consideration of the following elements: the existing number of households without services, changes in the number of households leading to additional demand and a calculation of the rate at which additional access is being provided. Yearly additional access is the difference between total access in the current year and total access of the previous year. Backlog is computed with the expression below, where the first two elements provide a figure for the historical element carried from previous years to which the current additional demand is added, from which the additional number having access can be subtracted. The current backlog, Backlog, is the result of the following: Carryover Backlog + Additional number of households−Additional number of households gaining access. The notational description is as follows; $B_t = (B_{t-1} + AD) - AC$, where B_t is the backlog for the current year/time, B_{t-1} is the carryover of historic backlog from the previous year, i.e. (current year−one year), AD is the additional demand for the current year from increase in households and AC is the additional access/connection for the current year.

7.1.1 Access at National Level

Using the Statistical Package for Social Sciences, SPSS, we compute household water access at the national level based on the two categories, i.e. Piped and Backlog as defined above. The results that are presented in Table 7.1 are derived from the SPSS output based on the analysis of data from national household surveys.

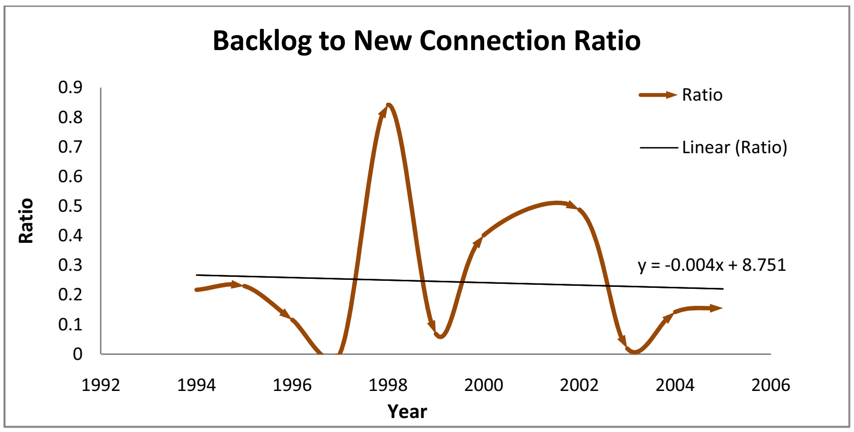
Table 7.1: Water Access at National Level

Year	**HH Total**	**Piped**	**Backlog**	**+Connections**	**Piped %**
1994	8,651,815	6,555,466	2,096,350	455,770	75.8
1995	8,802,344	7,011,235	1,791,109	412,562	79.7
1996	9,053,596	7,423,797	1,629,799	188,931	82.0
1997	9,301,283	7,612,728	1,688,555	7,470	81.8
1998	9,283,513	7,620,198	1,663,315	1,402,012	82.1
1999	10,798,643	9,022,209	1,776,434	121,671	83.5
2000	10,944,768	9,143,880	1,800,888	723,371	83.5
2002	11,780,379	9,867,251	1,913,128	933,890	83.8
2003	12,538,588	10,801,141	1,737,447	32,832	86.1
2004	12,624,143	10,833,973	1,790,170	254,756	85.8
2005	12,726,270	11,088,729	1,637,542	250,000	87.1

Source: Computed from Statics South Africa Household Surveys 94 - 05

In Table 7.1 we see that total households increased from 8.7 million in 1994 to about 12.7 million in 2005, i.e about a 46% increase. Households with access to piped water increased from 6.6 million in 1994 to 11 million in 2005, an increase of above 69% in percentage terms. This implies that all things being equal about 4 million additional connections were delivered over that period, but then these additional connections are against the 4.5 million additional demand or addition to backlog as a result of rapidly growing household numbers neglecting particular households that are formed and dissolved within the period as they cancel out. Column 5 (+Connection) in Table 7.1 shows what is supposed to an indicator of yearly delivery or additional connection on a yearly basis, i.e the difference between total households with piped water in the current year and total households with piped water in the following year. The yearly delivery data are very erratic and that illustrates clearly the difficulty of undertaking a year by year monitoring and evaluation of delivery of basic services in numeral terms. The last column in Table 7.1 shows the percentage of households with access to piped water. This increased from 75.8% in 1994 to 87.1% in 2005, which is a reasonable achievement over the period. On the other hand the backlog is still lingering at 1.6 million households.

Figure 7.1: Backlog to New Connection Ratio



Even though the data is erratic the trend line (95% confidence interval for x: -.0541329, 0456231) in Figure 7.1 shows that the new connection (i.e delivery) to backlog ratio has remained almost static throughout the period 1994 to 2005. That is why the backlog was still at about 1.6 million in 2005 despite the 4 million connections over the period.

With an average household size of about 3.7 in the series as data show the 1.6 million household backlog would translate to about 6 million persons. Therefore the mass actions/service delivery protests should not be surprising even though some of the indices are showing remarkable progress in delivery.

For simplicity we denote the time periods 1995 to 1999 and 1999 to 2005 as Phase I and Phase II respectively. We break the analysis down to these time periods, Phase I and Phase II.

Table 7.2: Changes in Households, Delivery & Backlog

Parameter	**Phase I**	**Phase II**
Average Annual Change in Backlog	-9	22,111
Average Annual Additional Demand	502,743	355,975
Average Annual Delivery	502,734	382,508

Source: Computed from Statistics South Africa Household Surveys 95, 99, 05

A deeper enquiry into the volume of delivery on a progressive annual basis in the phases reveals in Table 7.2 that the average annual additional access (Delivery) declined from 500,743 to about 355,975 from Phase I to Phase II. Annual additional demand also declined to almost the same measure between the Phases. Therefore the increasing percentage access does not really imply accelerated delivery in all the provinces, but could be as a result of changing household dynamics impacting upon additional demand over these Phases.

The critical issue is to investigate whether the Millennium Development Target could be reached first at national level and in the provinces if existing level of delivery is boosted and sustained. We also review if there are evidences of disparity and unevenness in terms of backlog situation and delivery among the provinces, establishing whether additional delivery is increasing or decreasing in provinces and the corresponding impact on backlogs. To do that one must make an analysis of delivery at provincial levels.

7.1.2 Access at Provincial Level

Here we investigate the provincial differences and the role of initial conditions of access on the delivery of water services among the provinces to establish whether the higher levels of delivery are in the provinces that had the highest existing level of access in 1994, in other words whether the lower levels of delivery are in the provinces that had the lowest existing level of access (low initial conditions).

In Tables 7.3-7.5 we present numerical records of total household numbers, households with access to piped water, backlog and percentage of households with access to piped water at provincial level for 1995, 1999 and 2005 respectively.

Tables 7.3 - 7.5: Water Access at Provincial Level 95/99/05

Province	**HH Total 1995**	**1995 Piped**	**1995 Backlog**	**% Piped**
Western Cape	960,450	915,842	44,608	95
Eastern Cape	1,244,999	701,598	543,401	56
Northern Cape	188,782	178,050	10,732	94
Free State	662,654	571,331	91,323	86
KwaZulu-Natal	1,575,726	1,031,198	544,528	65
North West	730,646	594,651	135,995	81
Gauteng	2,079,563	2,014,663	64,900	97
Mpumalanga	535,123	407,884	127,239	76
Limpopo	825,945	596,018	229,927	72

Source: Computed from Statistic South Africa Household Survey 95

Province	**HH Total 1999**	**1999 Piped**	**1999 Backlog**	**% Piped**
Western Cape	1,123,636	1,110,994	12,642	99
Eastern Cape	1,472,536	819,379	653,157	56
Northern Cape	237,375	221,544	15,831	93
Free State	764,588	731,304	33,284	96
KwaZulu-Natal	2,118,965	1,539,286	579,679	73
North West	889,434	772,266	117,168	87
Gauteng	2,345,070	2,319,299	25,771	99
Mpumalanga	736,102	652,597	83,505	89
Limpopo	1,127,119	855,537	271,582	76

Source: Computed from Statistics South African Household Survey 99

Province	HH Total 2005	2005 Piped	2005 Backlog	% Piped
Western Cape	1,283,775	1,261,052	22,723	98
Eastern Cape	1,731,898	1,132,238	599,660	65
Northern Cape	243,429	232,013	11,416	95
Free State	857,775	817,068	40,707	95
KwaZulu-Natal	2,456,962	1,950,712	506,250	79
North West	1,032,969	879,847	153,122	85
Gauteng	2,983,460	2,891,100	92,360	97
Mpumalanga	792,524	664,975	127,549	84
Limpopo	1,344,574	973,077	371,497	72

Source: Computed from Statistics South Africa Household Survey 2005

Backlogs can be seen from a number of perspectives. From one perspective the increased numbers represent the increase in the number of households, from another this could be the decline in operational water schemes in rural areas.

Tables 7.3-7.5 above show that over the period 1995 to 2005 the Eastern Cape is found to have the largest backlog, followed by KwaZulu-Natal and then Limpopo. What is clear is that the several provinces, such as Limpopo, the Eastern Cape and Gauteng have an increased backlog while the Free State, KwaZulu-Natal, and the Western Cape show a decline. In Table 7.6 the actual numerical changes over Phases I and II are presented.

Table 7.6: The Provincial Basic Water Backlogs Phases I & II

Province	**Ch I**	**Ch I %**	**Rank I**	**Ch II**	**Ch II %**	**Rank II**
Western Cape	-31,966	-71.7	4	10,081	79.7	5
Eastern Cape	109,756	20.2	9	-53,497	-8.2	2
Northern Cape	5,099	47.5	6	-4,415	-27.9	3
Free State	-58,039	-63.6	1	7,423	22.3	4
KwaZulu-Natal	35,151	6.5	7	-73,429	-12.7	1
North West	-18,827	-13.8	5	35,954	30.7	6
Gauteng	-39,129	-60.3	3	66,589	258.4	8
Mpumalanga	-43,734	-34.4	2	44,044	52.7	7
Limpopo	41,655	18.1	8	99,915	36.8	9

Source: Computed from Statistics South Africa Household Survey 95 - 05

In Phase I we observe from Table 7.6 (ranked by volume of change in backlog in descending order, where ChI and ChII represent changes in backlog in Phases I and II respectively) that backlog decreased in Western Cape by 71%, Free State by 63%, North West by 13%, Gauteng by 60% and Mpumalanga by 34%. Backlog increased in the other provinces with the highest increase of over 100,000 (20%) being in the Eastern Cape. We observe a different scenario in Phase II from Table 7.6. The provinces (Gauteng, Western Cape, Free State, Mpumalanga and North West) that manifested a decreasing trend in backlog in Phase I show increase in backlog in Phase II, while provinces like the Eastern Cape that reflected huge increases in backlog in Phase I show a decreasing backlog in Phase II.

We proceed in Table 7.7 by showing total delivery among the provinces in the two phases as a major indication of the efforts of the provinces towards eliminating the backlogs.

Table 7.7: The Provincial Level Additional Delivery Phases I & II

Province	**Ph I Total Del**	**Ph I Rank**	**Ph II Total Del**	**Ph II Rank**
Western Cape	195,152	5	150,058	4
Eastern Cape	42,893	9	312,859	3
Northern Cape	43,494	8	10,469	9
Free State	159,973	7	85,764	7
KwaZulu-Natal	393,254	1	526,260	2
North West	177,615	6	107,581	6
Gauteng	304,636	2	571,801	1
Mpumalanga	244,713	4	23,511	8
Limpopo	259,519	3	117,540	5
South Africa	1,821,249		1,905,843	

Source: Computed from Statistics South Africa Household Survey 95 - 05

For total additional delivery in Table 7.7 (ranked by volume of delivery, where Del I and Del II represent total delivery in Phases I and II respectively) dramatic changes in total delivery between Phase I and II could be noted in the Eastern Cape where delivery increased from 43,000 in Phase I to 313,000 in Phase II, delivery in Free State deceased from 160,000 in Phase I to 86,000 in Phase II while Mpumalanga was shown to have made a dramatic decrease in delivery from 245,000 in Phase I to 24,000 in Phase II. The national scenario looks fairly consistent increasing both in terms of percentage and absolute numbers 1.8 million (83%) in Phase I to 1.9 million (85%) in Phase II, but this could be misleading if it is inferred that all is well at the national level in terms of consistency of data and trends at the provincial levels.

Another approach towards the analysis would be to make an assumption that holds the total numbers numbers constant at 2005 assuming no additional demand.

Table 7.8: Number of Years to End Backlog Assuming No Increase in Households

Province	Average Yearly Del	2005 Backlog	End Backlog Yr
Western Cape	30,012	22,723	01
Eastern Cape	62,572	599,660	10
Northern Cape	2,094	11,416	05
Free State	17,153	40,707	02
KwaZulu-Natal	82,285	506,250	06
North West	21,516	153,122	07
Gauteng	114,360	92,360	01
Mpumalanga	2,476	127,549	52
Limpopo	23,508	371,497	16
South Africa	355,975	1,925,284	05

Source: Computed from Statistics South Africa Household Survey 95 - 05

Even on this unrealistic basis, as shown in Table 7.8, it takes Mpumalanga (which is not close to meeting the annual increase in households) up to 52 years to meet the demand posed by the historic backlog, Limpopo (which is also in a similar position) 16 years, and the Eastern Cape (which has annual access greater than the annual increase in households) 10 years. By way of comparison the Western Cape and Gauteng could end the backlog in a single year.

There is a considerable range of difference in the changes in the backlog at the provincial level. Although in the tables above it has been shown that there has been a substantial increase in delivery which in most provinces has approached meeting the increasing number of households in each province, this increased delivery has unexpectedly not made major inroads into the prior backlog.

7.1.3 Provincial Grouping

A suitable comparative analysis of water service delivery in the provinces would require fairly consistent data sets for each of the provinces.

In an effort to control for the inconsistency we employ a grouping system of provinces with similar characteristics. Though this does not entirely eliminate the inconsistency, it could give a better depiction of events between the Phases over time. We obtain three groups of the nine South African provinces; the grouping is with respect to their initial conditions and rate of basic water service delivery over time. This is to control for inconsistent data as explained above and also to reduce the problem of mismatching comparisons of provinces that started under very different circumstances in terms level of access, socioeconomic and political scenarii from 1994.

The Groups and Basis for the Grouping

Table 7.9: The provincial Groups

Group A	**Group B**	**Group C**
Gauteng	Northern Cape	Eastern Cape
Western Cape	North West	Mpumalanga
Free State	KwaZulu-Natal	Limpopo

Table 7.9 shows the provinces groups A, B and C with Group A consisting of Gauteng, Western Cape and the Free State. These provinces have similar initial conditions and are economically/technically more empowered to deliver, provinces in this group had recorded basic access above 95% at the starting period (1994/5). The intermediate Group B is made of Nothern Cape, North West and KwaZulu-Natal. KwaZulu-Natal had a remarkable lower initial percentage access than the two other provinces in this group, but it featured in this group based on progressive trend in delivery. The Group C is composed of Eastern Cape, Mpumalanga and Limpopo the least in the access ranking.

Apart from looking at backlogs and initial basic access levels and the trend over time, another important basis for the grouping is to look at provincial advances at the 'rudimentary level'. Here the rudimentary access as the next level of delivery is created to account for households which although did not fall into the basic service delivery category, but have access to some sort of water delivery which may not meet the basic service standards. This category helps to clarify who is served and at what level of service delivery, and also draws attention to community and individual self-help efforts towards service delivery to be represented in the delivery analysis. Under rudimentary access category are households whose main water source are Public tap more than 200 metres away from dwelling, neighbour's tap, Borehole (onsite or off site), Water-carrier/tanker, Dam/Pool and well. Studies [27, 56] have shown that majority of the households seemly transit from 'no access' category to 'rudimentary access' before getting into the 'basic access' category especially for the more rural provinces. For instance another reason why KwaZulu-Natal featured in group B is the trend reflecting that a good proportion of the households in the province witnessed a direct improvement from 'no access' in Phase I to 'basic access' in Phase II without having to pass through the Rudimentary stage implying better quality service delivery in KwaZulu-Natal than Eastern Cape, Limpopo and Mpumalanga.

Tables 7.10a-c below provide a summary of average annual delivery, average annual change in backlog and average annual change in household number for all the groups of provinces (A, B, C).

Table 7.10a: Delivery, Backlog & Access in Phases I & II, Group A

Parameter	Phase I (95-99)	Phase II (99-05)
Annual Del	164,940	161,525
Annual Change in Bklg	-32,284	16,819
Annual Change in HH	132,657	178,343
Piped HH	4,161,597	4,969,220
Total Households (HH)	4,233,294	5,125,010

Source: Computed from Statistics South Africa Household Survey 95 - 05

Table 7.10a for Group A provinces shows that during Phase I, i.e. 95-99, the initial base backlog was almost approaching elimination; implying that average annual delivery met annual additional demand and was enough to reduce gradually the initial base backlog. However, the second Phase manifests an annual increase in backlogs. The Table shows an average annual decrease in backlog at about 30,000 per annum during the first Phase. The second Phase (99-05) shows an annual increase in backlog of almost 17,000 households per annum. Annual additional connection could be seen to be almost steady at about 160,000 per annum while additional demand raised between Phases II and I from about 130,000 per annum to 180,000 per annum. This explains the rising backlog numbers during the second Phase.

Table 7.10b: Delivery, Backlog & Access in Phases I & II, Group B

Parameter	Phase I (95-99)	Phase II (99-05)
Annual Del	187,299	105,895
Annual Change in Bklg	5,356	-8,378
Annual Change in HH	187,655	97,517
Piped HH	2,533,096	3,062,572
Total Households (HH)	3,245,774	3,733,360

Source: Computed from Statistics South Africa Household Survey 95 - 05

In Table 7.10b Group B provinces show a different scenario; in Phase I the initial base backlog was rising at about 5,000 per annum while the second Phase manifests an annual decrease of 8,000 in backlog although annual additional connection was reduced from 180,000 during the first Phase to about 100,000 in the second Phase. The declining backlog here could be as a result of declining annual additional demand, which has considerably reduced from 190,000 during the first Phase to 100,000 in the second Phase.

Table 7.10c: Delivery, Backlog & Access in Phases I & II, Group C

Parameter	**Phase I (95-99)**	**Phase II(99-05)**
Annual Del	155,503	88,555
Annual Change in Bklg	26,919	18,092
Annual Change in HH	182,423	106,648
Piped HH	2,327,513	2,770,290
Total Households (HH)	3,335,757	3,868,996

Source: Computed from Statistics South Africa Household Survey 95 - 05

In Table 7.10c Group C provinces during Phase I witnessed a rising initial base backlog at about 27,000 per annum. The second Phase also manifests a rising trend in backlog although reduced to 18,000 per annum. Additional connections reduced from 155,000 per annum during the first Phase to about 90,000 during the second Phase. Although additional annual demand declined from 180,000 to 100,000 between the Phases, it did not have the desired effect on the backlog. This could be as a result of the inability of the Group C provinces to deal with the initial base backlog.

In general on a comparative basis the initial condition is most favorable to Group A provinces that started with a total backlog of 200,000 in 1995. This initial backlog was declining annually at 30,000 per annum during the first Phase. The Group A provinces have also been consistent with additional delivery at 160,000 per annum. These provinces have also witnessed a rising trend in additional demand, which could easily be attributed to in-migration as the results of the 2006 Community Survey show that Gauteng and the Western Cape are the most recipients of internal migrants in South Africa with migrants at 43% and 23% of the population respectively [79]. The Group C provinces started with the most unfavorable initial condition with a backlog of 900,000 in 1995. Although annual additional backlog decreased from 27,000 in 95 to 18,000 in 2005, this cannot be attributed to accelerated delivery, but could be due to out-migration to the Group A provinces as all the provinces in this group reflected above 20% of the population to have migrated from the provinces according to 2007 Community Survey [79].

It could be noted from the Tables 7.10a-c above that, although average annual delivery was almost stable for Group A for Phase I and II, annual delivery marginally decreased by 2%. On the other hand Groups B and C both show a remarkable decline of about 43% in average annual delivery from Phase I to Phase II. Backlog was declining annually in Phase I for Group A and we could notice an increasing backlog in Phase II for the same group. Also for Group A the annual change in household numbers increased from Phase I to II by about 34%. On the other hand Groups B and C show a decline in annual change in household number between Phases I and II.

Table 7.11 shows average percentage basic water access for all the groups of provinces across the period 1995 to 2005. Observe from the Table that for Group A the percentage access rose from 95 percent in 1995 to 98 percent in 1999 and maintained the percentage access at 98 percent till 2005.

Table 7.11: Percentage Access among the Groups in 1995, 1999 & 2005

Group	**95 Access %**	**99 Access %**	**05 Access %**
Group A	94	98	98
Group B	72	80	83
Group C	66	69	71

Source: Computed from Statistics South Africa Household Survey 95 - 05

The pattern of access could be noted where percentage access rose from the initial base of 94% in 1995 to 98% in 1999 and remained steady at 98% till 2005 irrespective of average annual delivery of over 160,000 in the Group A provinces. The inhibiting factor for reaching the 100% access mark could be in a good measure attributed to in-migration from the Group B and C provinces [41,79]. Tables 7.10b and 7.10c show that annual additions to household numbers have been on the decrease among the provinces in Groups B and C but on the increase for Group A. This implies that people could be out-migrating from B and C to Group A [79] and thus the resultant effect is the persistent backlog at about 2%.

For Group B we note in Table 7.11 the increase in percentage access from 72 percent in 1995 to 80 percent in 1999 and 83 percent in 2005. Although delivery slowed, percentage access is increasing at a remarkable rate as a result of decreasing additional household number over the years. This group of provinces could be attributed to be passing through the rapid rate of growth in percentage access. For Group C provinces Tables 7.10c and 7.11 show that they started the lowest at about 66% access in 1995. Although percentage access increased from 66% in 1995 to 69% in 1999 and to 71% in 2005, delivery declined most remarkably and additional household numbers also declined.

Table 7.12 is a summary of the ability of these provincial groups to respond to the general pressure of backlogs, initial/base backlogs and backlogs arising from annual additional households.

Table 7.12: Comparison of Total Delivery & Backlog for Phases I & II

Group	Total Bklg I	Total Del I	Total Bklg II	Total Del II
Group A	731,458	659,761	963,413	807,623
Group B	1,441,875	729,197	1,200,264	529,476
Group C	1,630,257	622,013	1,541,483	442,777

Source: Computed from Statistics South Africa Household Survey 95 - 05

Table 7.12 shows that Group A provinces responded by 90% to their backlog burden in Phase I and 84% in Phase II. Group B responded 51% and 44% in Phase I and Phase II respectively, while group C responded 38% in Phase I and was down to 29% in Phase II.

A notable inference from the numerical outcomes and graphics presented so far is the big question about capacity though there exists no generally accepted definition of capacity within the context of debates on sustainable development. Here capacity implies efficient process in realizing sustainable socio-economic development outcomes through efficient, economic and effective allocation of resources in the long term. In line with United Nations definition of capacity building as:

> *'the process by which individuals, organizations, institutions and societies develop abilities to perform functions, to solve problems and to set objectives'* [99].

An alternate manner to evaluate capacity and capacity building is to look actually at the numerical magnitude of delivery on a progressive comparative basis with time among the provincial groups. The Group A provinces could be noted to have made remarkable progress in terms of sustaining levels of delivery and even improving on delivery figures from 660,000 delivered in Phase I to 800,000 delivered in Phase II. However, Groups B and C show decline in delivery over the Phases where Group B was down from 700,000 to 500,00, Group C 600,000 to 400,000 in Phase I and Phase II respectively. This highlights issues and questions around capacity and capacity building in these provinces, i.e the ability of the provinces to a least sustain steady delivery thrust and gradually improve on it.

Remarkable and inconsistent variations on level of access and delivery over time could be noted when all the provinces are taken separately When the provinces are grouped according some matching criteria, the wide variations are spread and less fluctuation could be noted. Delivery slowed in Groups B and C from Phase I to Phase II (95 - 99 to 00 - 05), the Group A provinces maintained the delivery thrust between the phases and also had a marginal increase in delivery. While demographic factors like household fragmentation and internal migration could have played a contributing role to the access dynamics as we saw among the provincial groups other explanatory factors like corruption and the political dimensions should be investigated for their impact delivery dynamics.

A key concept historically in relation to social development in South Africa is the great regional and geographic divides which are evidence of past policies and separation of South Africa's peoples. The central question in current developmental strategy is the overcoming of these divisions through policies which elevate the poor and formerly disadvantaged areas; in short accelerating universal development by infrastructure and service delivery to narrow the divide. An outstanding remark in the evaluation process is the very diverse initial conditions of basic water access at the dawn of the new South Africa in 1994/95. We observe from the interplay of the political economy, demographic factors and capacity, i.e. the ability to sustain the delivery thrust.

The trend of water service connection showing declining tendency in the later years is only applicable to the provinces in Groups B and C. The Group A (Gauteng, Western Cape, Free State) provinces show evidence of sustainability of delivery levels and improvement on additional delivery from 660,000 in Phase I to 808,000 in Phase II.

7.1.4 Analysis based on the 1996 and 2001 Census

Here we present the dynamics of water service delivery based solely on the last two census, the 1996 census and the 2001 census. The census data remain the most inclusive data for indicators of the state of the nation. However, the long intercensal intervals do not allow for proper year to year, biannual and short-phase monitoring and evaluation of the dynamics of service delivery, changes in household structure and targets.

Table 7.13: Water Access and Backlog Based on 1996 Census

Province	**Total Piped**	**Backlog**	**Total Household**	**% Piped**
Eastern Cape	714,565	619,783	1,332,348	53.5
Free State	587,757	37,254	625,011	94.0
Gauteng	1,885,863	78,305	1,964,168	96.0
Kwazulu-Natal	1,100,416	560,518	1,660,934	66.3
Limpopo	359,209	623,248	982,457	36.6
Mpumalanga	496,660	107,350	604,010	82.2
Northern Cape	170,487	16,497	186,984	91.2
North West	586,755	133,888	720,643	81.4
Western Cape	951,917	31,098	983,015	96,8
South Africa	6,851,629	2,207,941	9,059,570	75.6

Source: Computed from 1996 South African Census

In Table 7.13 the 1996 census recorded about 7 (75%) million households out of a total of 9 million with access to piped water at national level. At provincial level it could be noted from Table 7.13 that the dynamics of access is quite diverse among the provinces. Provinces like the Western Cape, Gauteng and Free State recorded close to 100% access in 1996, while the likes of Limpopo and Eastern Cape recorded a percent access as low as 37% and 53% respectively in 1996.

Table 7.14: Water Access and Backlog Based on 2001 Census

Province	**Total Piped**	**Backlog**	**Total Household**	**% Piped**
Eastern Cape	944,311	568,353	1,512,664	62.4
Free State	701,652	31,650	733,302	95.7
Gauteng	2,584,397	66,847	2,651,244	97.5
Kwazulu-Natal	1,526,768	559,482	2,086,250	73.2
Limpopo	920,128	259,837	1,179,965	78.0
Mpumalanga	635,654	97,477	733,131	86.7
Northern Cape	199,792	7,050	206,842	96.6
North West	800,425	128,579	929,004	86.2
Western Cape	1,153,242	20,062	1,173,304	98.3
South Africa	9,466,369	1,739,337	11,205,706	84.5

Source: Computed from 2001 South African Census

Table 7.14 shows the record for access to water from the 2001. About 9.4 million households out of total recorded household 11.2 million households had access to piped water at national level. The percentage access improved from 75% in 1996 to 85% in 2001. At provincial level it could be noted from Table 7.14 that the wide gap in access between the top provinces and the provinces at the lower end of access narrowed significantly. In 2001 all provinces recorded percentage access above 60%.

Instances of discrepancy between the survey data-sets and the census data sets could easily be noted. At national level higher percentage access in the pre-96 survey data than 1996 census percentage access are reported in Tables 7.1 and 7.13. For a specific instance at the national level in Table 7.1 percentage access from the 1996 October Household Survey is shown to be 82% while the census figure for the same year in Table 7.13 is shown to be 75%. This could be attributed to the fact that the earlier October Household Surveys done before the 1996 census results used the 1991 census as the base and the 1991 census did not include Transkei, Venda, Bophuthatswana, and Ciskei (the so-called TBVC states) and their size had to be estimated and added later. Household surveys after the 1996 census used 1996 population census as base and so surveys after 2001 census used 2001 census as the base. Therefore the precensus 96 and postcensus 96 survey data are not strictly comparable in the series, and that is why we have dealt with the census data separately to see what information we could extract.

Table 7.15: Delivery Between 1996 and 2001

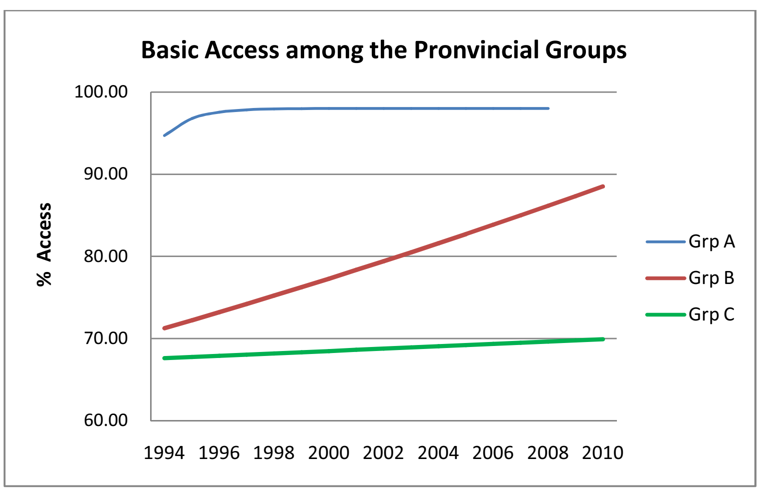
Province	**Delivery Total**	**Annual Average**
Eastern Cape	231,746	46,349
Free State	113,895	22,779
Gauteng	698,534	139,707
KwaZulu Natal	426,352	85,270
Limpopo	560,919	112,184
Mpumalanga	138,994	27,799
Northern Cape	29,305	5,861
North West	213,670	42,734
Western Cape	201,325	40,265
South Africa	2,614,740	522,948

Source: Computed from 1996 & 2001 South African Census

In Table 7.15 we show the delivery implications of the intercensal periods 1996 to 2001 based on records of water access as reported in Tables 7.13 and 7.14 above. The column 'Total Delivery' shows the total volume of new connections of piped water to households between 1996 and 2001. The 'Annual Average' column shows the yearly connection average over the five-year period. Although there is the natural tendency for yearly delivery output to improve with time with improvement in capacity, the annual average could shed some light of the performance of provinces.

Our enquiry into the dynamics of change in numbers of households and the interaction with demand and access rates of the provincial groups shows that in the provinces, where the existing service base is low and there is a relatively high level of out-migration leading to a decrease in household numbers, the annual rate of delivery is lower than in other areas and the percentage access rises marginally. In the provinces, where the existing service base is higher and there is a relatively lower level of out-migration, there is marginal change in household numbers and the annual rate of delivery is faster and the percentage access rises remarkably. In the provinces with most favorable initial conditions, i.e. where the existing service base is the highest, there is a remarkable change in household numbers possibly as a result of in-migration and the annual rate of delivery has remained at least stable over the Phases, percentage access rises at an early stage and remains stable at the limiting value as shown in Figure 7.2.

Figure 7.2: % Access Trend among the Provincial Groups



$$A_t = \frac{K}{1 + (K/A_0 - 1)\exp(-r_0 t)}. \tag{7.1}$$

$$B(t) = B_0 e^{rt}. \tag{7.2}$$

$$C(t) = C_0 + bt. \tag{7.3}$$

The proportion of households with basic access for the provincial group A could be described using the logistic model as in (7.1). Available data show that Group A had completed the movement on the logistic line having reached the limiting steady state at 98%. Group B could be attributed to the rapid advancement stage following an exponential function (7.2). The model predicts that all things being equal the Group B provinces could achieve 100% access in about 2019 at the current delivery rate and demographic change. A boost in delivery could make a huge difference in approaching 100% access as these provinces are favored by the out-migration. We observed the Group C provinces to be at the slow stage of growth following linear model (7.3), though these provinces are also favoured by out-migration; lack of capacity is a major issue of concern and delivery dropped quite remarkably.

The Group A provinces only need a little boost in delivery and maximum capacity of utilization to overcome their current limiting tendency to achieve 100% access in a year or two through strategic planning and good understanding of impact of the demographic factors.

In the next Chapter we present a least squares model of demand for piped water based on some sociodemographic parameters, where the dynamic headship model in Chapter Six provides the input data for the headship rate variable and the household projection data provides the imputation data for the computed annual additional demand for piped water.

Chapter 8

Sociodemographic Influences on Demand & Access to Piped Water

We present an investigation of the interaction of demographic parameters and their impact on demand for piped water connection in South Africa. From the previous chapters it is easily notable that a considerable number of households are persistently lacking basic services, possibly to a large extent due to rapidly increasing number of households even though service delivery seems to have been accelerated in the recent past in some provinces, the implementation has not been rapid enough to counter the demands as a result of the growing numbers of households. Also being mindful of the fact that issues around budgetary constraints that limit overall delivery and local factors such as differing levels of implementation by provinces, corruption and varying managerial capacity could contribute to the problem.

8.1 Demand & Access Modelling Approach

8.1.1 The Multiple Regression Model for Demand

For this analysis we would require consistent historical data on trend in household numbers, fertility, mortality, emigration and immigration. For the household numbers we use the national household survey data from the October Household Surveys to the later General Household Surveys from Statistics South Africa. Noting that the data from these surveys are inconsistent, we employ the results obtained from the household model (7.3) (partial differential equation) as imputation data for substituting outliers. From the obtained consistent household numbers and mid-year population estimates, yearly additional demand and average household size are computed. The fertility and mortality data are obtained from mid-year population estimates from Statistics South Africa and the U.S Census Bureau [79, 87]. From these data sets we compute estimates for Natural Increase in the population for South Africa. The Net-migration data was obtained entirely from the U.S Census Bureau [87] because there is a general lack of quality migration data from local sources in the developing countries.

Fitting the Least Squares Model

In Table 8.1 we present the input variables and data for the SPSS regression analysis.

Table 8.1: Variables and Data for the Least Square Model

Year	Ad Demand	NI	NM	HH Size	H Rate
1996	393,522	687,000	-193,000	4.6000	0.2232
1995	410,616	655,000	-29,000	4.3793	0.2283
1998	428,452	612,000	-22,000	4.2811	0.2336
1999	447,063	560,000	-23,000	4.1852	0.2389
2000	466,482	500,000	37,000	4.0914	0.2444
2001	486,745	438,000	49,000	3.9997	0.2500
2002	507,888	373,000	143,000	3.8550	0.2594
2003	529,949	310,000	155,000	3.8406	0.2604
2004	552,969	257,000	214,000	3.8316	0.2610
2005	576,989	224,000	210,000	3.8278	0.2612
2006	602,052	106,000	247,000	3.8283	0.2612
2007	628,203	187,000	240,000	3.8333	0.2609
2008	655,491	161,000	243,000	3.8399	0.2604

In Table 8.1 **Ad Demand** represents estimates for annual additional demand for connection, **NI** represents estimates for natural increase in the population (the difference between total births and total mortality), **NM** represents estimates for net migration (the difference between immigration and emigration), **HH Size** represents average household size and **H Rate** represents the headship rates. It is notable that most of the variables in Table 8.1 are in the scale of hundreds of thousand therefore some transformation need to be done to reduce the data to a manageable scale for the SPSS regression model.

Table 8.2: Log Transformed Variables and Data for the Least Squares Model

Year	*log***Ad_Demand**	*log***NI**	*log***NM**	**HH_frag**
1996	5.5950	5.8370	3.8451	0.04853
1995	5.6134	5.8162	5.2330	0.05214
1998	5.6319	5.7868	5.2504	0.05456
1999	5.6504	5.7482	5.2480	0.05709
2000	5.6688	5.6990	5.3747	0.05974
2001	5.6873	5.6415	5.3962	0.06251
2002	5.7058	5.5717	5.5353	0.06729
2003	5.7242	5.4914	5.5502	0.06780
2004	5.7427	5.4099	5.6170	0.06811
2005	5.7612	5.3502	5.6128	0.06825
2006	5.7796	5.0253	5.6503	0.06823
2007	5.7981	5.2718	5.6435	0.06805
2008	5.8166	5.2068	5.6464	0.06782

In Table 8.2 the data is reduced to a manageable scale for ease of computation and also to improve the normal spread of the data as a basic assumption of the regression model, we do a log transformation of the affected variables controlled for inconsistency. We also create an additional variable (**HH_frag**) out of the variables representing household size and headship rates. The quotient of these two variables forms the additional variable which is an interaction variable that gives an indication of the influence of household fragmentation on demand for connection in the light of rapidly growing numbers of households. It could be noted from Table 8.1 that some of the values for net-migration have negative values, a constant figure of 200,000 was added to each value in the series to control for the negative values before the log transform.

In the regression equation the variable log**Ad_Demand** for additional demand is the dependent variable while the three other variables(log**NI,** log**NM & HH_frag**) for natural increase, net-migration and household fragmentation respectively are the predictors for demand.

The standard least squares model is given as

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + ... + \beta_k x_{ki} + \epsilon_i, \quad (8.1)$$

where y_i represent the response variable, the βs represent the coefficients for the predicting variables the x_i, while ϵ represents an error term [78]. Ultimately we want to build a model for y with the line of best fit, i.e. of least (squared) residual between observed values and predicted values. In our case the regression equation would be

$$Ad\_Demand = \beta_0 + \beta \log NI + \beta \log NM + \beta HH\_frag + \epsilon_i. \quad (8.2)$$

Here the paramount issue would be in addition to the predictive aspect of the model the qualitative observation of the effects of the components of the drivers of population change on demand for services, that is the measure of the influence of natural increase and net-migration on the trend in demand for piped-water connection and of course the contribution of fragmentation of households.

Table 8.3: SPSS Output Results for the Multiple Regression Model

Variables	**Coefficients**	β	**Sig**(α)
Constants	6.215	22.537	0.000
Natural Increase	-0.145	-4.043	0.003
Net Migration	0.007	0.443	0.668
Fragmentation	4.272	2.608	0.028

From the above results in Table 8.3 we observe that the partial regression coefficients were statistically significant for both Natural Increase ($\beta =$ -.148, $t_{268} =$ -4.043, $p <$ .05) and Household Fragmentation ($\beta =$ 4.272, $t_{268} =$ 2.608, $p <$ .05), however, that negative value for the coefficient for natural increase and the negative partial correlation coefficient (-.947) indicate an inverse relationship between the natural increase in the population of South Africa and the annual additional demand for water connection. The partial regression coefficient for Net Migration ($\beta = .007$ & $p > .05$) indicates no statistically partial regression with annual additional demand. The overall goodness of fit statistic ($R^2 = 0.954$, standard error of estimate = 0.017) indicate that the partial combination of the control variables in the model explains to a satisfactory measure the variability in annual additional demand up to about 95%.

These outputs indicate that the main driver of the rapidly increasing trend in the demand for piped-water connection could be household fragmentation. Even though net-migration is statistically insignificant, one cannot rule out the influence of emigrants especially from the neighboring Southern African countries in the light of the xenophobic tensions of the recent past where competition between locals and foreigners for basic services could be inferred as one of the possible causes of the tension.

8.1.2 Logistic Regression Model of Access Profile

We seek to obtain a binary logistic model of the odds in favour or against households having access to basic water connection in South Africa under the combined interaction of different factors such as the population group of the household, type of dwelling occupied by the household, household income and the province where the household is located.

The logistic probability model is given by

$$prob(event) = \frac{e^{B_0+B_1x_1+B_2x_2+...B_nx_n}}{1+e^{B_0+B_1x_1+B_2x_2+...B_nx_n}}. \tag{8.3}$$

Simplifying (8.3) and setting $z = B_0 + B_1x_1 + B_2x_2 + ...B_nx_n$ as the linear combination of the model independent variable(s) coefficient(s)

B and their respective values we obtain [78]

$$prob(event) = \frac{1}{1 + e^{-z}}. \tag{8.4}$$

This model yields values for the probability that are between 0 and 1 as required [78].

Here our dependent variable is whether a household has basic access or not recoded into binary a variable from the 2005 General Household data with values 1 for basic access and 0 for no access. The control variables are Race, recoded as a categorical variable with values 1 = African, 2 = Coloured, 3 = Indian, and 4 = White. The variable Dwelling was recoded as ordinal with values 1 for formal dwelling and 0 for informal dwelling. The variable Income is recoded as ordinal with 6 income groups in order from 1 to 6 where 1 represents the poorest household with income $R0$ - $R400$ in a month and 6 represents the richest group with income above $R10,000$ a month. The variable Province for the 9 provinces is categorical listed as follows according to the Statistics South Africa listing (1 Western Cape, 2 Eastern Cape, 3 Northern Cape, 4 Free State, 5 KwaZulu-Natal, 6 North West, 7 Gauteng, 8 Mpumalanga, 9 Limpopo).

SPSS Output Results for the Logistic Regression Model

Table 8.4 **Variables in the Equation**

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1(a)	IncomeCat	.316	.001	91180	1	.000	1.371
	Dwelling1	.911	.002	232571	1	.000	2.486
	prov			743093	8	.000	
	prov(1)	2.795	.008	115793	1	.000	16.371
	prov(2)	-.103	.003	1421	1	.000	.902
	prov(3)	1.577	.010	24180	1	.000	4.841
	prov(4)	2.152	.006	150357	1	.000	8.601
	prov(5)	.459	.003	28802	1	.000	1.582
	prov(6)	.828	.003	56261	1	.000	2.290
	prov(7)	2.514	.004	383975	1	.000	12.351
	prov(8)	.688	.004	33896	1	.000	1.991
	prov(9)	.567	.012	32367	1	.000	1.867
	Race			50631	4	.000	
	Race(1)	-.841	.046	329	1	.000	.431
	Race(2)	.287	.047	37	1	.000	1.332
	Race(3)	1.125	.048	539	1	.000	3.081
	Race(4)	-.220	.047	22	1	.000	.803
	Constant	.425	.046	83	1	.000	1.530

a Variable(s) entered on step 1: IncomeCat, Dwelling1, prov, Race.

In Table 8.4 we note that the B coefficients of all the control variables are statistically significant ($p<0.01$). Our interest is to ascertain what factors amongst the control act in favour or against the chances of particular households of being connected. A look at the variable Income for instances shows that Income has the B coefficient 0.316, the odd ratio (Exp(B)) for Income is 1.371. This implies that the odds in favour of any household being connected increases by about 1.4 with one step into a higher income group. Dwelling type has odd ratio 2.486, meaning that households with formal dwelling has odds in favour of being connected at about 2.5 more that households with informal dwellings.

The variable province shows some interesting highlights reflecting that the location of households is major deciding factor as to whether households are connected or not assuming all other variables are constant. The prov(1) the Western Cape for instance could be observed with the highest odd ratio. That is the odds in favour of being connected increases to about 16.4 times if the household is located in the Western Cape, this is seconded by prov(7) Gauteng with the odd ratio of 12.35. Eastern Cape is the province where household have the least likelihood of being connected the with the negative B coefficient the odds are actually against households in the Eastern Cape being served, however, with the odd ratio for the Eastern Cape at .902, i.e. a value close to unity implies that being in the Eastern Cape does not actually increase or decrease the odds of households being served.

On the basis of race, one could observe that the Indian households (coded 3) have the greatest odds in favour of being connected. On this basis the odds are against the African households of being connected with the negative B coefficient and an odd ratio of less than one. The negative coefficient for the White household should also imply that the odds are relatively against them of being connected, but we also note that the odd ratio for the White is close to one therefore on the basis of race the White community have no odds in favour or against them of being connected against the common expectation they would be most favoured. The growing number of poor-White households moving into informal settlements in South Africa could have contributed to this [66].

The Nagelkerke R^2 statistic which is the measure of goodness of fit of logistic regression model has a value of about 0.30. This implies that the partial combination of the control variables in the model was only about to explain about 30% of variability in the likelihood of households being connected based on these sociodemographic factors. Therefore other explanatory factors should be explored to fully investigate explanatory inhibiting factors that influence access to basic water in South Africa.

Chapter 9

Summary of Results & Conclusion

In this Thesis we used qualitative and quantitative tools to study the interaction of social parameters in relation to household demand and access to basic water services in South Africa. The particular case of the supply of water is but one of a number of subjects to which the procedures of mathematical and statistical modelling may be applied to describe the present situation from a given past initial time and to make forecasts for the future. An aspect of the study was the consideration of public strategies to overcome the backlogs which have emerged as a result of a dramatic change in the structure of households in South Africa. Most of the findings/results are in tabular and graphical forms for easy understanding of the reader and efforts were made to present the mathematical aspects in the simplest manner due to the intended multidisciplinary audience.

9.1 Review of the Chapters

In Chapter One we provided the motivation and overview of the research problem highlighting the aims and objectives of the project.

Chapter Two illustrated the justifications for a quantitative study of water delivery, supply and access in South Africa. These are presented within the context of different themes such as impact of climate change on fresh water resources, the correlation of lack of access to portable water and human poverty, basic access to piped-water as a basic human right and access to piped-water as one of the targets of millennium development goals of the United Nations. The Chapter also presents the setting of water service delivery in South Africa.

Chapter Three gave a review of literature on some of the studies involving quantitative evaluation of service delivery in South Africa in the post-apartheid era. The Chapter draws attention to the issues around various service delivery promises to the people of South Africa and some attempts/methodologies by scholars towards evaluating progress on the promises. The indicates that the lack of reliable data is a major constraint to such studies and the contribution of this study towards filling gaps that are observed. Chapter Two also reflected on the state of official statistics in the developing world in general and in South Africa in particular and gives a brief historiography of census and official data in South Africa.

The Fourth Chapter gave an overview of household structure in South Africa, providing the scientific definition of a 'Household'. The Chapter also makes the case for more studies on quantitative evaluation of the trend in household formation and dissolution in South Africa within the context of the relationship towards household-based services. The Chapter also highlighted that changing patterns of household structure in South Africa.

The Fifth Chapter reflected on the benefits of the mathematical approach to the problem of estimating and projecting population and household numbers and the mathematical foundation for the study through a review of classical mathematical theories of population-growth processes. The Chapter also compares results of projection models of South African population with demographic methods and the classical mathematical models of populations. The findings show that with sound assumptions and care mathematical models could yield results that are comparable to the demographic models.

In Chapter Six we implemented a dynamic household-headship model for South Africa based on a partial differential equation. We numerically integrated the solution using it to estimate and project South African household numbers. We use the result as imputation data for least squares interaction model. The results of the dynamic model was compared with the household model of the Bureau for Marketing Research at the University of South Africa. The comparison shows some level of harmony between the two models.

In Chapter Seven we present a comprehensive review of the current scenario of water service access and demand with a thorough review of official data from the national household survey data from 1995 to 2006, the 1996 and 2001 census data. The case of access of water in South African households is the major indicator. Here we also highlight the position of South Africa in its ability to meet the millennium development goals and even at the local level the presidential targets in the water sector. We also highlight some instances of shortcomings of the data sets. The findings show that in the provinces, where the existing service base is low and there is a relatively high level of out-migration leading to a decrease in household numbers, the annual rate of delivery is lower than in other areas and the percentage access rises marginally. In the provinces, where the existing service base is higher and there is a relatively lower level of out-migration, there is marginal change in household numbers and the annual rate of delivery is faster and the percentage access rises remarkably. In the provinces with most favorable initial conditions, i.e. where the existing service base is the highest, there is a remarkable change in household numbers possibly as a result of in-migration and the annual rate of delivery is quite sustainable, percentage access rises at an early stage and remains stable at the limiting value.

In Chapter Eight we investigated the interaction of demographic parameters and their impact on increasing household demand for piped water connection in South Africa using SPSS regression analysis. The Chapter also reflects upon the profile of access of households on the basis of odds in favour or against households of being served using SPSS logistic regression analysis. The Chapters manifests that the increasing demand in household-based services in South Africa is to a greater measure attributable to the fragmentation of households, fragmentation contributes more to this phenomenon than the main components of population change, i.e, net-migration and natural increase.

9.2 Summary of Key Findings & Conclusions

In general we attempted to evaluate the process of attaining universal access to basic services in the post-1994 era. An outstanding remark in the evaluation process is the very diverse initial conditions of access to basic water services at the dawn of the New South Africa in 1994/95. We observe from the interplay of the political economy, demographic factors and capacity, i.e. the ability to sustain the delivery thrust that the trend of delivery of water services showing declining tendency in the later years is only applicable to the provinces in Groups B and C. The Group A provinces show evidence of sustainability of delivery levels and improvement on additional delivery from 660,000 in Phase I to 808,000 in Phase II.

Our enquiry on the dynamics of change in numbers of households and the interaction with demand and access rates of the provincial groups shows that, where the existing service base is low and there is a relatively high level of out-migration leading to decrease in household numbers, in these provinces the annual rate of delivery is lower than in other areas and the percentage access rises marginally.

In the provinces, where the existing service base is higher and there is a relatively lower level of emigration, there is a marginal change in household numbers, the annual rate of delivery is faster and the percentage access rises remarkably.

In the provinces with the most favorable initial conditions, i.e. those in which the existing service base is the highest, there is remarkable change in household numbers as a result of immigration and the annual rate of delivery is quite sustainable, percentage access rises at an early stage and remains stable at the limiting value.

Our attempt towards fitting percentage access growth in the provinces show that the provinces in Group A has completed the movement on the logistic line having reached the limiting steady state. Group B could be assigned to the rapid advancement stage. The model predicts that, all things being equal, the Group B provinces could achieve 100 percent access in about 2015 at the current rate of delivery and demographic change. A boost in delivery could make huge difference in approaching 100 percent access as these provinces are favored by out-migration. We observed the Group C provinces to be at the slow stage of growth though these provinces are also favored by out-migration; lack of capacity is a major issue of concern and delivery dropped quite remarkably. The Group A provinces only need a little boost in delivery and utilization at maximum capacity to overcome their current limiting tendency to achieve 100 percent access in a year or two through strategic planning and good understanding of impact of demographic factors.

Our model of the interaction of demographic parameters and their impact on increasing demand for household-based services suggests the fragmentation of household could be the main driver of the rapid increasing trend in demand for water connection. The model manifests that fragmentation contributes to this trend much more than natural increase in the population and net-migration.

A major difficulty for this project is the poor quality of historical data. The situation necessitated building mathematical models that could be used to estimate and project some demographic variables needed for some aspects of the study. To this we implemented a dynamic household-headship model for estimating and projecting South African households. The dynamic nature of the model implies the model's ability to capture some of the changes in household structure over the projecting period against static models that are built based on a fixed average value of some of the parameters like household size as we saw with the modeling approach presented by Van Aardt [85]. The results manifest some level of agreement between our model and that of Van Aardt (BMR) especially at the early stages. However, some remarkable discrepancies are notable as time approache the end of the projecting period.

Generally the near future is not alarming. Out-migration would seemly reduce the backlog pressure on the weaker provinces so that targets could be achieved not too far from target dates but not without a boost to current rates of delivery. However, there will increasingly be continued pressure on the Group A provinces as a result of unaccounted in-migration from both internal and international sources.

9.3 Limitations of the Study & Recommendations

A major weakness of this study and the models is the general assumption that the new or fragmenting households automatically need state intervention for connection to water services, therefore classifying all new households into backlogs category. We would therefore recommend for further studies a survey that would establish the proportion of fragmenting households that require state assistance for water connection. Thus a modelling approach that would build models considering that not all new households would automatically be classified into the backlog category.

The majority of the analysis on this study was entirely based on secondary research approach using secondary data-sets for the analysis. This is another limitation of the study as the researcher is left without first-hand and on-the-site assessment of some of the information on the data-sets. To this we recommend a follow-up research that would include strategies for the researcher/s to have some field and first-hand enquiry of the conditions of household access to basic services in key areas and to relate their findings to the information on the larger official and secondary data-sets. This would help the investigators to be more in touch with the reality on the ground thereby making better inferential interpretation of results from the data-sets.

In our attempt to fit the likelihood of households being served through the use of the logistic model, the goodness of fit of the model showed that our model only explains about 30% variability in the response variable i.e the probability of a household being connected. We would therefore recommend for further examination an approach that would introduce other explanatory variables that could possibly explore other aspects like the political dimensions of the problem thereby building a more complete model with improved goodness of fit.

There are some highlights on this study which suggest the possibility that in-migration into the group A provinces could be a major contributing factor towards the inhibition of households in these provinces to attain 100% access to basic water and rapid household growth in these provinces. It is critical to ascertain what proportion of the in-migrants are permanent and the proportion that are temporary economically induced 'Moves'. We therefore recommend for further studies a survey and study that would build models factoring the dynamics of internal circular migration in South Africa with some indication of who have migrated permanently and who are potential temporary in or out-migrants. The would also help in the estimation and control for possible doubly counted households/ers during the national surveys.

We advocate for a continual improvement strategy on the part of the official statistics providers (Statistics South Africa) for the estimates and projection of household numbers in South Africa. To this we call for the mid-year household estimates to be published on a yearly basis along side the mid-year population estimates, as the estimates would get better in time. This would provide the necessary benchmark that could be useful for the benchmarking of household-level data for the general household surveys.

The general results imply that in as much service delivery programmes and policies should focus on the formerly disadvantaged poor and rural communities, adequate provisions should also be made for the surge of in-migrants into the urban areas. The relative high population base of the urban areas accounts for low percentage scores in reporting lack of access to basic service in urban areas. In reality however, the low percentage scores translate to considerable high number of people without basic services in urban and this could be a contributing factor to the high service delivery protests around the urban and peri-urban centres.

Bibliography

[1] Abell M L and Braselton J P (1997). *Differential Equations with Mathematica*, London: Academic Press.

[2] Abia L M, Angulo J C and Lopez M (2003). *Numerical Solution of Structured Population Models*. Valladolid: Department of Mathematics, University of Valladolid.

[3] Actuarial Society of South Africa (2006). *South African Demographic Datasets based on ASSA HIV Model*, accessed from http://www.assa.org.za/aids/content.asp?id=1000000001.

[4] Amoateng A Y and Richter L M (2007). *Social and Economic Context of Families and Households in South Africa*; in Amoateng A Y and Heaton T B (eds), Families and Households in Post-apartheid South Africa: Socio-demographic Perspectives. Pretoria: HSRC.

[5] Anatol R (1957). *Contributions to the Theory of Random and Biased Nets*, Bulletin of Mathematical Biophysics, 19: 257-277.

[6] Berger J (2000). *Theory and Formalization: Some Reflections on Experience*, Sociological Theory, **18**(3): 821-835.

[7] Berlin T H and Kac M (1952). *The Spherical Model of a Ferromagnet*, Physical Review, **86**: 821-835.

[8] Berry J and Houston K (1995). *Mathematical Modelling*, London: Edward Arnold.

[9] Bhorat H and Kanbur R (2005). *Poverty and Well-being in Post-Apartheid South Africa: An Overview of Data, Outcomes and Policy*, Cape Town: Development Policy Research Unit, University of Cape Town.

[10] Bhorat H, Poswell L and Naidoo P (2004). *Dimensions of Poverty in Post-Apartheid South Africa 1996 - 2001*, Cape Town: Development Policy Research Unit, University of Cape Town.

[11] Bhorat H, van der Westhuizen C and Goga S (2008). *Welfare Shifts in the Post-Apartheid South Africa: A Comprehensive Measurement of Changes* , Cape Town: Development Policy Research Unit, University of Cape Town.

[12] Bhorat H, van der Westhuizen C and Naidoo P (2008). *Shifts in Non-Income Welfare in South Africa: 1993 - 2004*, Cape Town: Development Policy Research Unit, University of Cape Town.

[13] Bongaart J (2001). *Household Size and Composition in the Developing World in the 1990s*, Population Studies, **55**: 263-279.

[14] Borrelli R L and Coleman C S (1987). *Differential Equations: A Modeling Approach*, New Jersey: Prentice-Hall.

[15] Burghes D N and Borrie M S (1981). *Modelling with Differential Equations*, Chichester: Ellis Horwood.

[16] Castley D and Lury D (1980). *Data Collection in Developing Countries*, Oxford: Oxford University Press.

[17] Coleman J S (1964). *An Introduction to Mathematical Sociology*, New York: Free Press.

[18] Cohen J E (1995). *How Many People can the Earth Support?*, New York: W W Norton.

[19] Cross C (2001). *Why does South Africa need a Spatial Policy? Population Migration Infrastructure and Development*, Journal of Contemporary African Studies, **19**(1): 111-128.

[20] Dandekar H C (1997). *Changing Migration Strategies in Deccan Maharashtra, India, 1885-1990. Cities in the Developing World: Issues, Theory and Policy*, Oxford: Oxford University Press.

[21] Development Policy Research Unit (2005). *Internal Migration to the Gauteng Province*, DPRU Policy Brief Series, Cape Town: University of Cape Town.

[22] Dorwin C and Frank H (1956). *Structural Balance: A Generalization of Heider's Theory*, Psychological Review 63:277-293.

[23] Dorrington R, Johnson L, Bradshaw D and Daniel T (2006). The Demographic Impact of HIV/AIDS in South Africa: National and Provincial Indicators for 2006, Cape Town: Actuarial Society of South Africa.

[24] DWAF(2004). *A History of First Decade of Water Service Delivery in South Africa 1994 to 2004*, Pretoria: Department of Water Afairs and Forestry.

[25] Encyclopaedia: The Free Dictionary. *Mathematical models*, accessed from http:encyclopedia.the-free-dictionary.com/model, (12-7-2004).

[26] Haarmann C (2000). *Social Assistance in South Africa: Its Potential Impact on Poverty*, PhD Thesis, Cape Town: Institute for Social Development, University of the Western Cape.

[27] Hemson D, Dube B, Mbele T, Ngcobo D and Nnadozie R (2006). *Still Paying the Price: Revisiting the Cholera Epidemic of 2000-1 in South Africa*, Pretoria: Human Sciences Research Council.

[28] Hemson D and Galvin M (2006). *Water Service Rights in Laws, Conventions, and Policies in South Africa*, Pretoria: Human Sciences Research Council.

[29] Hemson D and O'Donavan M (2006). *Putting the Numbers to the Scorecard: Presidential Targets and the State of Delivery*; in Sakhela Buhlungu, John Daniel, Roger Southall and Jessica Lutchman (eds), State of the Nation: South Africa, 2005-2006. Pretoria: Human Sciences Research Council; 11-45.

[30] Hinrichsen D and Tacio H (2002). *The Coming Freshwater Crisis is Already Here*, accessed from, www.wilsoncenter.org/topics.

[31] Hirschowitz R (2001). *Methodology for Census 2001 South Africa: Applying the Lessons Learnt from Census 1996*, Pretoria: Statistics South Africa.

[32] Hollmann F W, Muller T J and Kallon E J (2008). *Details of the Cohort-Component Method*, Population Division, Working Paper No 38, Washington, DC: US Census Bureau.

[33] James C S (1964). *An Introduction to Mathematical Sociology*, London: Free Press.

[34] Joseph A and Mcfalls J (2003). *Population: A lively introduction*, Population Bulletin, **58**(4): 10-14.

[35] Kermack W O and McKendrick A G 1927. *Contributions to the mathematical theory of epidemics*, Proceedings of the Royal Society of London, **A 155**: 700-721.

[36] Keyfitz N (1985). *Applied Mathematical Demography*. New York: Springer-Verlag.

[37] Khalfani A K and Zuberi T (2001). *Racial Classification and Modern Census in South Africa*, Race and Society, (4): 161-176.

[38] Khalfani A K, Zuberi T, Sulaiman B and Lehohla P J (2005). *Population Statistics*; in Tufuku Zuberi, Amson Sibanda and Eric Udjo (eds), The Demography of South Africa. New York: M.E Sharpe.

[39] Kibirige J (1997). *Population Growth, Poverty and Health*, Social and Medicine, **45**: 247-259.

[40] Kline M (1985). *Mathematics for the Nonmathematician*, New York: Dover.

[41] Kok P, O'Donavan M, Bouare O and van Zyl J (2003). *Post-Apartheid Patterns of Internal Migration in South Africa*, Pretoria: Human Sciences Research Council.

[42] Land K C, Yang Y and Yi Z (2006). *Mathematical Demography*, New York: Springer.

[43] Leach P G L and Andriopoulos K (2004). *An Ocillatory Population Model*, Chaos, Solitons and Fractals, **22**: 1183-1188.

[44] Livernash R and Rodenburg E (1998). *Population Change, Resource and Environment*, Population Bulletin **54**(1): 2-41.

[45] Ljung L and Glad T (1994). *Modelling of Dynamic Systems*, New Jersey: Prentice Hall.

[46] Maharaj A and Leach P G L (2005). *Some Mathematical Aspects of Competing Species*. Durban: School of Mathematical Sciences, University of KwaZulu-Natal.

[47] Maharaj A (2006). *Singularity and Symmetry Analysis of Models arising in Populations*, Dissertation, Durban: School of Mathematical Sciences, University of KwaZulu-Natal.

[48] Malthus T R (1970). *An Essay on the Principle of Population*, Harmondsworth: Penguin.

[49] May R M and Leonard W J (1975). *Nonlinear aspects of competition between three species*. SIAM Journal of Applied Mathematics, **29**, 243-256.

[50] Mbeki T (2006). *Responsibilities of the people's local representatives*. ANC Today **6** (10): 17-23.

[51] Mbeki T (2005). *The Presidency Response of the President of South Africa to the Debate of the State of the Nation Address*, Cape Town: Parliament of the Republic of South Africa.

[52] Mbeki T (2004). *Address to the First Joint Sitting of the Third Democratic Parliament*, Cape Town: Parliament of the Republic of South Africa.

[53] McDonald D A and Pape J (2002). *Cost Recovery and the Crisis of Service Delivery in South Africa*, London: Zed Press.

[54] Meyer P S and Ausubel J H (1996). *Human population dynamics revisited with the Logistic Model: How much can be modeled and predicted*? Technological Forecasting and Social Change **52**, 1-30.

[55] Murray J D (1993). *Mathematical Biology*, New York: Springer.

[56] Newell C (1988). *Methods and Models in Demography*, New York: Guilford Press.

[57] Nnadozie R C (2006). *Population Dynamics: Description by a System of Nonautonomous Ordinary Differential Equations*, Dissertation, Durban: School of Mathematical Sciences, University of KwaZulu-Natal.

[58] Nnadozie R C (2006). *Provincial Groups and Delivery/Access in SA Water Services Sector*, Draft Research Report Draft, Pretoria: Human Sciencces Research Council.

[59] Orieji C D (1993). *Population policy in South Africa*, Studies in Family Planning, **24**(1): 1-30.

[60] O'Neill B C and Jiang L (2007). *Projecting U.S. Household Changes with a New Household Model*, New York: Population Association of America.

[61] Population Reference Bureau (1998). *Population and Environmental Dynamics*, Washington DC: Population Reference Bureau.

[62] Population Reference Bureau (2006). *In the News: The Nigerian Census*, accessed from http:www.prb.org/Articles/2006/Inthe News/TheNigerianCensus.aspx.

[63] Pressat R (1978). *Statistical Demography*, London: Methuen.

[64] Saaty T L and Alexandar J M (1981). *Thinking with Models*, New York: Pergamon Press.

[65] Smith M (1998). *Painting by numbers: Mathematical models of urban systems*, Journal Environment and Planning B, 25, 483-493.

[66] Solidarity Helping Hand (2008). *White poverty in South Africa with an emphasis on the Tshwane Metropolitan Area*, accessed from http://www.soldeer.co.za/nuusbriewe/hh/hh15/report.pdf.

[67] South African Data Archive (1995).*October Household Survey 1994*, Pretoria: Statistics South Africa.

[68] South African Data Archive (1996). *October Household Survey 1995*, Pretoria: Statistics South Africa.

[69] South African Data Archive (1997). *Population Census 1996*, Pretoria: Statistics South Africa.

[70] South African Data Archive (1998). *October Household Survey 1997*, Pretoria: Statistics South Africa.

[71] South African Data Archive (1999). *October Household Survey 1998*, Pretoria: Statistics South Africa.

[72] South African Data Archive (2000). *October Household Survey 1999*, Pretoria: Statistics South Africa.

[73] South African Data Archive (2002). *Population Census 2001*, Pretoria: Statistics South Africa.

[74] South African Data Archive (2003). *General Household Survey 2002*, Pretoria: Statistics South Africa.

[75] South African Data Archive (2004). *General Household Survey 2003*, Pretoria: Statistics South Africa.

[76] South African Data Archive (2005).*General Household Survey 2004*, Pretoria: Statistics South Africa.

[77] South African Data Archive (2006). *General Household Survey 2005*, Pretoria: Statistics South Africa.

[78] SPSS Inc (1999). *SPSS Regression Models*, Chicago: SPSS Inc.

[79] Statistics South Africa (2007). *Statistical Release, 2006 Community Survey*, Pretoria: Statistics South Africa.

[80] The Constitution of the Republic of South Africa (1996). *Act No.108 of 1996*, accessed from http:www.polity.org.zagovdocs/ constitutionsaconst.html.

[81] The Constitution of the Republic of South Africa (1999). *The 1999 Statistics Act*, accessed from http://www.acts.co.za.

[82] Thomas Malthus Biography. accessed from http:www.blupete. comLiterature/BiographiesPhilosophy/Malthus.htm.

[83] Udjo E (2007). *Population Estimates for South Africa by Magisterial District and Province*, Pretoria: Bureau for Marketing Research, University of South Africa.

[84] Udjo E O (2008). *Demographic Projections of Africa's Population for the Period 2000 - 2050 taking into Account of HIV/AIDS and it's Implication for Development*, Southern African Bussiness Review, **3**(12).

[85] UNDP (2004). *The Human Development Report for 2000*, New York: United Nations Development Programme.

[86] United Nations (2000). *UN Millennium Development Goals*, accessed from http:www.un.org/millenniumgoals/.

[87] U.S. Census Bureau (2009). South Africa: Demographic Indicators, accessed from http://www.census.gov/ipc/www/idb.

[88] van Aardt C J (2007). *Population and Household Projections for South Africa by Province and Population Group, 2001 - 2021*, Pretoria: BMR, University of South Africa.

[89] van Imhoff E, Kuijsten A, Hooimeijer P and van Wissen J G (1995). *Household Demography and Household Modeling*, New York: Springer.

[90] Varvra Z (1967). *Future trends in world population growth*, Demography, **4** (2): 497-514.

[91] Verhulst P F (1838). *Notice sur le loi que la Population suit dans son Accroissement*, Correspondence des mathématiques et physiques, **54**: 113-121.

[92] Wasserman S and Faust K (1992). *Social Network Analysis: Methods and Applications*, Cambridge: Cambridge University Press.

[93] Water Research Commission of South Africa (2003). *Water in South Africa*, accessed from, http://www.wrc.org.za/downloads.

[94] Westergaard H (1932). *Contributions to the History of Statistics*, London: King.

[95] White H C (1963). *An Anatomy of Kinship*, New Jersey: Prentice-Hall.

[96] Wikipedia (2007). *Differential Equations*, accessed from en.wikipedia.org/wiki/Differential_equation.

[97] Wikipedia (2007). *Water Privatisation in South Africa*, accessed from http:en.wikipedia.org/wiki/Water-privatisation-in-South-Africa.

[98] Wikipedia (2007). *Water Supply and Sanitation in South Africa*, accessed from http:en.wikipedia.org/wiki/Water-supply-and-sanitation-in-South-Africa.

[99] WHO/UNICEF (2005). *Meeting the MDG Drinking Water and Sanitation Target*: A Mid-Term Assessment of Progress, accessed from http:www.unesco.org/water/wwap/wwdr2/case-studies/pdf/south-africa.pdf.

[100] Wolfram S (1996). *The Mathematica Book*, Cambridge: Cambridge University Press.

[101] World Resources Institute (2000). *World Resources*, Washington DC: World Resources Institute.

[102] Zulu E M and Sibanda A (2005). *Racial Differences in Household Structure*; in Tufuku Zuberi, Amson Sibanda and Eric Udjo (eds), The Demography of South Africa. New York: M.E Sharpe.

APPENDIX

SPSS SYNTAX CODES

1. Frequency Cross-tabulations for level of Water Access by Province for the General Household Surveys

```
GET
  FILE='F:\Sa dat\OHS\SPSS Datasets\OHS 95\house.sav'.
DATASET NAME DataSet1 WINDOW=FRONT.
FREQUENCIES
VARIABLES=col36
/ORDER=  ANALYSIS .
WEIGHT
  BY col252 .
CROSSTABS
  /TABLES=col248  BY col36
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL .
GET
  FILE='F:\Sa dat\OHS\SPSS Datasets\OHS 96\OHS_96\SP'+
 'SS\House.sav'.
DATASET NAME DataSet2 WINDOW=FRONT.
DATASET ACTIVATE DataSet2.
DATASET CLOSE DataSet1.
WEIGHT
  BY newhwgt .
CROSSTABS
  /TABLES=prov  BY mainwate
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL .
GET
  FILE='F:\Sa dat\OHS\SPSS Datasets\OHS 97\houses.sav'.
DATASET NAME DataSet3 WINDOW=FRONT.
DATASET ACTIVATE DataSet3.
DATASET CLOSE DataSet2.
WEIGHT
  BY hhwgt .
CROSSTABS
  /TABLES=hhwater  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL .
GET
  FILE='F:\Sa dat\OHS\SPSS Datasets\OHS 98\houses1.sav'.
DATASET NAME DataSet4 WINDOW=FRONT.
DATASET ACTIVATE DataSet4.
DATASET CLOSE DataSet3.
```

```
WEIGHT
  BY hhwgt.
CROSSTABS
  /TABLES=q9_13wat  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
GET
  FILE='F:Sa dat\OHS\SPSS Datasets\OHS 99\houses1.sav'.
DATASET NAME DataSet5 WINDOW=FRONT.
DATASET ACTIVATE DataSet5.
DATASET CLOSE DataSet4.
WEIGHT
  BY hhwgt.
CROSSTABS
  /TABLES=q6_7wate  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
GET
  FILE='F:Sa dat\General Household Survey 2002\SPSS'+
 ' data\house.sav'.
DATASET NAME DataSet6 WINDOW=FRONT.
DATASET ACTIVATE DataSet6.
DATASET CLOSE DataSet5.
WEIGHT
  BY house_wg.
CROSSTABS
  /TABLES=q48watrs  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
GET
  FILE='F:\Sa dat\General Household Survey 2003\Data'+
 '\SPSS\house.sav'.
DATASET NAME DataSet7 WINDOW=FRONT.
DATASET ACTIVATE DataSet7.
DATASET CLOSE DataSet6.
WEIGHT
  BY housewgt.
CROSSTABS
  /TABLES=q412watr  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
GET
  FILE='F:\Sa dat\General Household Survey 2004\Data'+
 '\SPSS\house.sav'.
DATASET NAME DataSet8 WINDOW=FRONT.
DATASET ACTIVATE DataSet8.
DATASET CLOSE DataSet7.
WEIGHT
  BY housewgt.
CROSSTABS
  /TABLES=q421watr  BY prov
```

```
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
GET
  FILE='F:\Sa dat\General Household Survey 2005\SPSS'+
 '\house.sav'.
DATASET NAME DataSet9 WINDOW=FRONT.
DATASET ACTIVATE DataSet9.
DATASET CLOSE DataSet8.
WEIGHT
  BY house_wg.
CROSSTABS
  /TABLES=q421watr  BY prov
  /FORMAT= AVALUE TABLES
  /CELLS= COUNT
  /COUNT ROUND CELL.
```

2. Syntax for the Regression Analysis

```
GET
  FILE='F:\Acada\SpssModel_Data.sav'.
DATASET NAME DataSet3 WINDOW=FRONT.
REGRESSION
  /MISSING LISTWISE
  /STATISTICS COEFF OUTS R ANOVA
  /CRITERIA=PIN(.05) POUT(.10)
  /NOORIGIN
  /DEPENDENT Ad_demand
  /METHOD=ENTER LogN_Incr LogN_Mig H_frag.
```

3. Syntax for the logistic Regression and Data Recodes

```
GET
  FILE='F:\Acada\2005GHS_Data.2sav.sav'.
DATASET NAME DataSet1 WINDOW=FRONT.
DATASET ACTIVATE DataSet1.
RECODE
  q41maind
  ('02'=1)  ('07'=2)  ('08'=2)  ('01'=3)  ('03'=3)  ('04'=3)  ('05'=3)
('0'+
 '6'=3)  ('09'=3)  ('10'=4)  ('11'=4)  INTO  Dwelling.
VARIABLE LABELS Dwelling 'Type of Dwelling'.
EXECUTE.
RECODE
  q479tota
  ('01'=1)  ('02'=2)  ('03'=2)  ('04'=3)  ('05'=3)  ('06'=4)  ('07'=5)
 (MISSING=SYSMIS)  (ELSE=6)  INTO  IncomeCat .
VARIABLE LABELS IncomeCat 'Income Category.
EXECUTE .
LOGISTIC REGRESSION VARIABLES  water1
  /METHOD = ENTER Race IncomeCat prov Dwelling1
  /CONTRAST (Race)=Indicator  /CONTRAST (prov)=Indicator
  /CRITERIA = PIN(.05) POUT(.10) ITERATE(20) CUT(.5).
```