A CRITICAL REVIEW OF CURRENT WATER USE IN MAGADI TOWNSHIP, KENYA WITH RECOMMENDATIONS FOR LONG TERM SUSTAINABLE MANAGEMENT PRACTICES

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A research report submitted to the Faculty of Science, University of the Witwatersrand, in fulfillment of the requirements for the degree of Master of Science in Environmental Science.

Johannesburg, 2009

DECLARATION

I declare that this research report is my own, unaided work. It is being submitted for the degree of Master of Science in Environmental Sciences at the University of the Witwatersrand. It has not been submitted before for any degree or examination in any other university.

LUCY ANDERE CHIMOYI **(0708657E)**

_____ Day of ____________________, 2009.

DEDICATION

This work is dedicated to my parents, Mr. and Mrs. Chimoyi for their love, support and encouragement and to my sisters Carol, Anne and Sylvia. A special dedication goes to my husband, Kennedy Naviava Otwombe, whose unconditional love and support has been the greatest inspiration in my life.

God bless you all

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To God Almighty who has been a source of strength, inspiration, refuge and hope in my life. Without Him, clearly, everything is impossible.

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Thank you all!

GLOSSARY AND ACRONYMS

Acronym	Meaning
a.s.l.	above sea level
ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
EHS	Environmental, Health and Safety
FSW	Fish Springs Water
HSD	Honestly Significant Difference
ICWE	International Conference on Water and Environment
IDA	International Desalination Association
IWRM	Integrated Water Resources Management
MOWR	Ministry of Water Resources
MSC	Magadi Soda Company
MSF	Multi Stage Flash
PCA	Principle Component Analysis
RO	Reverse Osmosis
SAS	Statistical Analysis Software
TDS	Total Dissolved Solids
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WC	Western Closet
WDC	Water Development Committee
WHO	World Health Organization
XOC	Xenobiotic Organic Compounds

ABSTRACT

In recent years, Magadi Soda Company has experienced short supplies of water to the company and the Township. This problem has been caused by a prolonged dry spell coupled with the installation and commissioning of a new fly ash plant and an increase in the population of Magadi Township. Water rationing to the Township residents as well as the local community surrounding the Township was introduced by the Water Development Committee as a short term sustainability measure in 2005 to ensure a continuous supply of water to the processing plants. The effectiveness of this rationing as part of a water conservation strategy has been assessed and it has been established that a long term sustainability plan is needed to co-ordinate water demand and supply in Magadi.

This study looked at the current water use in Magadi Township while trying to establish a relationship between the number of occupants in each household, the class of housing in Magadi Township and the daily consumption of water. To achieve this, data was collected in three stages: site visits, interviews with company representatives and interviews with the Township residents by use of questionnaires. Site visits were performed to understand the intricacies in the water distribution network. The outcome of the interviews with the company representatives presented some of the problems that led to the implementation of the rationing program and the current issues the company faces as a result of implementing the program. The interviews with the Township residents indicated that the high demand for water was as a result of the high number of people who depend on Magadi Soda Company for water.

The study reveals that the amount of water consumed in the Township during the dry and wet seasons was not significantly different and the daily water consumption throughout the weeks was constant. The number of occupants determined the amount of water consumed daily in each household. In addition, the households in the upper class housing were seen to consume more water daily than the households in the middle and lower class despite having the least number of occupants. The daily domestic activity that consumed a lot of water in Magadi Township was the irrigation of gardens which was mostly practised in the upper class households.

Several options for improving the long term sustainability of water supply to the local community, Township residents and the Magadi Soda Company processing plants are discussed. The options considered explore the possibility of using alternative sources of water such as stormwater, greywater and desalination to supplement the current water supply to Magadi. These options need to be both cost effective and practical.

Proper management of water was one of the solutions discussed with the company representatives in averting a water crisis in the future. A water monitoring program should be formulated to monitor the distribution system of water in Magadi. This includes minimising wastage of water and penalising residents who fail to adhere to such measures, creating awareness on the appropriate use of water by conducting educational campaigns to all the residents of Magadi, installation of technologically advanced plumbing appliances and fittings in the households such as low flush toilets and proper maintenance of the existing water infrastructure to prevent water losses through leaks caused by faulty and worn out infrastructure.

LAYOUT OF THE DOCUMENT

This research report comprises of six chapters and an appendix.

Chapter 1 gives an overview of the study and the legislative requirements on the abstraction and use of water in Kenya. It provides a description of the study area and introduces the problem which provides the basis of this research report.

Chapter 2 is a survey of existing literature which focuses on water sustainability. This enables an understanding of the scope, theory and practices adopted by different countries in addressing the problem of water scarcity and some of the interventions implemented to alleviate the problem.

Chapter 3 outlines the methods used in collecting data in Magadi. Informal conversations, questionnaires and site visits were used to collect data for the study.

Chapter 4 discusses the analysis of the data. Hypotheses were set and tested through different statistical techniques. The results obtained during the site visits are also included in this chapter.

Chapter 5 answers the questions posed during the study at Magadi as well as the limitations faced during the study. It tries to give answers to some of the problems that face Magadi in managing water by focusing on the daily consumption of water in the Township.

Chapter 6 draws conclusions and makes recommendations identified from the literature and observations in the preceding chapters. These recommendations recognize that the scarcity of water and a growing population in Magadi can be mitigated by adopting effective management of water and water conservation practices, exploring alternative sources of water, and creating awareness on proper use of water to consumers.

The appendices provide relevant attachments to the research report collected during the site visits. Photographs and tables were used to summarize the data collected on the site. Other additional statistical results were also included in the appendices.

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CHAPTER 1: INTRODUCTION

1.1 DESCRIPTION OF STUDY AREA

Magadi Soda Company (MSC) is located at 36°30'E, 2°10'S and at an altitude of 600m a.s.l. It covers an area of 220,000 acres and is situated in Magadi division, Kajiado District in Kenya's Great Rift Valley. It is 120 km south west of Nairobi and 36 km from the Tanzanian border (Figure 1.1) (Stevenson, 2000). It was established in 1911 by the Brunner Mond Company for the extraction and processing of soda ash (trona) from Lake Magadi (Figure 1.2) with salt as a byproduct and is currently owned by Tata India. Other deposits of soda ash in East Africa are found in Lake Natron in Tanzania but Lake Magadi currently produces the largest amount of soda ash in Africa. Soda ash is used in a variety of processes including the manufacture of detergents, glass and paper and also in leather tanning and metallurgical industries (Hill, 1964). Soda ash is also used as a softening agent during the treatment of water in Magadi Soda Company (MSC) water treatment plant.

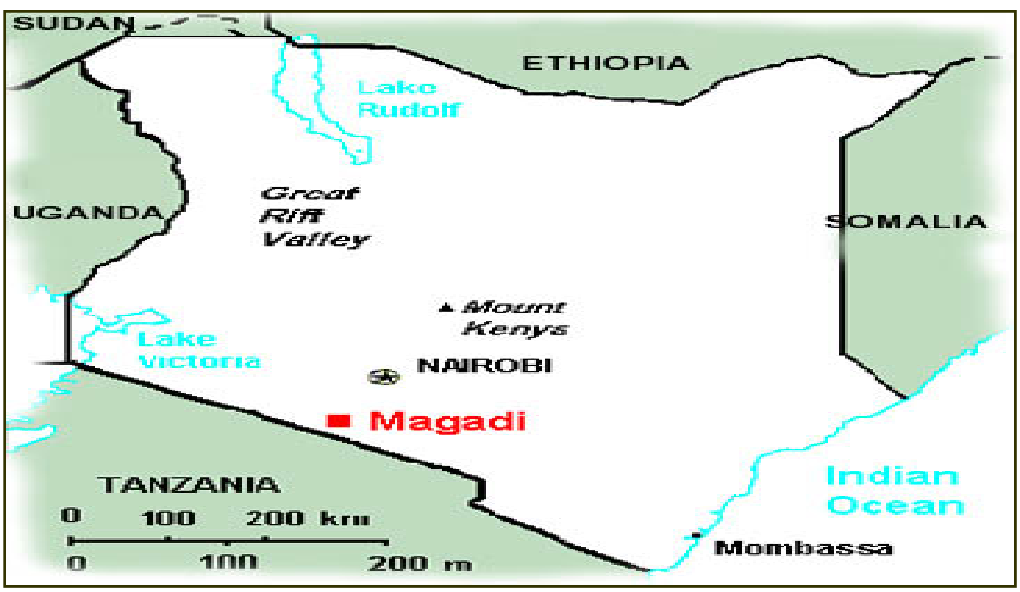


Figure 1.1: The location of Magadi in Kenya (Stevenson, 2000)

Lake Magadi contains a renewable supply of raw trona (Figure 1.2) from which good quality industrial sodium carbonate is produced. Trona is a natural product formed by chemical processes involving volcanic eruptions. The trona deposit is constantly renewed through natural means. When rain falls in Magadi, the water seeps into the ground where it is heated by the hot rocks underlying the bedrock. The heated water dissolves the sodium compounds held by the rocks and forms an alkaline solution. The alkaline solution comes to the surface in form of springs around the lake (Hill, 1964). Long sunny days and high evaporation rates in Magadi cause the water to evaporate leaving behind a crust of crystalline trona on the surface of the lake as seen in Figure 1.2. Figure 1.3 illustrates the formation of trona.

Figure 1.2: Crystalline trona on the surface of Lake Magadi

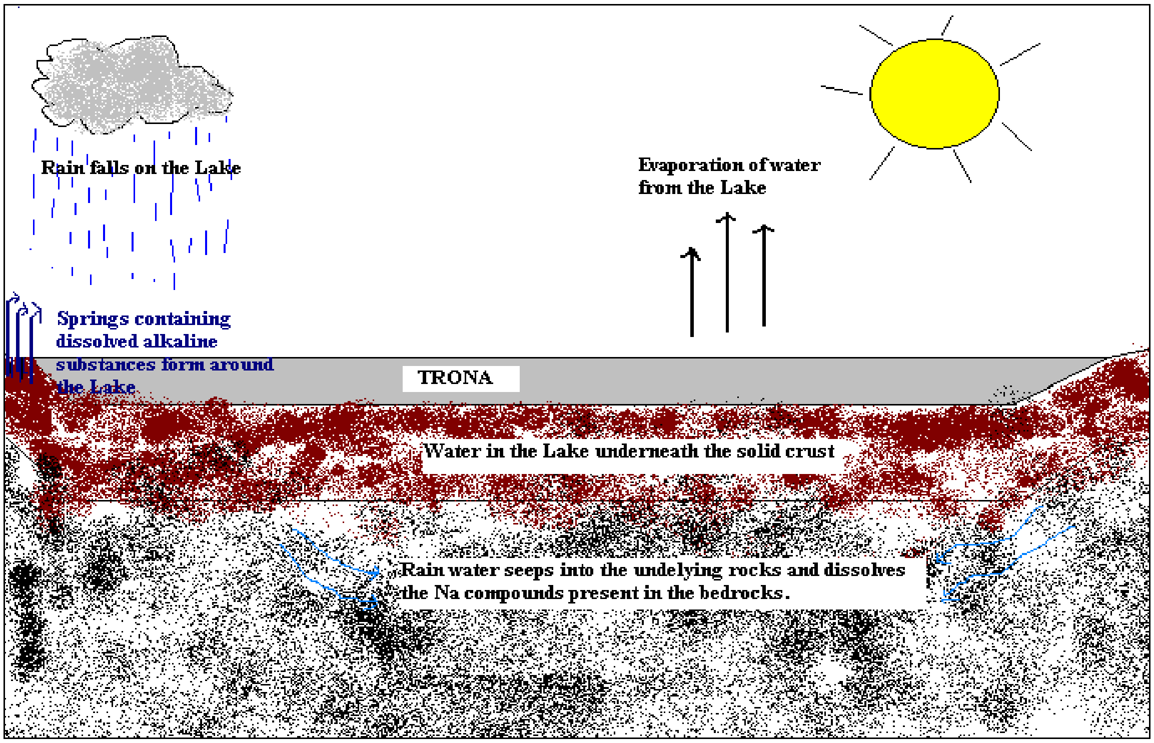


Figure 1.3: Formation of trona in Lake Magadi

Physical Characteristics

Climate

Magadi Soda Company has a weather station that houses a rain gauge (Appendix 1). The ambient temperature and humidity are collected and recorded daily. Table 1.1 shows a summary of the average climatic conditions experienced in the year 2006 and Figure 1.4 shows the mean annual rainfall in Magadi from 2001 to 2006. The rainfall is seen to have a bi-modal pattern where rains fall between October to December and March to May. Gichuki *et al.* (2002) describe the average annual rainfall and evaporation rates as 600 mm and 3,500 mm respectively. The average monthly temperatures range from 28.6^0 C to 32.9^0C while the average monthly Relative Humidity is 63%. The limited rainfall, low humidity and high evaporation rates indicate that Magadi is a semi-arid to arid area Gichuki et *al.* (2002).

Table 1.1: Average climatic conditions for the year 2006 collected from the weather station, Magadi (Quality Control Laboratory Records, 2007).

Monthly mean	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
Maximum temperature (°C)	36.1	37.2	34.7	33.1	34.8	34.8	34.2	34.1	34.9	36.9	31.8	32.9	**34.6**
Minimum temperature (°C)	28.6	28.9	27.7	25.3	29.7	28.6	27.5	29.3	27.7	29.9	29.0	30.7	**28.6**
Rainfall (mm)	21.9	32.5	103.8	100.5	22.5	0	0	9	12	2.7	163.7	81.5	**45.8**
Humidity (% RH)	66	63	67	64	75	70	68	76	66	68	85	88	**63**
Number of rain days	3	2	10	13	4	0	0	1	1	4	18	10	**6**

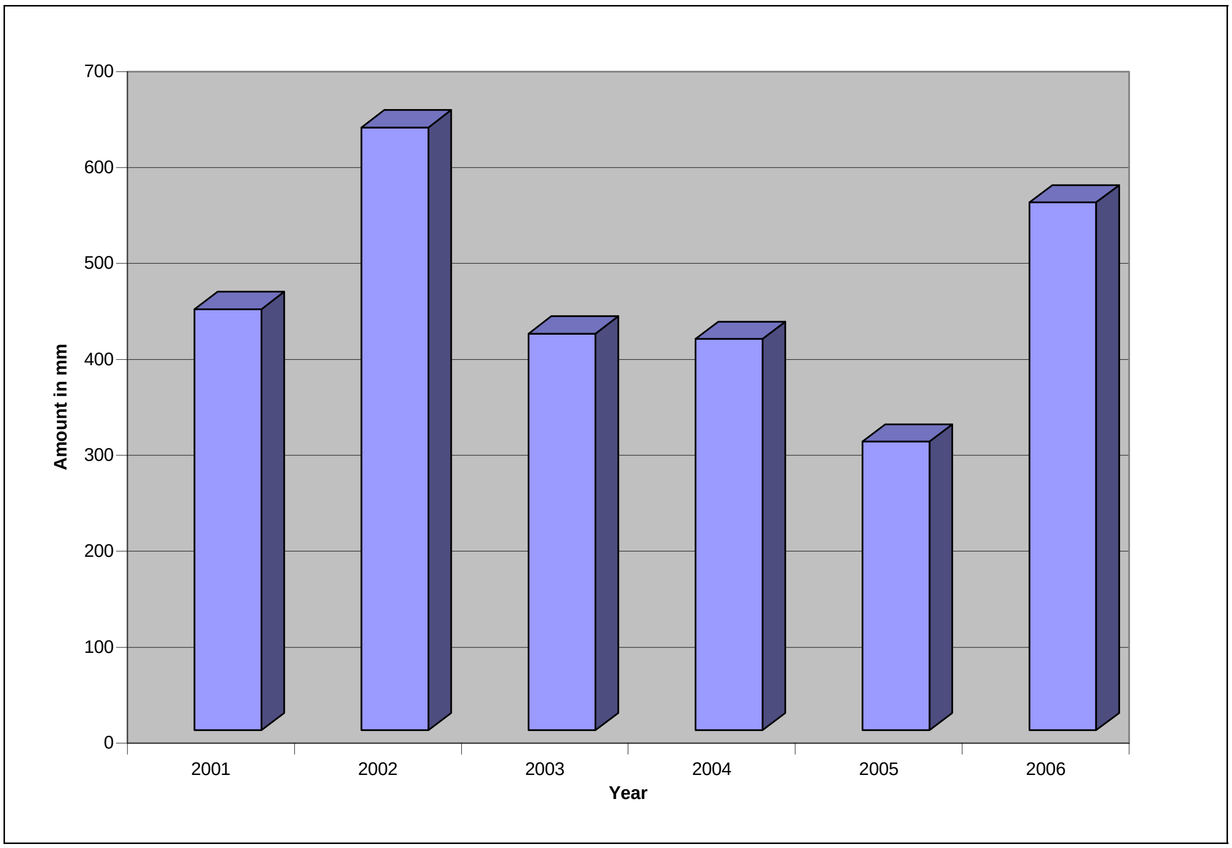


Figure 1.4: Mean annual rainfall at Magadi, 2001-2006 (Quality Control Laboratory Records, 2007).

Geology

Baker (1963) distinguishes between several formations of rocks in Lake Magadi and its surroundings. These were Precambrian metamorphic rocks, Pliocene to Pleistocene volcanic rocks and Holocene to recent lake and fluvial sediments. These sediments, known as lacustrine sediments, are exposed around the lake trough in the central part of the Rift Valley floor which is a narrow basin filled with three successions of quaternary fluvio-lacustrine sediments. The increasing desiccation of the lake, led to the accumulation of the Holocene evaporative series which in turn, formed the present day alternating trona sheets ($Na_2Co_3.NaHCo_3.2H_20$) that contain black mud with sodium carbonate and chloride rich brine (Baker 1958). The underlying rocks have a chemical composition of magnesium, sodium and calcium carbonates. The seismic and volcanic activity of these rocks results in hot alkaline springs observed around the edge of the lake (Baker, 1958).

Soils

The ground surface in Magadi is littered with many small stones. The soils are shallow, poorly developed and have low moisture content. This restricts vegetative growth and exposes the bare ground to direct sunlight. The black cotton soils are predominant and have high clay content. These soils are susceptible to water logging during the rainy season, however, during the dry season, they compact causing the ground to become hard (Stevenson, 2000).

Topographical characteristics

The topography is characterized by plains, valleys and volcanic hills. Lake Magadi lies at the lowest elevation (596 metres a.s.l.) of the Ngurumani Escarpment of the Great Rift Valley. It is surrounded by hills rising up to heights of between 2000 and 3000 m a.s.l. The ground surface between the escarpments is generally smooth (Stevenson, 2000).

Hydrology

The low gradient of the land and low permeability of water through the underlying rocks creates a favourable condition for formation of alkaline wetlands (Gichuki and Macharia, 2003). Ewaso Nyiro is the only perennial river in Magadi Division which flows from the Kenyan highlands into Lake Natron in Tanzania. Two perennial streams (Sampu and Oloibortoto) originate from the Ngurumani Escarpment to form tributaries to the Ewaso Nyiro River. MSC abstracts water from the Oloibortoto Stream to supply the Township, processing plants as well as the local community who are the indigenous Maasai people (Stevenson, 2000). Fish Springs Works is an important part of the lacustrine ecology because a series of five lagoons have been dug out by the company to collect water from the underground springs which feed into the Lake (Figure 1.7) (Stevenson, 2000).

Vegetation

The vegetation in this area is described as open and wooded grassland which is observed during the rainy season. The main trees present in Magadi are the *Acacia* and *Commiphora* species (Stevenson, 2000). During the dry season, the vegetation becomes very dry and parched as seen in Figure 1.5a. However, the Township practices irrigation thus green and lush vegetation with plenty of undergrowth is observed in Figure 1.5b. Figure 1.5a shows the vegetation found in Magadi Division. This picture shows acacia trees and an almost bare ground littered with stones and very dry grass and Figure 1.5b shows a well irrigated garden that is mainly found in the upper class households and the Magadi Soda Company Sports Club in the Township.

(a) (b)

Figure 1.5: Vegetation found in the Magadi Division.

1.5a shows a general view of the vegetation in Magadi Division and 1.5b shows an example of well irrigated gardens in the Township

1.2 SOCIO-ECONOMIC CHARACTERISTICS

Demographic characteristics

The population density of Magadi division is 9.5 people/km^2 (Stevenson, 2000). The area is predominantly occupied by the Maasai. However, Magadi Soda Company has particularly attracted skilled migrant labour from across the country and the world (India, United States of America, Republic of South Africa and the United Kingdom). According to the town census conducted in the year 2000 (Appendix 2), Magadi Township supported 2020 people including

286 employees. At the time of the visit, no recent census data was reported however, the Township now supports 5,000 people including 550 employees (D. Ogol Town Welfare Manager pers. com).

Magadi Soda Company has an open door policy where the local community can easily access the available resources from the Township surrounding the company. In addition, the presence of a shopping centre and recreational facilities such as two swimming pools, basketball courts, a golf course and a cinema has also attracted the local community to the Township for trade and recreation. This situation is in sharp contrast with the Debswanna Mine situated in Orapa town, Botswana, which has a closed door policy to the local community and access to the mine is restricted by the company[1] . As a result of these restrictions, the population in Debswanna is limited as opposed to Magadi where the unrestricted access increases the population which in turn increases water demand.

The main difference between these two mines lies in the value of the mineral mined or extracted. Soda ash is not classified as a valuable mineral whereas the diamonds mined in Debswanna mine are valuable and are susceptible to theft.

Socio economic activities

The main activity in the company is the extraction of soda ash and salt for both export and local trade. Apart from this activity, other economic activities in the town include small businesses like tailoring, selling groceries and butcheries which are all located in the shopping center situated in Magadi Township. The surrounding local community is pastoralist and therefore, the main economic activity is trading in livestock (cows, goats and donkeys) and

[1] http://en.wikipedia.org/wiki/Orapa

their products (milk and meat). This emphasizes the company's open door policy since the local community uses the shopping center for trading as other trading centers are located far away.

Land use

Throughout the larger part of Magadi division, grazing is the dominant land use. Group ranches have been introduced in the local communities for rearing livestock. Cultivation, on the other hand, is practiced on very small pieces of land during the short rainy season (Stevenson, 2000). The land use in Magadi Township include; the administrative offices, processing plants, a power plant, urban settlements, recreation places, a golf course, airstrip and the lake as seen in the layout in Appendix 3.

Extractive industry

There are two fly ash plants and one salt manufacturing plant with varied water demand levels as seen in Table 1.2. The company extracts soda ash with salt as a byproduct for both local and export sales. Soda ash is obtained by washing and drying the trona that has been extracted from the lake. The salt (NaCl) is placed in evaporation pans and through solar evaporation, dry NaCl is produced.

Table 1.2: Water demand for the industries in Magadi (Magadi Records, 2007)

Consumers	Demand m^3/day
Std Ash plant dredges	15.80
Premium Ash plant	58.08
Salt plant	-

1.3 WATER SUPPLY FOR MAGADI TOWNSHIP

1.3.1 Sources of water

Extraction of soda ash is a water intensive process. A constant supply of water is required for the processing of trona. Magadi has therefore abstracted water from Oloibortoto Stream and Fish Springs works to supply water to the processing plants and also the Township for domestic purposes.

Oloibortoto Stream

This perennial stream originates from the Ngurumani hills and flows into the Ewaso Nyiro River. Water is tapped from the river at an abstraction source (Figure 1.6a) and transported 60 km to Magadi via a pipeline to the water treatment plant by way of gravity (no pumps required). The treated water is used for industrial and domestic use including irrigation. Six off take points, with different tank sizes, have been introduced along the pipeline for supplying untreated water to the local community in Magadi Division and are summarized in Table 1.3. Water is supplied to small and big tanks three times and once a week respectively. Since no flow meters have been installed along the pipelines, the calculations of the flow rate are based on the pipe capacity. The calculations are based on the assumption that there is a consistent flow of water in the pipelines at all times with no leakage. The total water supplied to the local community is estimated to be 128.61 m^3per hour (Table 1.3).

Table 1.3: Off take points along the pipeline supplying water from Oloibortoto Stream to Magadi Soda Company (Magadi Records, 2007).

	Off take	Pipe diameter (inches)	Flow rate (m^3/hr)	Size of tank	Frequency/week	Amount of water /hr (m^3)
1	Ministry of Wildlife ICIPE and KETRI	1	1.2138	Big	once	30.5
2	Olkiramatian Trading centre	0.5	0.6092	Big	once	30.5
3	Tirangui Birikani	0.5	0.6092	Small	thrice	12.37
4	Olesirian Cattle tank	2.5	3.0459	Small	thrice	12.37
5	Birika- 3	0.5	0.6092	Small	thrice	12.37
6	Chief Sayanka's boma	1	1.2138	Big	once	30.5
	Total					**128.61**

(a) (b)

Figure 1.6: Abstraction point of water from the Oloibortoto Stream (a) and reservoir point from Fish Springs Water (b) to Magadi Soda Company.

Note: One of the processing plants in the background.

Fish Springs Water (FSW)

This water originates from five underground springs dug out around the lake and collects into five dug out lagoons namely; Bird rock, Northern, South Western, Grahams and Fish Springs Lagoons. The Google image in Figure 1.7 shows the location of each lagoon. The water is pumped into the reservoir shown in Figure 1.6(b) and is distributed without undergoing any treatment to different sections of the Township as seen in Figure 1.9.

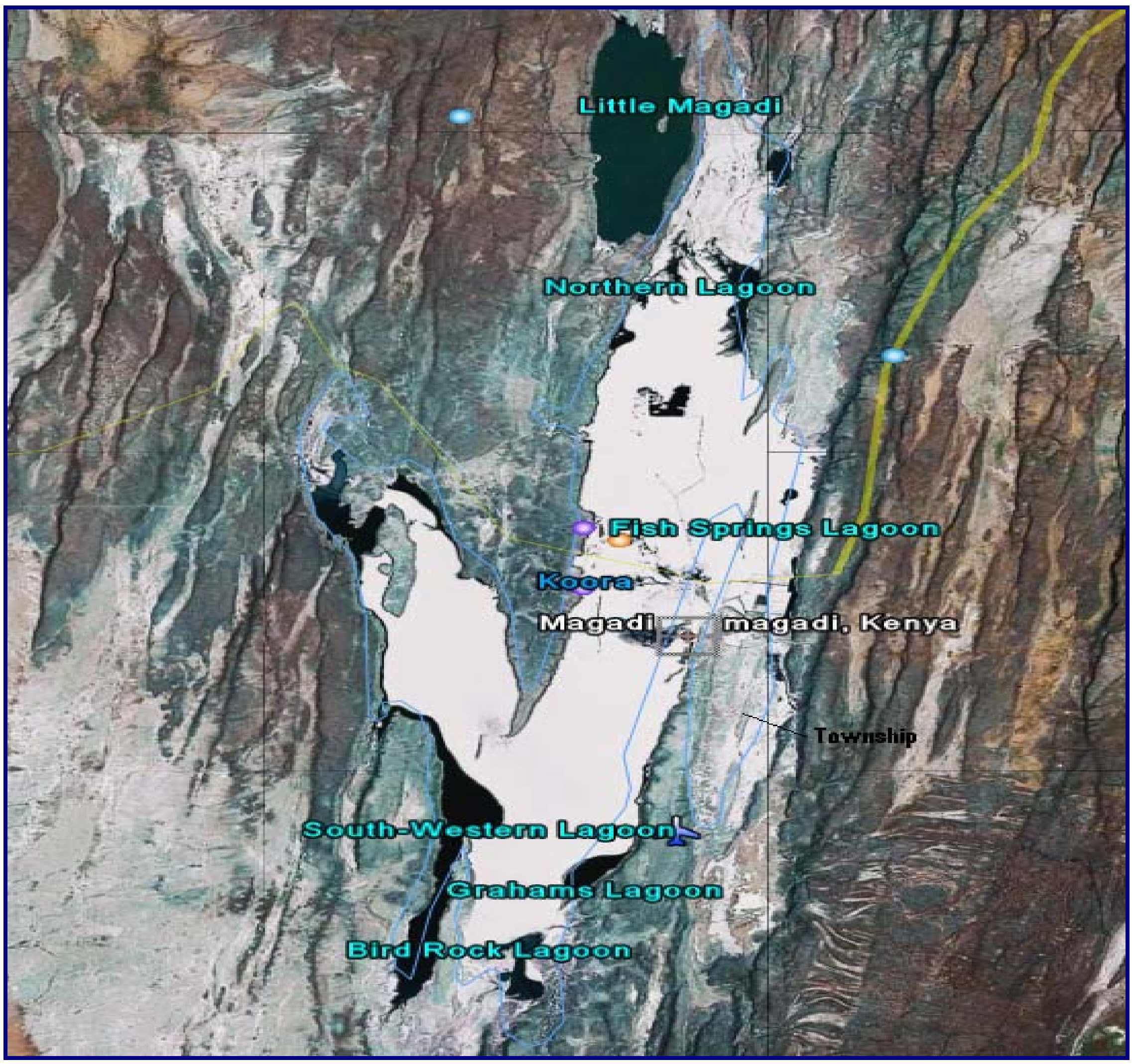


Figure 1.7: The Lagoons that feed into Lake Magadi (Google Earth).

1.3.2 Water treatment and quality

Water from Oloibortoto stream is transported via a 60 km pipeline to the water treatment plant. The untreated water flows into a sedimentation tank with a capacity of 1363.827m^3 at a rate of 52.28 to 59.10 m^3 / hour. A bypass at the bottom of the tank allows for excess water to overflow to the Township parks during the rainy season. During treatment, the first step is adding aluminum sulphate (Al_2SO_4) in the sedimentation tank to flocculate the mud and ease the decanting process. The mud settles at the bottom of the tank while clear water is pumped to the treatment facility. A second tank with aluminum sulphate ensures that any mud that bypassed the sedimentation tank is flocculated. Soda ash, a dealkalization agent, is added to the clear water as a softening agent to remove any natural acids present in the water. Water contains high levels of alkalinity which requires dealkalization before use. The type of alkalinity found in water depends on the pH such as P-alkalinity and M-alkalinity (total alkalinity) (Table 1.4). Natural surface water, like Oloibortoto stream, contains no P-alkalinity and relatively low levels of M-alkalinity (Ziarkowski, 1997). After softening, the water is passed through two filtration tanks (FT). These tanks are lined with wire mesh, small stones and silica respectively which facilitates the filtration process. This ensures that the smallest dirt particles are removed from the water. As the water is pumped into the backwash tank, chlorine (Cl_2) is simultaneously injected into the pipeline for purification. This tank has a holding capacity of 1.1 to 2.1m^3 and has filters that filter off any particles that may have found their way through the filtration tanks. In the event where the tank fills up, an overflow pipe, seen in the Figure 1.8, drains excess water into a watering point owned by the local community for livestock watering. The water is pumped to a reservoir tank which holds 2418.52 m^3 of water ready for distribution to the Township and processing plants (Figure 1.8).

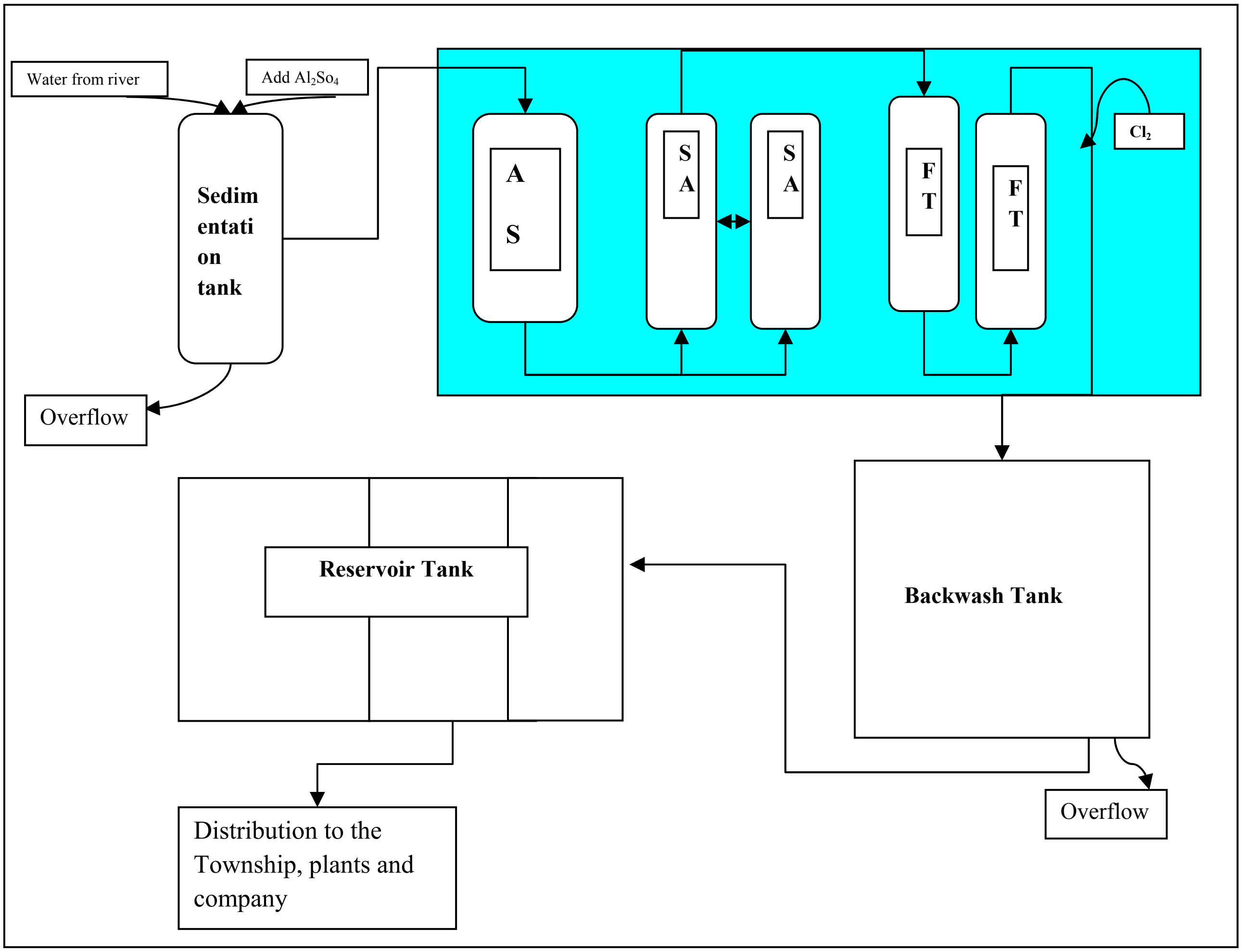


Figure 1.8: A summary of the water treatment process in Magadi Soda Company. The shaded area represents the water treatment plant.

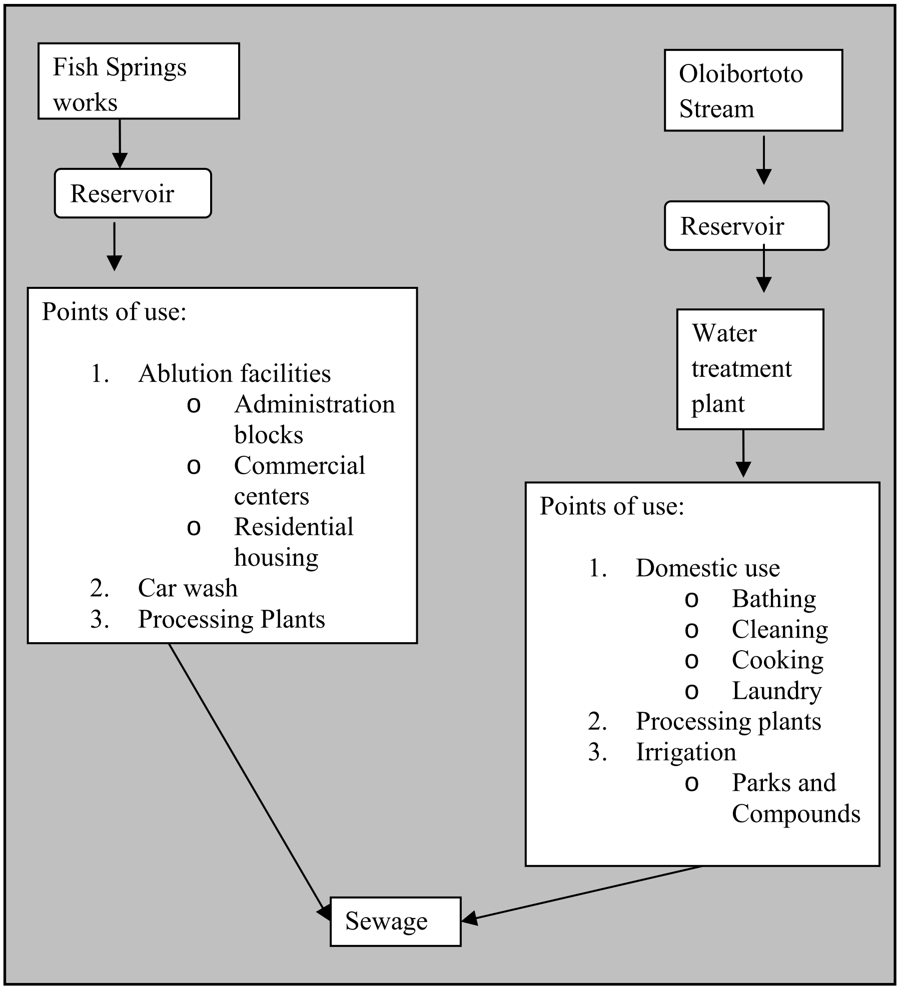


Figure 1.9: Summary of the sources of water and their points of use in Magadi

Water quality

Since water quality is under threat everywhere, water quality standards are applied to ensure that water is fit for its intended use. The quality of water varies according to its intended use. Water intended for irrigation would not have to meet the high quality standards as those intended for human consumption.

MSC ensures that the water quality supplied is acceptable for use in the processing plants and the Township. Samples of water from different sources are collected for analysis in the laboratory prior to its distribution. Table 1.4 outlines the results of the analysis performed on process water, swimming pool water and domestic water in Magadi and their specifications.

Table 1.4: Water parameters tested in the Quality Control Laboratory in Magadi (Quality Control Laboratory, 2007).

Parameters	**Units**	***Specifications (Limits)***		
		Process water	***Swimming pool water***	***Domestic water***
pH	*pH* units	***6.9 - 7.1***	***7.2 – 7.8***	***7.7***
P-Alkalinity	Ppm	***Nil***	***Nil***	***Nil***
M-Alkalinity	Ppm	***<50***	***<100***	***80.6***
Total Alkalinity	Ppm	***<50***	***<100***	***80.6***
Ca-hardness	mmol/l	***<1***	***<5***	***0.4***
Mg-hardness	mmol/l	***<1***	***<5***	***ND***
Total-hardness	mmol/l	***<1***	***<5***	***ND***
Free chlorine	Ppm	***0.1-0.2***	***1.0-1.5***	***<0.1***
TDS	Ppm	***<1500***	***<1500***	***<100***
Clarity		***Good***	***Good***	***Good***
Chloride	Ppm	***200-600***	***200-600***	***6***
Fluoride	Ppm	***1-15***	***1-15***	***ND***

Table 1.4 shows the analytical tests and results of the water used in Magadi. In domestic water, fluoride, Mg-hardness and total hardness are non-detectable. Free chlorine is higher in swimming pool water than in process water and domestic water. This could be attributed to the sodium hypochlorite added to the swimming pool water as a form of an antiseptic. The chloride present in the water is as a result of chlorine reacting with other substances present in the water to form chloride compounds.

1.3.3 Water requirements for Magadi Township

The Ministry of Water and Resources (MOWR) has outlined the consumption rates of fresh water for all categories of consumers in Kenya in the MOWR Design Manual clause 4.7.2. These rates serve as guidelines on how much water different consumers should be allocated on a daily basis. Tables 1.5 and 1.6 give the per-capita consumptions from the Ministry of Water Designers manual (MOWR, 1996) and MSC, respectively.

Table 1.5: The consumption rates of water/consumer/day reported by the Ministry of Water and Resources, Kenya (MOWR, 1996).

Consumer Type	High class housing	Medium class housing	Low class housing
Human			
People with I.C[2]	$0.25m^3$/day	$0.15m^3$/day	$0.075m^3$/day
People with N.C[3].	-	-	$0.02m^3$/day
Institutions			
Day Schools with WC	$0.25m^3$/day		
School without WC	$0.005m^3$/day		
Boarding schools	$0.05m^3$/day		
Health Services			
Number of beds	0.4 m^3/day		
Out Patients	$0.02m^3$/day		
Administration	$0.025m^3$day		
Livestock unit	$0.05m^3$/day		
Commerce			
Shops	$0.1m^3$/day		
Hotels	$0.3m^3$/bed/day		
Bars	$0.05m^3$/day		
Butcheries	$0.15m^3$/day		
Unspecified Industries	$2.0m^3$/hr/day		
Coffee Factory[4]	$0.025m^3$/kg		

MOWR allocates different consumption rates for different consumers. People with individual connections (I.C) are given more water per day than those with group connections (N.C). Day

[2] *I.C = Individual Connection (Water Piped into households) which applies to the Township*
[3] *N.C = Non-Individual Connection (Water shared from communal boreholes or wells) which applies to surrounding community.*
[4] *No coffee factory operational in the area.*

schools with water closets (WC) have a higher allocation of water than day schools without WCs within the institutional category. Boarding schools should have the highest allocation of water in the institution category. However, a possible error in Table 1.5 indicates that Day schools may require more water than Boarding schools. In the health institutions, in-patients have a higher water demand than out-patients. Contrary to the values reported in Table 1.6, MSC has calculated the water demand that is required by different categories of consumers and tabulated the results in Table 1.6 which slightly differ from the figures reported in Table 1.5.

The results in Table 1.6 indicate that domestic and industrial demand account for the highest water demand in Magadi. An increase in the population of the Township and the commissioning of a new fly ash plant has increased the demand for water in Magadi. In-patients and boarding schools use more water than out patients and day schools. Hotels/canteens and butcheries require more water per day than shops because hotels and butcheries use water for cooking, washing utensils and cleaning the buildings while other shops are likely to use water for drinking purposes and toilet facilities.

Table 1.6: Water demands for different categories of consumers in Magadi (Magadi Records, 2007)

Category	Consumer	Total number of consumers	Demand/group (m^3/day)	Demand/individual (m^3/day)
Domestic	High class	200	50	0.25
	Medium class	2842	426.3	0.15
	Lower class	1583	118.8	0.075
Commercial	Shops	20	0.25	0.0125
	Hotels/canteens	5	2	0.4
	Butcheries	2	0.3	0.15
Administration	Police post	15	2.25	0.15
	Chiefs camp	5	0.25	0.05
	Divisional Education Officer	4	0.1	0.025
	Division Officer	10	1.5	0.15
	Group ranches	14	2.1	0.15
Academic Institutions	Day schools	926	23.15	0.025
	Boarding school	400	50	0.125
	Training centres	50	12	0.24
Health services	In- patients	90	14	0.156
	Out-patients	35	1.8	0.05
Industrial demand	Standard Ash plant	1	15.80	15.80
	Premium ash plant	1	58.08	58.08
	Salt plant	1	0	0
	Power plant	1	116.16	116.16

1.3.4 Water management in Magadi

Legal Obligations

The amended Water Act number 8 of 2002, chapter 372 of the Constitution of Kenya squarely puts the state in charge of all natural water sources. The act governs the administration and management of the water resources and makes provision for the conservation, control, distribution and use of the water resources of Kenya as well as regulation and management of sewerage services. It has introduced major changes to the water management structures that opens up the water sector to a more participatory and decentralized approach. With the high levels of poverty in rural areas and the prohibitive costs of water in such areas, communities have shied away from constructed water schemes in preference for raw waters from unsafe sources. In this regard, MSC has taken upon itself, as part of its Corporate Social Responsibility (CSR) to voluntarily supply water to the Township and local community. Water scarcity in Magadi can be alleviated by proper management of the resource. To ensure water is used efficiently, proper water management practices have to be implemented by the company to ensure long term sustainability of water. To provide a better understanding on how the company can adopt proper water management practices, issues surrounding the current water use by the Township residents should be addressed as it forms the basis of this study.

Water Catchment Management strategy

To ensure a constant supply of water, the management of the catchment is essential. The amended Water Act no. 8 of 2002 outlines a water catchment management strategy for the management, use, development, conservation, protection and control of the water resource within each catchment area. An advisory committee which oversees the management of the catchment is appointed from representatives within the concerned catchment area. It includes:

1. Ministry representatives
2. Local Authority representatives
3. Farmers or pastoralist representatives
4. Business community representatives
5. NGO representatives

6. Other persons who have demonstrated competence in matters relating to management of resources.

Lack of proper water management has led to short water supplies in Magadi. A water rationing program was initiated to ensure a continuous supply of water to the processing plants throughout the day. Water to the Township is rationed as seen in Figure 1.10. The Township residents receive water during peak use hours from 5.a.m to 8.a.m in the morning and from 5.p.m to 11.p.m in the evening.

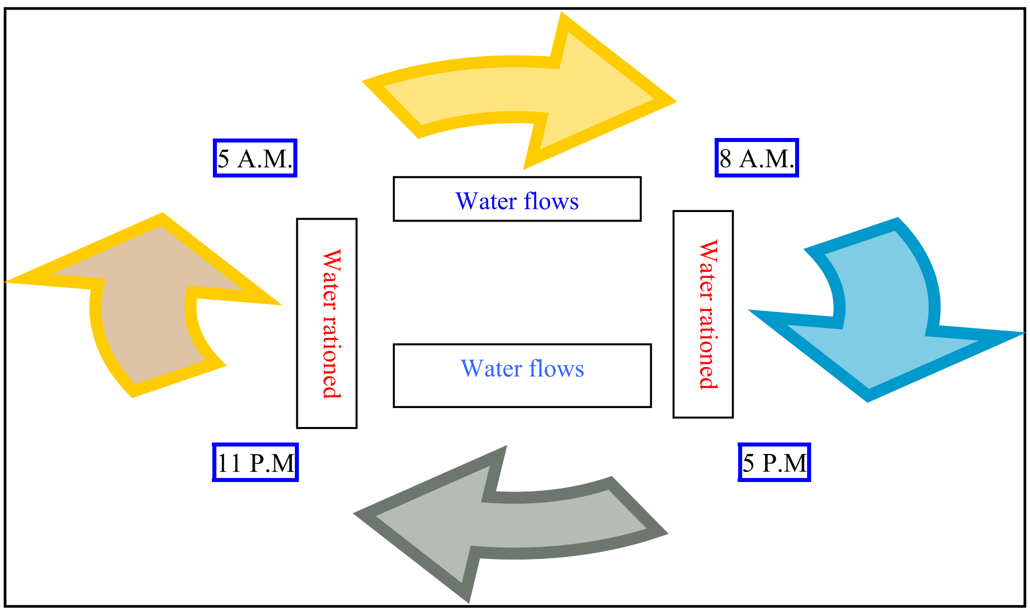


Figure 1.10: Water rationing schedule in Magadi

CHAPTER 2: LITERATURE REVIEW

Water is maintained by the hydrological or water cycle (Figure 2.1). It is the most important natural resource for the survival of all living things. It is indispensable for human domestic use and of vital importance to other sectors such as agriculture, transport, recreation and industry. As the world populations increase, demand for freshwater increases while its quantity decreases. If freshwater resources are severely strained, development and people's livelihoods would be adversely affected (Charalambous, 2001). As a result, ways of sustaining this diminishing resource are continually researched as it is subject to depletion when not managed properly (Charalambous, 2001). Almost 97% of the world's water occurs as salt water. Of the remaining 3%, two-thirds occurs as snow in the polar and alpine regions and 1% of global water occurs as liquid fresh water of which 98% occurs as underground water while less than 2% is available in streams and lakes (Bouwer, 2000).

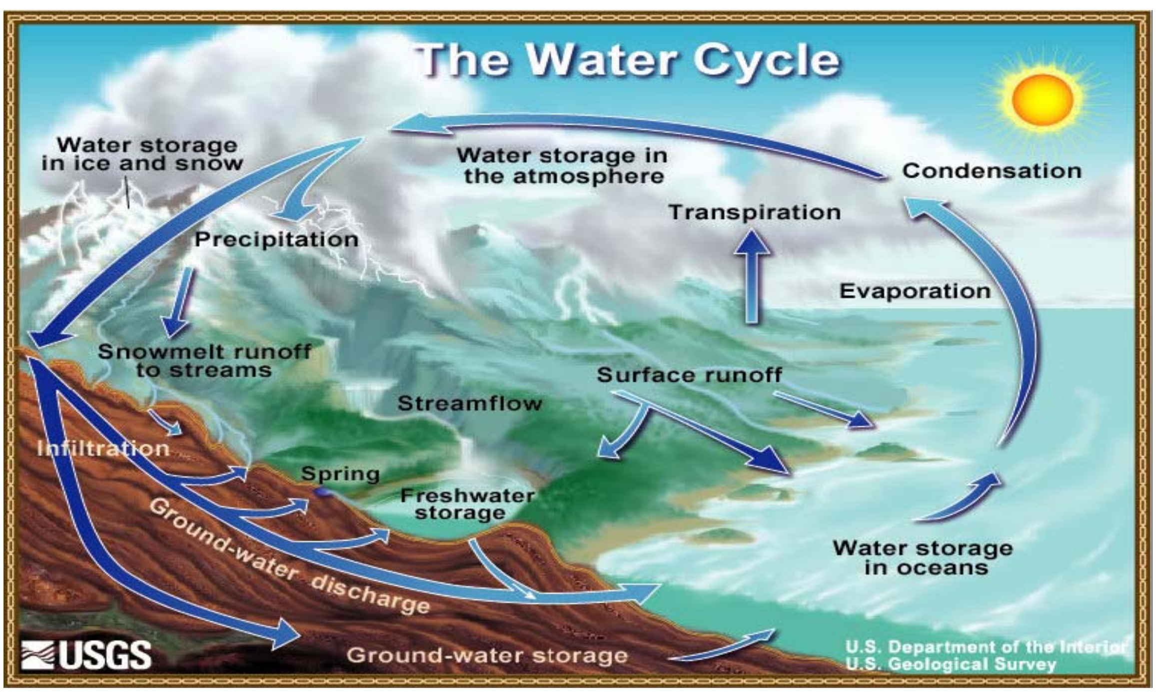


Figure 2.1: The hydrological cycle (USGS, 2004)

In many towns and cities, the available fresh water resources are heavily committed and in some cases, overcommitted. This is because freshwater resources are increasingly under pressure from continual growth in population, increased economic and agricultural activity and improved standards of living, leading to increased competition for water and an increase in the withdrawal of water from the hydrological cycle over time (Radif, 1999). To avoid a water crisis, Hinichsen *et al.,* (1999) suggests the following:

- Active water conservation practices
- Water demand and supply management
- Reduction of pollution.

The withdrawal of water from its source can either be consumptive or non-consumptive. The consumptive use of water occurs when water is withdrawn and is not returned to its source. This is observed during evaporation and transpiration from water bodies and plants respectively, absorption of water by plants and animals, the inclusion of water in finished pharmaceutical and chemical products and in domestic use. The non-consumptive use of water is the short term use of water before returning it to its source (lake, stream or river). It includes hydroelectricity generation and cooling systems in industries (Kemp, 2007).

2.1 FRESH WATER SCARCITY

Although the world has abundant water, freshwater has an uneven distribution upon the earth's surface. It varies from region to region and is dependent on seasonal and annual variations according to climatic conditions (Kemp, 2007). Widespread water scarcity is a common and growing phenomenon in most countries in the world despite continuous improvements in the water supply and distribution technology. Projections show that about half of the world's population faces real constraints in their water supply (Falkenmark and Widstrand, 1992). Mays (2007) estimated that the total water demand was going to increase steadily from 2001 to 2020 reaching 8.4 billion m^3 by the year 2011. This exerts pressure on the already stretched fresh water resources available in the world and would lead to communities across the world facing water supply challenges. Recycling, reuse and water treatment address these challenges by contributing water that is of high quality (Miller, 2006).

2.2 WATER CONSERVATION

Due to declining water tables and diminishing spring flows, it has become necessary to improve the utilization and management of water through conservation (Akkad, 1989). Water conservation can be defined as procedures, techniques and technologies that improve efficiency and effectiveness of water use. Efficiency is a measure of the extent to which the resources of water in an organization are utilized to provide the service while effectiveness is a measure of the extent to which the target objectives are met (Salmon, 2007). Water conservation should not be equated with water restrictions for consumer use. While water conservation programmes concentrate on continuous improvements in water use efficiency, water restrictions (water rationing) have been used as a quick fix measure for drought management or a water shortage situation (Charalambous, 2001).

Chalarambous (2001) explains that in Cyprus, the Water Board embarked on a detailed program of leakage control and pressure reduction which showed that the rate of leakage varied substantially with the pressure of water in the pipeline network. Therefore, any reduction in pressure initiated, resulted to a proportional reduction in leakage. This led to the reduction of unaccounted water losses from 25% in 1987 to 15% in 1997. The board also embarked on a promotional campaign through television, radio and leaflets to increase public awareness of water conservation and to change the attitudes of consumers on the efficient use of water (Charalambous, 2001).

A report on urban use of water in California, USA entitled, "Waste Not, Want Not", estimated that up to one-third of California's current urban water use (more than 2.8 billion cubic metres) can be saved using existing technologies (Gleick, 2004). The report shows that numerous opportunities were available to improve water use efficiency. They range from low flush toilets to mandating the installation of dual piping systems in new government buildings. The dual piping would allow the use of reclaimed water in urinals and HVAC (Heating, Ventilating and Air conditioning) systems (Gleick, 2004).

Water conservation serves two main purposes; reducing the use of water over a prolonged period of time and suppressing peak demand requirements which have a considerable impact on the size and capacity of facilities required to provide reliable supply to consumers. Akkad (1989) outlined these three ways of conserving water.

- Suppression of water use by physical methods using water efficient fittings and appliances such as low flush toilets.
- Incentive by implementing pricing policy options and
- Educating the consumers through media on the importance of conservation policies

Water conservation plans should address conservation both on the supply and demand of water. Conservation in the supply of water includes leak detection facilities, repairing and maintenance of water infrastructure and metering. This may require additional financial resources, however; this has some potential for reduction in operating costs and recovery of lost revenue. Conservation of water also includes reduction in consumer use by changing the attitudes of consumers. These attitudes can be changed through creating awareness among consumers on the proper and efficient use of water.

2.3 INTERVENTIONS TO ALLEVIATE WATER SCARCITY

Scarcity of freshwater restricts development. In order to meet the demands of an ever growing population, modern societies have spent massive amounts of time, money and effort to make water distribution uniform. Some interventions are discussed in the following sections.

Integrated Water Resource Management (IWRM)

IWRM is a systematic process for sustainable development, allocation and monitoring of water resource use in the context of social, environmental and economic objectives. The Global Water Partnership defines it as "a challenge to conventional practices, attitudes and professional certainties. It confronts entrenched sectoral interests and requires that the water resource is holistically managed for the benefit of all" (Radif, 1999).

In 1992, The International Conference on Water and Environment (ICWE) held in Dublin, Ireland, gave rise to four principles which became a basis for much of the subsequent water sector reforms. The four principles are highlighted in Table 2.1.

Table 2.1: Principles of Integrated Water Resource Management (ICWE, 1992).

• Fresh water is a finite and vulnerable resource which is essential to sustain life, development and the environment.
• Water development and management should be based on a participatory approach that involves policymakers and planners at all levels.
• Women play a central part in the provision, management and safeguarding of water.
• Water has an economic value to all its competing users and should be recognized as an economic good.

Countries in water scarce areas have increased their focus on improving and developing the water sector (supply management) and efficient utilization of water resource (demand management) for sustainable development. Because of the increased scarcity of water resources and the significant benefits of water for society, economy and the environment, IWRM plays an important role in sustainable development (Radif, 1999). The flowchart in Figure 2.2 summarizes the concept of IWRM.

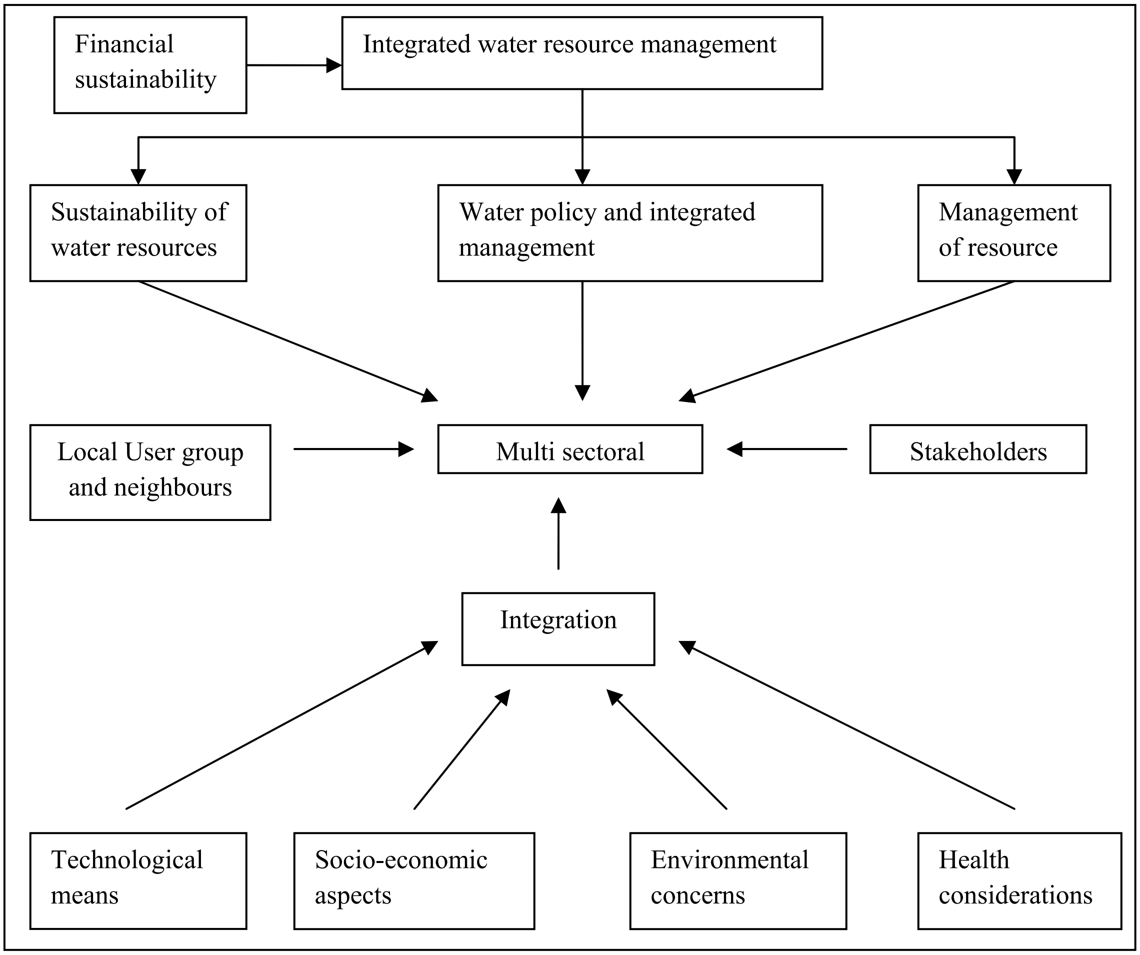


Figure 2.2: A flow diagram of Integrated Water Resource Management (Radif, 1999).

In Kuwait, an Integrated Water Resource Management strategy was implemented for developing unconventional water resources such as desalination of brackish ground and sea water, water reuse and water conservation measures (Hamoda, 2001). These water conservation measures included minimizing water leakage and losses during storage and distribution by developing more efficient water distribution and irrigation systems. The following alternative solutions were analysed in order to develop an IWRM strategy for water scarce countries. These solutions would be developed independently or in combination with each other.

- Developing any underdeveloped water resources including desalination of brackish water and promoting wastewater treatment and reuse (Smith *et al*., 2001).
- Minimizing water leakages and losses (Hamoda, 1998).
- Developing more efficient water distribution and irrigation systems (Sheikh *et al.,* 1998).
- Implementation of water conservation programs (Waveren, 1999).
- Application of adequate charges for water (Asano, 1998)
- Importing water from neighbours (Xu *et al.,* 2000).

Kuwait, an energy rich country, has integrated IWRM and has developed various strategies in response to the growing water demand. Strategies include the making of recent advanced technology in desalination which is a cost and time intensive method of treating wastewater. The recent advances have led to the dramatic decline in costs making desalination a viable and cost effective solution to constant water supply. Other alternative solutions that have been implemented to conserve water include; water reuse and using water efficient technologies such as using low flush toilet systems (Hamoda, 2001).

The City of Windhoek has an annual growth rate of approximately 5% and its water supply is based on the surface water and underground acquifers. Due to the uncertainty in the rainfall patterns and prolonged dry spells, the water supply to the city cannot be guaranteed to sustain the growing population. As a result, in 1994, the City of Windhoek, Namibia, approved an integrated Water Demand Management Program where a direct injection of reclaimed water to potable water is applied to increase the amount of water supplied in Windhoek (Lahnsteiner *et al*., 2004). Van der Merwe (1999) highlighted the points implemented in the program as:

- Maximum wastewater reuse by exploiting alternative sources of water through reclamation

- Water savings through preventing undue water consumption on private properties

- Prevention of pollution through regular inspection of underground water tanks.

Wastewater reuse

Miller (2006) explains that wastewater reuse involves taking an impaired source of water and utilizing advanced water treatment technologies to remove the impurities. However, the challenges faced include:

- Reducing the concentrations of total dissolved solids including organic chemicals and inorganic chemicals to extremely low levels.
- Accomplishing this task as inexpensively as possible.
- Disposing of the concentrate generated during the removal process.

In recent years, the reuse of wastewater has received serious attention as it presents an additional source of water supply. In arid areas, this is very logical as it alleviates water shortage provided the quality of treated water is acceptable for potable and non-potable use (Kuiper and Wechsler, 1974; Chu *et al.,* 2004). Water shortage caused by low rainfall combined with high evaporation rates in Australia (Christova-Boal *et al.,* 1996), large freshwater demand in Japan (Dixon *et al.,* 1999) or environmental and economic considerations in Germany (Nolde, 1999) and France (Faby *et al.,* 1999), are some of the examples of the driving forces that have led to practices of wastewater reuse. The types of wastewater are determined by their origin (Figure 2.3) which include municipal and industrial wastewater effluent (greywater), brackish water, poor quality (contaminated) groundwater, agricultural return flow, and storm water (Miller, 2006).

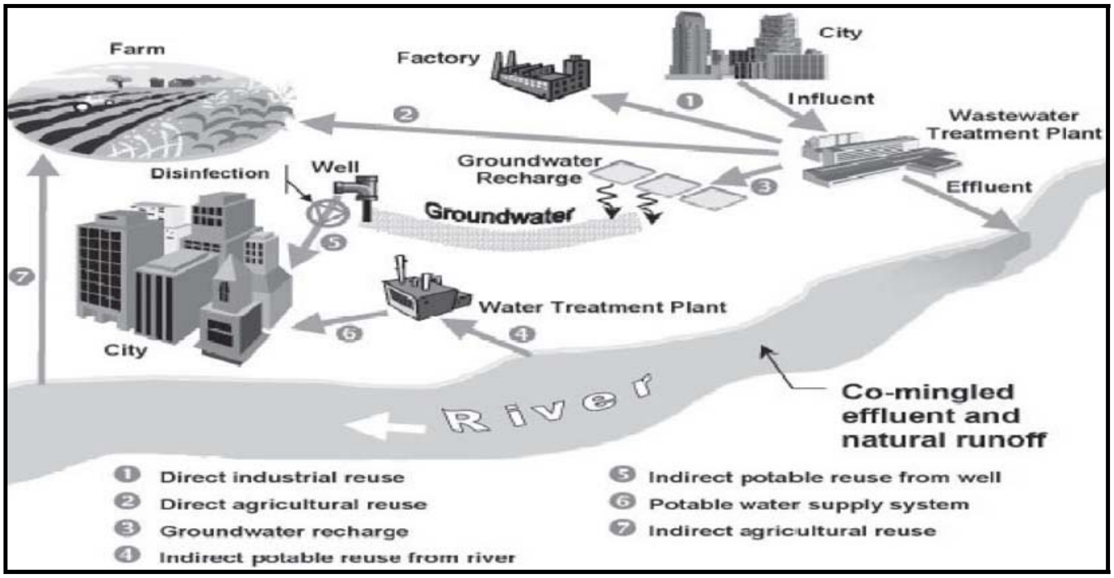


Figure 2.3: A water cycle in which wastewater treatment is used (Angelakis and Durham, 2008).

Characteristics of wastewater

Wastewater characteristics are useful in determining how wastewater can be treated efficiently. The effectiveness of wastewater stabilization during each treatment and the potential effects of the wastewater on the environment are also important factors to consider during treatment. The composition of wastewater refers to the actual amounts of physical, chemical and biological constituents present in the water (Muttamara, 1996).

Colour: This characteristic is indicative of age. Recycled wastewater should be free from colour. Fresh wastewater is grey in colour while industrial effluent has different colours depending on the type of effluent produced. The colour of sewage water depends on the level of decomposition and highly decomposed sewage water has a characteristic black colour and is known as black water (Muttamara, 1996).

Odour: These are gases that arise from the decomposition of organic matter present in the wastewater. Fresh wastewater has a distinctive odour. The most common odor is hydrogen sulphide which is produced by anaerobic bacteria turning sulphate compounds present in the water into sulphides. Odours are a major public concern when implementing wastewater treatment facilities and have caused the rejection of most water treatment projects (Eriksson *et al.,* 2002).

Solids: Solids are classified as total and suspended solids. Total solids are the total matter left after water has been evaporated at 103^0C whereas suspended solids are those that can be removed from water through filtration via membranes. Suspended solids increase the turbidity and silt loads in receiving water environments thereby reducing the oxygen content in receiving aquatic environments. Measurement of turbidity and suspended solids give information about the content of colloids that may cause clogging of installations; for example, piping and sand filters (Eriksson *et al.,* 2002). Total solids promote the decomposition of sulphates present in wastewater producing offensive odours (Muttamara, 1996).

Temperature: The temperature of wastewater has an effect on aquatic life by depleting the level of oxygen in the receiving water. High temperatures increase the growth of fungi and other undesirable species which absorb the oxygen in the water while low temperatures limit the form of wastewater treatment methods as well as increase the time required for treatment. An ideal temperature would prevent the growth of fungi and other species in addition to limiting the duration of wastewater treatment (Muttamara, 1996).

Organic compounds: They contribute to the toxicity of wastewater and are composed of carbon, nitrogen and oxygen and are either bio-degradable or non-degradable. Bio-degradable compounds reduce the oxygen resources of the receiving water while non-degradable compounds complicate the wastewater treatment process (Muttamara, 1996). Measurements of the BOD, COD and other nutrients like nitrogen (N) and phosphorus (P) will give an indication of oxygen depletion in the water due to degradation of organic matter during transportation and storage. Oxygen depletion causes sulphide production which causes the characteristic offensive smell of grey wastewater (Eriksson *et al.,* 2002).

Inorganic compounds: They include chloride ions, alkaline and acidic compounds and heavy metals. They affect the growth of organisms in receiving water by facilitating eutrophication (Muttamara, 1996).

Gases: Oxygen, hydrogen sulphide and methane are the common gases present in fresh wastewater. In absence of aerobic conditions, methane-producing bacteria reduce inorganic salts such as sulphates to sulphides that produce offensive smells which are a public concern. To eliminate this, an aerobic state should be maintained in wastewater treatment facilities (Muttamara, 1996).

Xenobiotic compounds: These compounds originate from the chemical products used in households such as detergents, soaps, shampoos, perfumes, preservatives, dyes and cleaners. These products are also known as bulk XOC's because they are produced in large quantities and cause the greatest problems when introduced into the environment. It is expected to find large amounts of soaps and detergents in grey wastewater as people frequently use these products for daily cleaning and housekeeping (Eriksson *et al.,* 2002).

Biological characteristics: These include micro-organisms such as pathogenic viruses, bacteria, protozoa and helminthes from bodies of infected persons or animals and strongly affect the quality of water in the receiving environment (Toze, 2006). These micro-organisms may be introduced from hand washing after toilet use, bathing and during laundry. *E.coli* is commonly used as an indicator for faecal contamination by investigating its presence in wastewater. Some viruses (enteroviruses) easily spread in faecally contaminated waters (Eriksson *et al.,* 2002). *Legionella* species is resistant to water treatment process and pose a specific threat as it can be spread through aerosols which can be inhaled during irrigation or toilet flushing (Dixon *et al.,* 1999). Protozoa and helminthes would not pose a great threat in relation to groundwater contamination. Their large size makes their removal by filtration easier when water percolates under gravity through sand filters. Some organisms such as *Cryptosporidium* species are resistant to disinfectants and are spread by spores. The spores can be used as indicators for cumulative faecal contamination (Faechem *et al.,* 1983).The wastewater discharged into the environment affects all organisms and this needs to be considered during the treatment of wastewater. Limits should be set to ensure that the presence of these biological characteristics in wastewater is acceptable (Table 2.4) (see page 52).

2.4 GREYWATER

Greywater is defined as wastewater without any input from toilets and urinals. It is collected separately from sewage flow and includes water from laundry, bathrooms and showers but not dishwashers, kitchen sinks or toilets of office buildings, schools and households and is estimated to account for 50-80% of all residential wastewater (Eriksson *et al.,* 2002). The early applications of wastewater reuse included the irrigation of golf courses and landscapes while present applications include industrial reuse, irrigation of edible and non edible agricultural crops and household reuse (Oasis, 2005).

In Tuscon, Arizona, the use of greywater in flushing toilets and urinals was estimated to contribute to savings of about 30% of the total household consumption (Karpiscak *et al*, 1990). Greywater reuse has been applied as a sustainable water management tool in some arid areas such as Jordan, where the greywater has been collected separately from the flow from toilets, dishwasher and kitchen sinks and the flow from washing machines, showers, bathtubs and sinks for use after treatment (Al-Jayyousi, 2003). In Germany, it has been technically feasible to reuse greywater collected from bathrooms because the health requirements are met after treatment (Nolde, 1999).

Greywater represents the largest potential source of water in domestic use and makes a significant contribution towards the reduction of potable water use (Eriksson *et al.,* 2002). Its adoption is gaining considerable attention more in developed nations than in developing African nations where development of new water sources is perceived as the only way of meeting the water requirements of its population (Maeda *et al.,* 1996). Greywater reuse differs slightly between countries. In developed countries, people use washing machines, dishwashers, bath tubs and showers while in the developing countries, prohibitive costs of these appliances lead people to use the basic equipment for washing which includes tubs and basins. This makes the collection and treatment of greywater in developed countries relatively simple compared to the developing countries. Good infrastructure in developed countries promotes wastewater reuse and controls the disposal of greywater into the environment whereas in developing countries, the reuse would be at the discretion of the user (Eriksson *et al.,* 2002).

Since greywater is generated by the use of bathing and laundry soaps, its quality varies according to the source, geographical location, demographics and level of occupancy (Al-Jayyousi, 2003). Table 2.2 shows the typical composition of greywater from various sources.

Table 2.2: Typical composition of greywater (Al- Jayyousi, 2003)

Source	Biological Oxygen Demand (mg/l)	Chemical Oxygen Demand (mg/l)	Turbidity (NTU)	NH_3 (mg/l)	P (mg/l)	Total coliforms
Hand basin	109	263	-	9.6	2.58	-
Shower or bath tub	121	371	69	1	0.36	-
Synthetic greywater	181	-	25	0.9	-	1.5×10^6
Single person	110	256	14	-	-	-
Single family	-	-	76.5	0.74	9.3	-
Block of flats	33	40	20	10	0.4	1×10^6
College	80	146	59	10	-	-
Large college	96	168	57	0.8	2.4	5.2×10^6

Thorough characterization and evaluation of possible sources of pollutants of grey wastewater before reuse is very important for establishing the proper treatment method. These characteristics depend on the following (Eriksson *et al*., 2002):

- The quality of water supplied.
- The type of distribution network for both drinking water and the grey wastewater.
- The activities in the household.

The compounds present in the water vary from the source, the lifestyles and customs as well as the use of chemical products in the households. The composition will vary significantly due to variations in water consumption in relation to the amount of substances discharged.

Eriksson *et al* (2002) points out the number of problems associated with the reuse of untreated greywater and this explains the importance of treating greywater before use.

- The risk of spreading waterborne diseases due to exposure to micro organisms in the water is evident. The micro organisms are spread in the form of an aerosol generated during irrigation and by flushing toilets they are transmitted through inhalation and by hand to mouth contact (Albrechtsen, 1998).
- Growth within the wastewater reuse systems is another source of micro organisms and chemical contaminants.
- The risk of polluting the receiving environments (soil and water) due to the different pollutants from wastewater is another question that has been raised following infiltration into the main water supply and irrigation.

The World Health Organisation (WHO) has offered guidelines for the limits of treated wastewater used for irrigation of agricultural crops and public sports fields as seen in Table 2.3.

Table 2.3: The World Health Organisation limits for treated wastewater (WHO, 1989).

Micro organism	Limits
Faecal coliform bacteria	< 1000 per 100ml
Nematodes	<1 per litre

Several countries have worked on guidelines for reuse of treated wastewater for non-potable use. These guidelines provide the limits of the bacterial count that should be present in recycled wastewater (Table 2.4).

Table 2.4: The limit for total coliforms in different wastewater applications in different countries (Nolde, 1999).

	Country	Application	Limit for total coliforms
1.	USA		
	• California	Toilet and urinal flushing, commercial laundries and decorative fountains.	Max. 2.2 per 100 ml (total coliforms).
	• Florida	Toilet flushing and irrigation of recreation areas.	No detected faecal coliforms per 100 ml.
2.	Australia	Recreational applications Irrigation of salad vegetables	<150 per 100 ml <10 per 100 ml
3.	Germany	Recreational applications Irrigation of salad vegetables	<150 per 100ml <10 per 100ml

2.4.1 Applications and benefits of grey wastewater

Greywater presents a sustainable supply of water as it can be used in place of freshwater for a variety of activities and it also reduces the use of potable water (Madungwe and Sakuringwa, 2007; Toze, 2006). Some of the applications and benefits of using greywater are discussed below.

Irrigation and Agriculture

Plants not only require water for their growth, but also nutrients to flourish. Greywater contains the nutrients (N and P) necessary for plant growth enabling landscapes and decorative plants to flourish. The recycling of greywater for agricultural purposes utilizes a valuable onsite resource as well as reclaiming wasted nutrients which are responsible for maintaining the fertility of the land (Oasis, 2005). Greywater reuse has contributed significantly to the supply of fresh fruits and vegetables to urban markets in Latin America and the Caribbean (Oasis, 2005). The reuse of water for agricultural irrigation is often viewed as a positive means of recycling water due to the potential large volumes of water used. The continuing increase in crop yields has increased the demand of water for irrigation (Toze, 2006). In Bulawayo, Zimbabwe, the use of greywater in landscape and agricultural irrigation consumes a significant amount of reclaimed water. As a result potable water is conserved and the cost of fertilizer is reduced since reclaimed water provides the nitrogen and phosphorus necessary for plant growth (Taigbenu and Ncube, 2005).

A study conducted in the City of Los Angeles on the use of greywater for irrigation of landscapes and lawns, showed 12-65% of potable water savings (Sheikh, 1993). In Sydney, Australia, a Water Reclamation and Management Scheme (WRAMS) was designed and adopted to treat raw domestic sewage to recycled water. This reclaimed water was used in the Sydney Olympic park during the Olympic Games in 2000 and it provided a continuous supply of water for irrigation of landscapes and lawns in the Olympic park as well as the surrounding suburb of Newington (Chapman, 2006).

Western closet (WC) and urinal flushing

Greywater is used in toilet and urinal flushing because it is considered wasteful to use potable water for these activities (Madungwe and Sakuringwa, 2007) In Brisbane, Australia, the use of greywater in ablution facilities has achieved 30-50% of potable water savings (Jeppesen, 1996).

Industrial use

Some industrial processes particularly cooling processes use a considerable amount of water. Reclaimed water would be suitable for use in cooling towers. This is, however, not practiced in many countries because many industries in developing countries enjoy a cheap source of water that is exploited in an unregulated manner (Taigbenu and Ncube, 2005). These countries should therefore enforce regulations that promote the use of recycled process water on processes that are water intensive not only to conserve potable water but also to reduce the amount of contaminated water released into the environment.

Groundwater recharge

This is the replenishment of groundwater by assimilating and storing reclaimed water in underground aquifers. This can be achieved by pumping reclaimed water to underground basins or by directly injecting reclaimed water into groundwater aquifers (Asano, 2001).

Extending potable water resources

Highly treated wastewater can either be blended in the water supply storage reservoirs or directly injected in the water distribution network. This application has been successful in Windhoek, Namibia which is an arid country with limited freshwater resources (Harhoff and van der Merwe, 1996).

The costs incurred by municipalities in treating and supplying potable water are drastically reduced because municipalities can avoid the construction and development of new water infrastructure (Madungwe and Sakuringwa, 2007). The use of greywater can also reduce the costs incurred by importing water from other locations (Madungwe and Sakuringwa, 2007). The inception of WRAMS in Sydney, Australia during the Olympic Games in 2000 has saved up to 800 ML of drinking water per household each year and it has been projected to save up to 1000 ML in the future (Chapman, 2006).

Other applications

Recycled greywater can be used in car washing bays, infrastructure construction (roads and houses) where considerable amounts of water are used in the compaction of bases during construction. Greywater can also be used in fire protection appliances and air conditioning.

The use of greywater/reclaimed water in recreation is also another application (Madungwe and Sakuringwa, 2007). Greywater is used to create manmade lakes and wetlands which can be found in golf courses and fountains in urban developments. These wetlands provide creation of habitats and an alternative to discharge effluent water into receiving environments (Asano, 2001).

2.5 BLACK WATER

This is water collected from toilets, kitchen sinks, dishwashers and may also include water from baths (Erikkson *et al., 2002*). In developing countries, this untreated sewage is discharged into aquatic environments without any treatment. This unregulated practice results to contamination of water that is then unsuitable for human consumption, irrigation, fish production and recreation (Denny, 1997). Municipal and industrial sewage contain readily biodegradable organic matter, inorganic and organic chemicals, toxic substances and disease causing agents (Shuval *et al.,* 1986).

In Bulawayo, Zimbabwe, reuse of water from sewage treatment works has been carried out since 1960 (Taigbenu and Ncube, 2005). This water has been reused in toilets and urinals as well as in the construction industry where water is used for compacting bases when building houses and highways (Taigbenu and Ncube, 2005). Countries like Morocco, Tunisia, Egypt, Sudan, Namibia, India and China have been known to use reclaimed sewage water for irrigation of vegetables (Shuval *et al.,* 1986). Although the nutrient value (fertiliser) of sewage water is seen as an economic benefit, the high risk of easy transmission of water borne diseases is one of the main concerns during the use of reclaimed sewage water. As a result, adequate treatment prior to its reuse or redistribution into the environment is needed (Kivaisi, 2001).

Kadlec and Knight (1996) outline the advantages of using wetland technologies as compared to other conventional methods in the treatment of sewage water. These wetlands provide an alternative source of sewage and other wastewater treatment especially in developing countries because of their low technology, low cost, easy operation and do not require chemicals during treatment of water (Kivaisi, 2001).

These wetlands are manmade copies of natural wetlands and are increasingly used throughout the world as secondary and tertiary treatment of wastewater (Rousseau *et al*, 2008). Studies have been conducted where artificial wetlands which contain macrophytes have been used to breakdown the compounds present in the human and animal waste by removing pollutants (Kadlec and Knight, 1996) by processing the contaminants found in greywater (Townshend, 1993). They are suitable for small communities in developing countries where potential health benefits from pathogen removal are considerable (Shutes, 2001). Careful designing and maintenance of these artificial wetlands can yield at relatively lower costs, an effluent suitable for reuse (Rousseau *et al*, 2008). The management and maintenance of these systems require trained and experience staff since their long-term efficiency and sustainability is dependent on the understanding of their biological, chemical and hydrological processes (Shutes, 2001).

Artificial wetlands prevent the discharge of harmful wastewater effluents into the environment. This reduces the financial costs required in cleaning up a polluted environment. In addition, species living in receiving environments for example fish, birds, insects and plants are able to thrive in a less contaminated environment by reducing or eliminating the quantity of treated wastewater discharged to sensitive surface water (Shutes, 2001).

2.6 DESALINATION

Tsiourtis (2001) defines desalination as a method of treating water by removing salinity to meet the standards for intended potable use. It is a necessary component for future water supplies as it is perceived to be able to supplement the limited freshwater supplies. Globally, desalination practices are rapidly growing. To establish the relationship between desalination and the environment, analysis of the process, inputs and outputs and their relationship to the environment should be evaluated (Tsiourtis, 2001). Each input and output has a positive and negative effect on the environment. With proper mitigation measures, adverse effects may be minimized where positive effects are maximized. Desalination of brackish water, poor quality groundwater and sea water is expanding rapidly to support urban and industrial developments in arid and semi-arid regions as well as remote areas where water is not available or too costly to develop (Tsiourtis, 2001). The desalinated water is recovered for consumption where the salts are concentrated in a stream of water called the brine reject. This reject is disposed either to the sea, a saline aquifer or evaporation ponds and has potentially severe environmental impacts on the receiving environments. This process requires high amounts of energy to operate and can use a number of technologies to produce pure water (Al-Alawi, 2000). The process of desalination can be summarized in Figure 2.4.

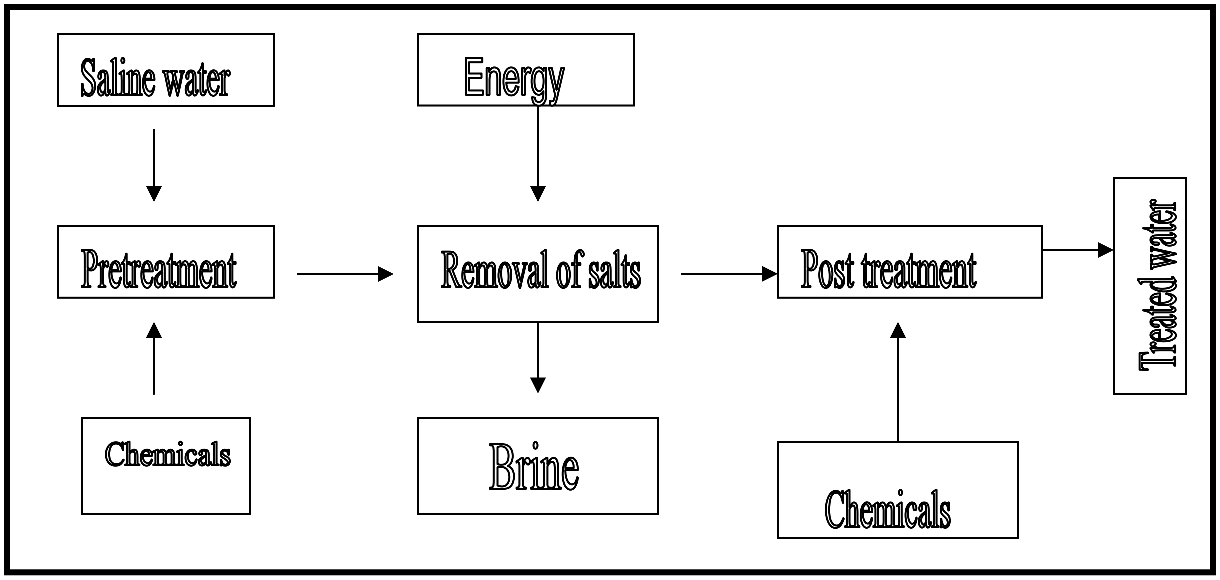


Figure 2.4: A flow diagram describing a hypothetical desalination process (Al-Alawi, 2000).

Tsiourtis (2001) outlines the most important concerns for a desalination plant in relation to the environment. These concerns are explained by the following three points.

1. **Location of the plant:** The site should be close to the raw water, energy supply, existing water system and the consumers in order to reduce the costs of supplying water by avoiding installation of unnecessary infrastructure such as installation of additional pipelines, pumping machines and power plants.

2. **Brine disposal:** The brine should have a minimum impact on the receiving environment (land or water). The brine is disposed in the sea, an inland water body and evaporation ponds.

3. **Energy considerations:** These considerations must include the availability of energy, the cost of production, its environmental effects and the type of desalination process

required. Both renewable and non-renewable sources of energy have to be considered. Renewable sources of energy include solar, water, geothermal and wind. However, these sources are often limited, unreliable and costly. On the other hand, non-renewable sources of energy such as fossil fuels and atomic energy are subjected to depletion and are among the biggest global environmental threats.

According to the International Desalination Association (IDA), there were 15,000 desalting units installed globally with a capacity of 6 billion gallons/day (22,714,470 m^3/day) in 2002. IDA projects that an additional 3 billion gallons/day (11,356,235 m^3/day) capacity would be added during the period between 2002 and 2004. In the USA, the El Paso Water Utilities are working in collaboration with the US Army's Fort Bliss base in constructing the world's largest inland brackish groundwater desalination facility (Miller, 2006).

In the United Kingdom (UK), a large entertainment complex (Millennium Dome) located in London has an 87 m borehole sunk on the site to provide water for flushing the toilets. The water was found to be brackish and contaminated with hydrogen sulphide, ferrous iron and aromatic hydrocarbons. The treatment utilized oxidizing the sulphide, and ferrous ions with hydrogen peroxide, adsorption of the organics and filtration of the precipitated ferric hydroxide on granular activated carbon before desalination by Reverse Osmosis (RO). The final water product was re-hardened and disinfected before use in the Dome's toilets. A saving of approximately 50% of drinking water supply was observed (Smith *et al.,* 2001).

In Kuwait, seawater and brackish groundwater have been considered as alternative sources of water. Almost 90% of freshwater demand is satisfied by seawater desalination using Multi-

Stage Flash (MSF) distillation and Reverse Osmosis (RO) technology. The water is used for irrigation and landscaping, construction works, household purposes and livestock watering. The current desalination capacity is 1.65 million m^3/day of which 1.45 million m^3/day is provided by MSF distillation and 0.17 million m^3/day supplied by RO (Hamoda, 2001).

Thermal methods

This method is similar to the hydrological cycle in that the salty water is heated to produce a vapour which is condensed to form fresh water that is free of salts. The pressure of the water is adjusted to control the boiling point. Minerals are added to the fresh water to make it suitable for human consumption. The important factors considered for this method are: proper temperature, ambient pressure and adequate energy for vaporization (Al Alawi, 2000). The known thermal methods are:

- Multi-stage Flash distillation (MSF) process.
- Multi-effect distillation (MED) process.
- Vapour compression distillation (VC) process.

Membrane methods

Membranes have the ability to differentiate and separate dissolved salts and water. Al Alawi, (2000) outlines the two desalination processes which have been developed and are commercially available for desalting water as:

a. Electrodialysis (ED) which is voltage driven and uses electrical potential to move salts selectively through the membranes and leaving pure water as a product.

b. Reverse osmosis (RO) which is a pressure driven process where pressure is used for separation by allowing fairly pure water to move through a membrane leaving behind a brine solution (Al Alawi, 2000).

Other methods

These methods have not achieved the same level of commercial success but may be valuable under other circumstances or with further technological improvements. They include; freezing, membrane distillation, solar humidification, wind and solar driven processes which produce energy for other desalination processes (Al Alawi, 2000). For the purpose of this research, these methods will not be discussed in detail.

2.7 STORM WATER

Villarreal (2003) defines storm water as the water flow that results from precipitation either from rainfall or snowmelt. Its collection and use has been acknowledged to promote potable water savings in different countries and reduce environmental impact. In urban areas, it is generated by rain run-off from roofs, roads, driveways, footpaths and impervious surfaces and it is not treated before its discharge to the waterways, constructed wetlands or ponds (Villarreal, 2003). If storm/rainwater systems are efficiently managed, they can add to the available potable water increasing the total supply of water to various consumers (Gardner, 2001). The storm water system should be properly managed to avoid onsite and offsite problems through erosion and transportation of soil, chemical nutrients, chemical pollutants and sediments to waterways (Gardner, 2001).

In developed countries like Australia, the storm water system is collected separately from the sewerage system but this is not the case in developing countries. The Storm Water Recycling background study, released by the Australian government in 1999, investigated the status of storm water recycling. The report cited a brief overview of the applications, costs and other issues associated with the storage, collection, treatment, quality environmental and implementation of rainwater recycling. The study found out that storm water recycling was a feasible option with significant environmental benefits (Hatt *et al.,* 2006).The main benefits include:

- Having a sustainable alternative supply of water.
- Using less energy in water treatment.
- Reduction in the quantity of treated wastewater discharged into the environment by recycling and reusing it.

In Brazil, it has been reported that the use of rainfall/storm water has led to potable water savings ranging from 48-%-100% in the northern region and 34%-92% in the southern region. A study conducted in the City of Palhoca, Brazil showed that the combined use of storm water and greywater led to a potable water savings of 35.5% (Ghisi *et al*, 2007). Figure 2.5 shows a hypothetical diagram of flow of rainwater from a roof run-off.

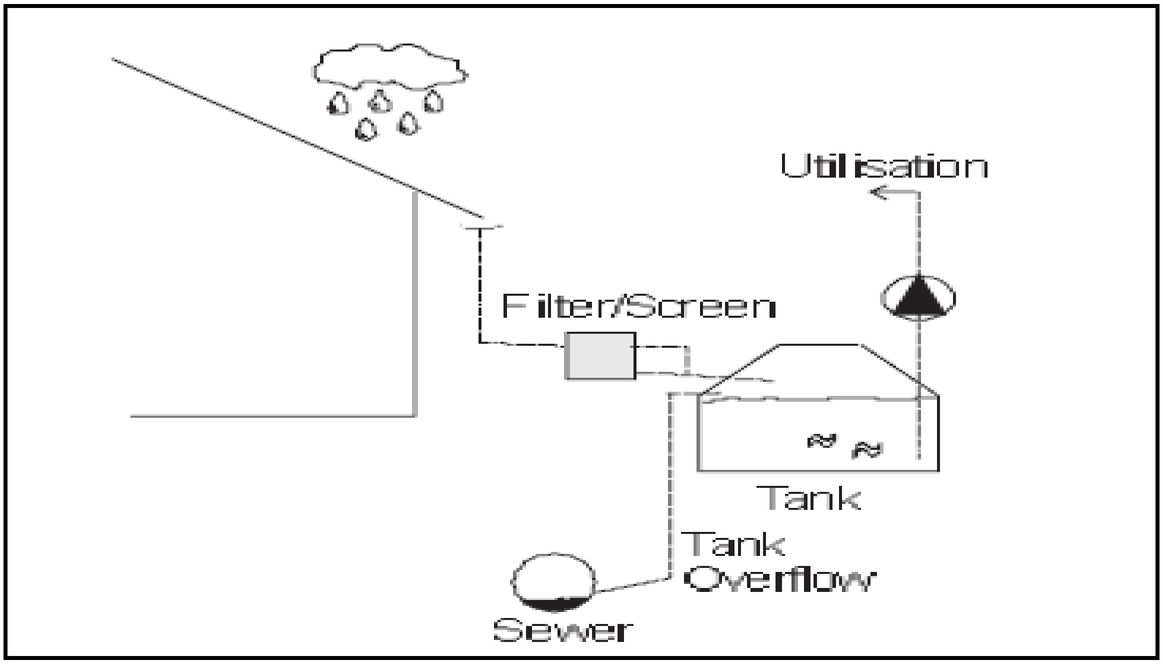


Figure 2.5: Collection of rainwater from a roof run-off to a storage tank (Hermann and Schmidt, 1999).

2.8 AIMS OF THE STUDY

The aim of this study was to identify different methods for achieving long term water sustainability in Magadi. Magadi has limited fresh water resources and to avoid a crisis, water must be conserved and properly managed. The proposed methods for better management of this scarce resource should be cost effective, practical and sustainable. This project is a first approximation of the volume of water usage in Magadi. The study identified the following issues.

- The volume of water used in the Township
- Areas where water is wasted in the Township.
- Any water conservation practices carried out in Magadi Township.
- The existence of a water balance system in MSC.

- Possibilities for recycling waste water/effluent/process water released into the environment by MSC.

Main Objective

To contribute to long term plans towards managing the sustainability of water supply to the Township by looking at the current water consumption by Magadi residents.

Specific objectives

- To identify all the water uses in the Township as opposed to the industrial use.
- To determine the daily consumption rate of water in the Township.
- To contribute towards the creation of a water balance tool in Magadi.
- To ascertain the possibility of greywater use.
- To identify ways of conserving water both by MSC and community.

Questions

- Is the daily consumption of water the same across the three classes of housing in Magadi Township?
- Is there a relationship between the number of occupants in a household in the different classes of housing and the daily amount of water consumed in Magadi Township?
- Are the number of occupants in each household and the class of housing good predictors of the total daily water consumption in Magadi Township?
- Is there a difference between the total daily consumption of water during the dry and wet season?
- Does a relationship exist between the water consumption pattern and the household activities in Magadi?

CHAPTER 3: RESEARCH FRAMEWORK AND METHODOLOGY

3.1 INTRODUCTION

Water scarcity in Magadi arose after a prolonged dry spell since 2000 and an increase in the population of residents in the Township. In addition, a new fly ash plant was commissioned in 2005, to increase the production of Na_2CO_3 for sale. However, this new plant affected the supply of water to the Township as it required large amounts of water for processing the trona into soda ash. The Water Development Committee (WDC) was charged with the responsibility of identifying measures that would promote the sustainability of water to support the new plant and the Township. Water rationing to the Township was introduced as a short term measure to ensure a continuous supply of water to the processing plants. However, long term efficient use of water is required to ensure that adequate water is supplied not only to the processing plants but also to the Township and the local community. Current water use was determined through collection of data from the Township residents on their daily consumption of water on different domestic activities.

3.2 METHODOLOGY

Water is provided free of charge to the residents because MSC has not installed water meters along pipelines to monitor and quantify the water usage. A questionnaire (Appendix 4) was therefore designed to acquire information from the Township residents to estimate the daily consumption of water in their households on various domestic activities. The number of 20-L buckets or jerry cans determined the daily amount of water used by each domestic chore. These activities included; laundry, cooking, washing utensils, bathing and toilet flushing, car wash and irrigation.

The questionnaire was drafted and sent for vetting to Mrs. Cathy Reichardt. The corrected copy was sent to the Human Research Ethics Committee for approval (Protocol No. H080622), the final copy was sent electronically to the EHS Manager (Mr. Alfrrey Kasalu) and the WDC representative (Mr. Nick Kuru) in MSC for comments. The questionnaire addressed the following main issues; quantity and quality of the water consumed, the conservation methods adopted by the Township and number of occupants living in each household. The quantity of water consumed daily was measured by the number of 20-Litre buckets or jerry cans each sampled household used for a particular domestic activity. Three aspects of this study were investigated and they include:

1. Site Visits
2. Interviews with the company representatives
3. Interviews with the Township residents

Site visits

During the research period, visits to different sites were made to provide a general understanding on the water distribution network in Magadi. These sites included: The sources of water (Oloibortoto Stream and Fish Springs Water), the water treatment plant, the sewage area and the six off take points (Table 1.3) along the pipelines that supply water to the local community.

Interviews with the company representatives

An informal interview approach was facilitated by the Environmental, Health and Safety manager (Mr. Alfrrey Kasalu) and was conducted with some employees of the company through conversations (Table 3.1). Face to face interviews allowed for further probing to acquire more information from company representatives. These representatives were directly involved in the implementation of water policies in Magadi and they have firsthand experience on the issues challenging MSC on the use of water in Magadi. The interviews were conducted for 30 – 60 minutes. The main aim of conducting these interviews was to investigate;

1. The current solutions MSC undertook to alleviate the water scarcity problem.
2. The challenges facing the implementation of these solutions.
3. The identification of other sources of water.
4. Future practices that can be adopted to ensure that long term sustainability of water is achieved.

Table 3.1: List of Informal interview schedule for officials in Magadi Soda Company

NAME	DAY/TIME	POSITION	ACTIVITY
Sammy Chepkwony	4th Sept 2007 (8.00 – 9.00 am)	Human Resources Director	Signing of confidentiality document and giving consent for commencing the research
Alfrey Kasalu	4th Sept 2007 (9.00-9.45am)	Safety, Health and Environmental Manager	Giving insight on the environmental projects undertaken in Magadi
Lemarron Kaanto	4th Sept 2007 (11.00-11.30am)	Community Development Manager	Explaining the distribution of water to the surrounding community
Daniel Ogol	6th Sept 2007 (2.00-2.30pm)	Town welfare Manager	Examining the town records including the census reports
Nathaniel Parantai	10th Sept 2007 (10.00-11.00)	Quality Control Head	Explaining the analytical tests performed on the water in Magadi. Collects and records climatic data from the weather station in Magadi
Nick Kuru	11th Sept 2007 (2.00-2.45pm)	Civil engineer and Water representative	Explaining the layout of the water distribution systems in Magadi. In charge of the water records for the whole company

Interviews with the Township residents

The research was conducted over a period of two weeks by the researcher and commenced from the 4th of September, 2007 to the 18th September 2007. The target population for this research was the Magadi Township residents. Conducting interviews was the best approach for acquiring quantitative data as the researcher is able to extract as much information from the respondent as possible. The interviews were conducted at a household level where random sampling was the preferred choice to ensure a full representation of the classes of housing in Magadi Township. Prior to commencing the interviews, an introduction and explanation was made to the respondent about the nature of the study that was being conducted.

Data collection involved the use of a questionnaire (Appendix 4). This questionnaire was structured to have both open ended and closed questions[5] where majority of the questions were closed. A questionnaire was administered to sampled households through face to face interviews. These interviews were designed to encourage dialogue with the respondent and the responses were recorded on the questionnaire. A tape recorder was not used to collect data as this increased the chances of having a successful interview by reducing respondent inhibition. During some of the interviews, observations were made on how the residents performed the activities and this provided an understanding on how much water was being used for each domestic activity and this was used to modify the estimates of water consumed for each chore. Observations were also useful in identifying which areas the water was wasted during distribution and points of use.

[5] *Open ended questions allow the respondent to express an opinion without any influence from the interviewer while closed ended questions limit the respondent to the alternatives that are likely to be offered (Foddy, 1993).*

3.2.1 Sampling of Township residents

Random sampling involves drawing independent samples from the population. However, this may not completely represent the data. Therefore, stratified sampling was introduced to eliminate this anomaly. Stratified sampling involves the selection of samples from different strata within the population. In this study, the population was divided into three groups/strata (upper, middle and lower class) and samples were drawn from each group. This ensured that the sample was impartial and a representation of the whole population.

The sample size in this study was determined using the formula,

$n = \left(z_{1-\alpha/2} \,\sigma/D \right)^2$, where D is the size of effect, n is the sample size, α is the significance level and σ is the standard deviation of the population from which the sample is drawn. Using an α value of 0.05 and a power of 86.1%, the sample size for use in this study was determined as 100 respondents. This was a single sample split into three different classes[6] of housing where 22, 176 and 286 households belong to the upper, middle and lower class respectively. A ratio of 1:8:13 was used and as a result, out of a sample size of 100 respondents; 6, 37 and 57 households were sampled from upper, middle and lower class of housing respectively. The sample size for the upper class households is relatively smaller than the other two housing classes because the upper class houses senior members of staff in the company who make up a small number of employees in the company.

[6] Upper management houses (high), Middle level management houses (middle) and junior employees (low class houses).

3.2.2 Data collection

The questionnaire was structured to investigate the amount of water used for different day to day domestic activities in different households, which day the water consumption was the highest and methods of recycling water that have been adopted by the Township residents. The data collected from the study was recorded in a MS Excel Spreadsheet (Appendix 5). Statistical analysis was performed using *SAS Enterprise Guide 9.1, (2002)* and *MS Excel spreadsheet, (2003)*. Data was checked for normality and no transformations were required since the distribution was not skewed.

3.2.3 Data analysis

The quantitative data was presented by use of standard errors and *p*-values. Parametric and non parametric tests were conducted to determine any significant differences in the hypotheses. Descriptive statistic techniques such as the mean, standard deviation, median and range were used to summarize the data. The analysis was based on the following questions formulated for the study.

1. Is the daily consumption of water the same in the three classes of housing in Magadi Township?

This was investigated by comparing the interactions of the different variables to see whether a significant difference existed between them. ANOVA using Welch's ANOVA and the Bartlett's test was used to compare the different housing classes in Magadi and the daily amount of water used for domestic activities by measuring the assumption of equal and unequal variances respectively between the classes of housing.

A multiple comparison test was performed to determine where the actual differences in the consumption of water lay.

2. Is there a relationship between the number of occupants in a household in the different classes of housing and the daily amount of water consumed in Magadi?

This relationship was determined by a correlation analysis through the Pearson correlation co-efficient. This co-efficient was used to show whether a weak or strong correlation existed between the two variables.

3. Are the number of occupants in the households and the class of housing good predictors of the total daily water consumption in Magadi Township?

To determine whether the number of occupants and the class of housing were good predictors of the daily total consumption of water, a multi regression analysis was used. Diagnostic tools such as residual plots, collinearity diagnostics, leverage, covartio, dffits were used in conjunction with the residual plots which were used to graphically represent the data and determine whether the data needed to be transformed before analysis. The residual plots showed that the data was randomly distributed and as a result, no transformation was required.

4. Does a difference exist between the total daily consumption of water during the dry and wet season?

To establish whether a difference existed between the consumption of water during the dry and wet season, a two sample t-test was used.

5. Does a relationship exist between water consumption pattern and the household activities in Magadi?

To identify which daily domestic activity consumed more water, a Principal Component Analysis (PCA) was used. A Covariance matrix was used since all the variables had the same units (m^3). Eigen values and vectors were used to explain the variability in each variable. Scree and vector plots were used to show the pattern of water consumption in the households.

CHAPTER 4: ANALYSIS OF DATA AND RESULTS

Descriptive statistic techniques have been used to present the data collected during the field visit to Magadi. The total mean amount of water consumed/day/household in Magadi Township is 379.5 litres. The range varied from 25 to 1,550 litres (Table 4.1). The results are summarized in Table 4.1

Table 4.1: Descriptive statistics of the daily total water consumption/day/housing class in Magadi Township

Water consumption/day (m^3)	**Median**	**Range**	$\bar{x} \pm S.D$
Lower class housing	230.0	25 - 1035	274.4 ± 185.2
Middle class housing	390.0	80 - 1550	462.7 ± 215.0
Upper class housing	990.0	165-1260	867.5 ± 406.4
Mean water consumption in Magadi			**379.5 ± 280.0**

Contrary to expectation, the mean daily consumption of water in the upper class households was higher than the consumption in the middle and lower class households despite accommodating the least number of occupants in Magadi Township. This could be contributed by the large sizes of the houses and presence of gardens which require irrigation. Lower class of households showed the least daily consumption of water in Magadi despite housing the largest number of occupants in Magadi Township.

Table 4.2: The average daily consumption of water per the number of occupants living in each household and the average consumption of water per occupant

Number of occupants in each household	Total number of households sampled	Total daily amount of water consumed in litres	Mean daily amount of water consumed in each household (in litres)	Mean daily amount of water consumed (in litres) per occupant
1	7	665	95	95
2	10	1,865	186.5	93
3	23	6,684	290.6	96
4	19	9,638	507.6	127
5	22	10,106	459.4	92
6	10	5,100	510	85
7	3	1,358	452.7	65
8	4	1,225	306.3	38
10	2	1,155	577.5	58

Most of the households sampled during the study accommodated between 1 – 10 occupants. The total daily consumption of water per individual in Magadi Township ranges from 38-127 litres with the households with fewer occupants consuming less water while the households with more occupants consumed more water daily. However, households with four and eight occupants recorded abnormal levels in the daily water consumption as seen in Table 4.2 and this could represent the outlying points observed in the residual plots in Figure 4.3.

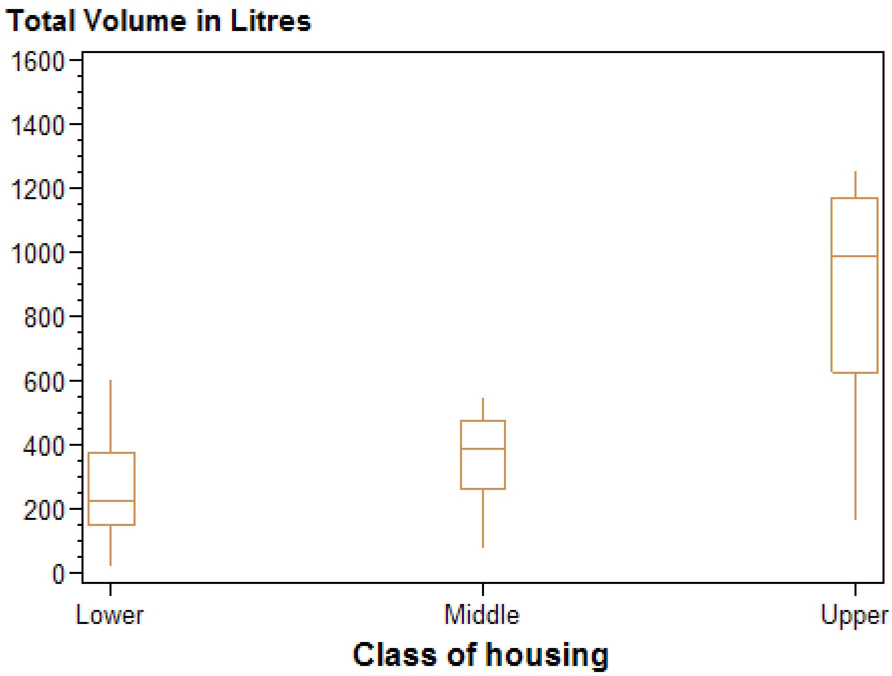


Figure 4.1: Box plot showing the relationship between the classes of housing in Magadi Township and the total daily water consumption/household.

The lower and upper horizontal lines represent the lower and upper quartiles where 25 and 75% of the observations lie respectively. The observations lie between 150-380, 265-480 and 630-1170 litres for the lower, middle and upper class households respectively. The horizontal line in the middle represents the median and the lines extending on the top and bottom (whiskers) are the maximum and minimum observation.

The Box and Whisker plot in Figure 4.1 are used for interpreting the distribution of the total daily consumption of water between the three classes of housing in Magadi. From the plot, it can be concluded that the people in the lower class of housing consume the least daily amount of water while the people in the upper class of housing use the highest daily amount of water. The range of daily consumption of water per individual was 150-350 litres, 250 – 500 litres and 650 – 1200 litres for the lower, middle and upper classes respectively (see table 4.2).

4.1 IS THE DAILY CONSUMPTION OF WATER THE SAME IN THE THREE CLASSES OF HOUSING OF MAGADI TOWNSHIP?

This question was addressed by comparing the daily consumption of water and the class of housing in Magadi Township. The housing has been classified as Upper, Middle and Lower classes of housing. A one way Analysis of variance **(ANOVA)** is used to compare the mean daily consumption of water in all the three classes of housing in Magadi.

The null hypothesis is **H_O: μ_1[7] = μ_2[8] = μ_3[9]** while the alternative hypothesis is **H_A: At least two means differ.**

Table 4.3: Analysis of variance showing the comparison of water consumption in the three classes of housing in Magadi Township

Source	**DF**	**Sum of squares**	**Mean squares**	**F value**	**P- value**
Model	2	2319172.11	1159586.06	16.98	<0.0001
Error	97	6625250.73	68301.55		
Corrected total	99	8944422.84			

R^2	**Coefficient variance**	**Root MSE**	**Daily total mean**
0.259287	68.87	261.34	379.46

Source	**DF**	**ANOVA SS**	**Mean Square**	**F Value**	**P Value**
Class of housing	2	2319172	1159586.06	16.98	<0.0001

Welch's ANOVA

Source	**DF**	**F Value**	**P Value**
Class of housing	2	10.15	0.0024
Error	12.53		

Bartlett's test

Source	**DF**	**Chi square**	**P Value**
Class of housing	2	17.06	0.0002

[7] μ_1 = Mean in Upper class household
[8] μ_2 = Mean in Middle class household
[9] μ_3 = Mean in Lower class household

Since the *p*- value **(0.0001**) in Table 4.3 is less than 5% significant level, the null hypothesis is rejected and the alternative is accepted. Therefore, the mean consumption of water in the three different classes (High, Middle and Low) differs significantly. The Welch's ANOVA and Bartlett's tests were used to measure the assumption of unequal and equal variances respectively between the groups. Since their *p*-values are less than 0.05, the null hypothesis is rejected and this means that there is a significant difference among the variances (the three different classes of housing).The Tukey HSD multiple comparison test was performed to determine where the differences in the consumption of water between the three classes occurred (Table 4.4).

Table 4.4: Multiple comparison tests of the different classes of housing in Magadi in the daily consumption of water.

Class Comparison	Difference Between Means	Simultaneous 95% Confidence Limits		Significance at 0.05 level
1 – 2 (High and Middle)	404.77	131.00	678.55	***[10]
1 – 3 (High and Lower)	593.46	326.48	860.45	***
2 – 1 (Middle and High)	-404.77	-678.55	-131.00	***
2 – 3 (Middle and Low)	188.69	57.37	320.02	***
3 – 1 (Low and High)	-593.46	-860.45	-326.48	***
3 – 2 (Low and Middle)	-188.69	-320.02	-57.37	***

The comparisons between the different classes of housing in Magadi Township as shown in Table 4.4 above are significant. This implies that a difference exists in the daily consumption of water between all the classes of housing in Magadi.

[10] Significance indicated by ***

4.2 IS THERE A RELATIONSHIP BETWEEN THE NUMBER OF OCCUPANTS IN A HOUSEHOLD IN THE DIFFERENT CLASSES OF HOUSING AND THE DAILY AMOUNT OF WATER CONSUMED IN MAGADI?

The relationship between the number of occupants in a household and the daily amount of water consumed is determined through correlation. To show whether a strong or weak correlation existed between the variables, a Pearson correlation co-efficient was used. The correlation tests were performed using the three classes of housing and the results of the analysis are tabulated in Table 4.5. Correlation scatter plots (Figure 4.3) were also used to represent the results graphically. The hypotheses were set as;

H_O: No correlation between daily total consumption of water and the number of occupants in each household

H_A: There is a correlation between daily total consumption of water and the number of occupants in each household.

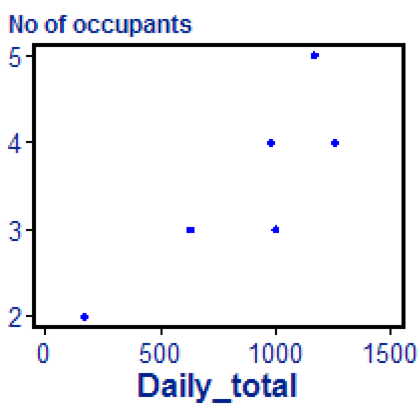
Table 4.5: Correlation results between the total daily consumption of water/household and the different classes of housing in Magadi Township

Classes of Housing	Upper Class	Middle Class	Lower Class
Number of households sampled in the study	6	37	57
Minimum number of occupants in each sampled household	2	1	1
Maximum number of occupants in each sampled household	5	10	10
Pearson correlation coefficient	0.8503	0.2035	0.6055
P- Value	0.0318	0.2270	<0.0001

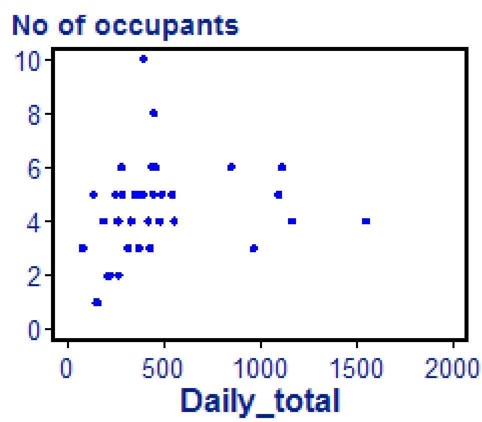
The *p*-value **(0.0318 and <0.0001)** for the upper and lower class respectively is less than 0.05. Therefore, the null hypothesis is rejected and this shows that a correlation exists between the daily consumption of water and the number of occupants in each household. Pearson correlation co-efficient value **0.8503** and **0.60554** show a strong positive correlation between these two variables. This implies that as the number of occupants in the upper and lower class households increase, their daily consumption of water also increases and vice-versa.

The *p*-value **(0.2270)** for the middle class is greater than 0.05. Therefore, the null hypothesis is accepted and this shows that a correlation does not exist between the daily consumption of water and the number of occupants in each household. However, the Pearson correlation co-efficient value **0.2035** shows a weak positive correlation between these two variables. This implies that the average consumption of water and the number of occupants in the household does not fluctuate much.

1)Upper Class



2)Middle Class



3)Lower Class

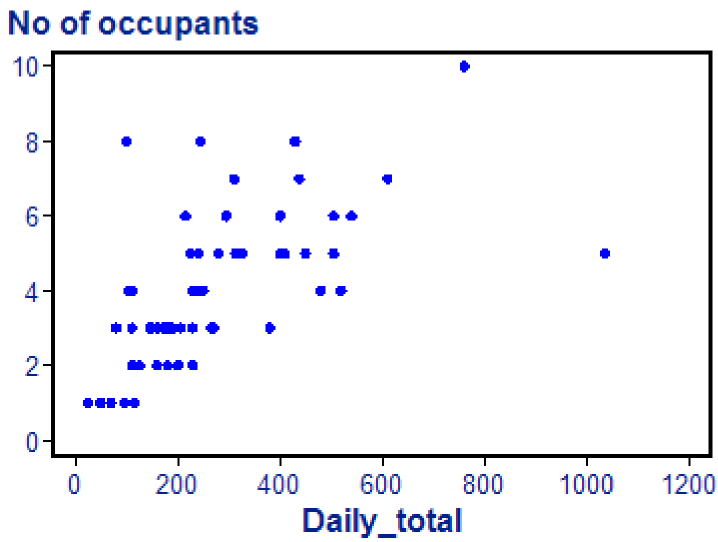


Figure 4.2: Scatter plots of the three classes of housing in Magadi Township showing the relationship between the number of occupants in each household and the daily water consumption

Figure 4.2 shows the correlation scatter plots of the three different classes of housing in Magadi Township. Scatter plot **(1)** and **(3)** show a positive correlation while **(2)** shows a weak correlation. This indicates that the total daily consumption of water in each household increases as the number of occupants increase and vice-versa.

4.3 ARE THE NUMBER OF OCCUPANTS IN THE HOUSEHOLDS AND THE CLASS OF HOUSING GOOD PREDICTORS OF THE TOTAL DAILY WATER CONSUMPTION IN MAGADI TOWNSHIP?

To establish whether the number of occupants and the class of housing are good predictors of the total daily water consumption in Magadi, a multiple regression was used. A null and alternative hypothesis were set as: $\mathbf{H_{O:}}$ Class of housing (x_1) and number of occupants (x_2) in the household does not predict the total daily water consumption (y) and $\mathbf{H_{A:}}$ Class of housing

(x_1) and number of occupants (x_2) in the household predict the total daily water consumption (y) respectively. The regression output is tabulated in Table 4.6 and Figure 4.3.

Table 4.6: Parameter estimates showing the outputs of a regression analysis

Source	DF	Sum of squares	Mean square	F Value	Pr > F
Model	2	3068194	1534097	25.32	<.0001
Error	97	5876229	60580		
Corrected Total	99	8944423			
Root MSE			246.13		
Dependent Mean			379.46		
Coefficient variance			64.86		
R-Squared			0.34		
Adjusted R-Square			0.33		
Durbin-Watson D			1.13		
Number of Observations			100		
1st Order Autocorrelation			0.42		

Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|	95% Confidence Limits	
Intercept	Intercept	**1**	771.83	118.23	6.53	<.0001	537.16	1006.49
Class of housing (x_1)	Code		-240.72	40.47	-5.95	<.0001	-321.04	-160.40
No occupants (x_2)	occupants	**1**	51.05	13.18	3.87	0.0002	24.89	77.21

Table 4.6, an analysis of variance table, shows that the regression is a good model. Since the *p*-value <0.001 is less than 0.05, the null hypothesis is rejected in favour of the alternative hypothesis. This implies that the number of occupants in a household and the class of housing would predict the amount of water that is daily consumed in Magadi. Table 4.6 confirms the results by identifying which of the independent variables is a good predictor and the regression equation can therefore be expressed as $y=6.53+ (-5.95)+3.87+e$. The *p* values of x_1 (class of housing) and x_2 (number of occupants) which are <**0.0001 and 0.0002** respectively, are less than 5% significance level and it is therefore concluded that the number of occupants in a

household and the class of housing influences the daily amount of water consumed. The multiple R^2 value of **34.30%** shows the percentage of variation explained by the model. The Durbin-Watson parameter checks for autocorrelation in the residuals of a regression analysis and it ranges between 0-4. Values closer to 2 signify no correlation between predictor variables while values between 1 and 2 imply a positive correlation between the predictor variables. Table 4.6 shows a Durbin Watson value of **1.133** implying a weak positive correlation between the number of occupants in each household, the class of housing and water usage.

Collinearity tests the correlation between variables in a regression model using the Eigen values and condition indices as shown in Table 4.7. Variables are said to be correlated if their condition index values are greater than 30. The condition index values in Table 4.7 are less than 30 and this shows that the predictor variables (number of occupants and class of housing) are not correlated.

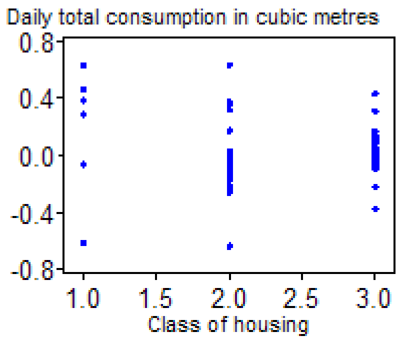
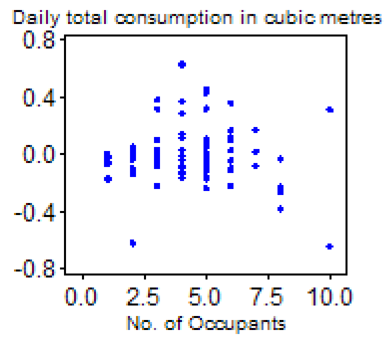
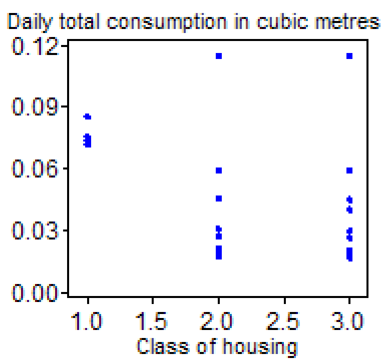
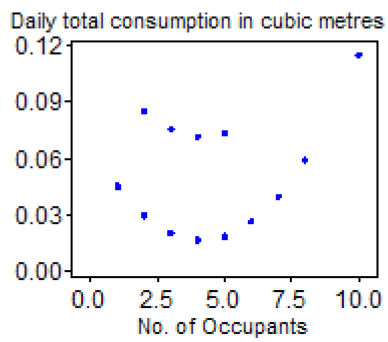
Table 4.7: Condition index and Eigen values of the independent variables

Number	**Eigen value**	**Condition Index**	**Proportion of Variation**	
			Intercept	**No of occupants**
1	2.84682	1.00000	0.00521	0.00655
2	0.12744	4.72643	0.02845	0.11052
3	0.02574	10.51643	0.96634	0.88293

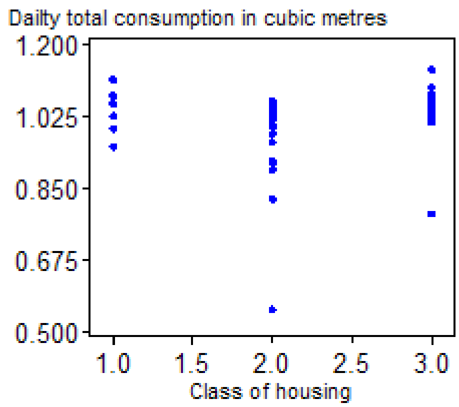
Other regression diagnostic tools used in the analysis of the data include dffits, leverage and covratio. These tools mainly identify influential and outlying points in the regression model. Their ranges are tabulated in Table 4.8. Values that lie outside the specified range are said to be outliers that can be influential to the regression model. The results of the diagnostic tests are explained in Appendix 6.

Table 4.8: Diagnostic tests and their specified ranges

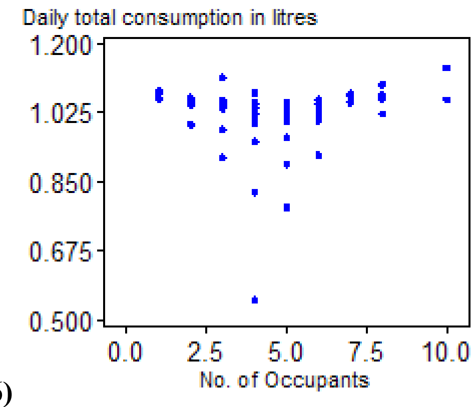
DIAGNOSTIC TEST	RANGE
Dffits	-2 to +2
Leverage	0.01 to 1
Covratio	0.91 to 1.09

Dffits	 **1)**	 **2)**
Leverage	 **3)**	 **4)**

Covratio



5)



6)

Figure 4.3: Regression diagnostic tests

The above residual plots shown in Figure 4.3 indicate presence of outliers in the data. This could be attributed to the fact that the respondents estimated the daily water consumption in their households. The outlying points are explained further in Appendix 6.

4.4 DOES A DIFFERENCE EXIST BETWEEN THE TOTAL DAILY CONSUMPTION OF WATER DURING THE DRY AND WET SEASON?

One of the concerns from the management was to investigate whether the total amount of water consumed in the households was the same during the dry and wet seasons. A two sample t-test was used to identify if any differences existed. A null and alternative hypothesis was set as follows;

H_O: There is no difference in the daily consumption of water in Magadi during the wet and dry season. **($\pi_1 = \pi_2$)**.

H_A: There is a difference in the daily consumption of water in Magadi during the wet and dry season. **($\pi_1 \neq \pi_2$).** The results of the analysis are presented in Table 4.9 and Figure 4.4.

Table 4.9: The *p*-values, mean and standard deviation of the daily water consumption in the dry and wet seasons

Variable	F Value	Pr > F		
Water consumption	3.61	0.14		
Variable	**t Value**	**Pr > |t|**	**Mean**	**Std Deviation**
Dry season	-0.08	0.94	10,597	1,425
Wet season	-0.08	0.94	10,645	750.5

The *p*-values shown in Table 4.9 above are greater than 5% significance level therefore the null hypothesis was accepted and it was concluded that there was no difference in the total daily consumption of water during the wet and the dry season. This means that there is no significant difference in the total daily amount of water consumed in the households during both seasons.

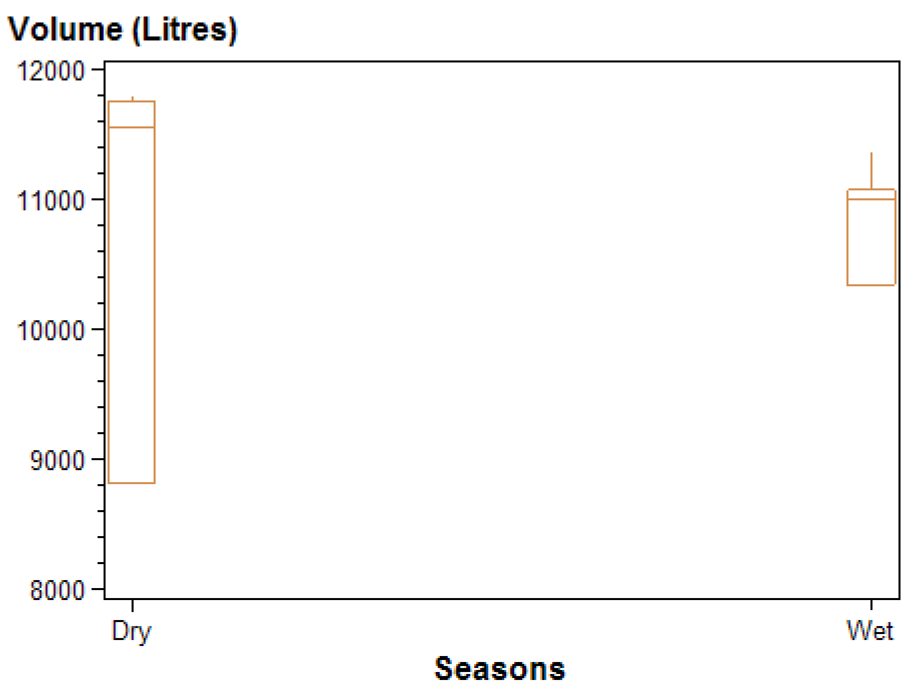


Figure 4.4: Box plot representation of the consumption of water during the dry and wet season

The box plot shows the median of the daily water consumption between the two seasons as 11,600 and 11,000 litres respectively. The daily consumption ranges from 8,800-11,800 litres and 10,200-11,200 litres in the dry and wet season respectively. The range in the wet season is narrower than that of the dry season.

4.5 DOES A RELATIONSHIP EXIST BETWEEN WATER CONSUMPTION PATTERN AND THE HOUSEHOLD ACTIVITIES IN MAGADI?

To examine relationships in the daily consumption of water in Magadi Township, a multivariate statistical technique (Principal Component Analysis) is used. The goal of this analysis is to determine the principal components of all the domestic water activities in Magadi Township. The Eigen values are used to assess how much a component represents the data (the higher the Eigen value of a component, the more representative it is of the data) while Eigen vectors show patterns in the dataset. The descriptive statistics of variables considered are presented in Table 4.10 where the mean daily consumption of water in each household in Magadi is outlined. The households use the least daily amount of water on cooking, washing utensils and carwash, while the highest daily consumption of water is observed in laundry, irrigation, toilet flushing and bathing.

Table 4.10: The mean and standard deviation of the daily consumption of water in m^3/per household in Magadi Township

Domestic Activity	**Cooking**	**Cleaning House**	**Wash utensils**	**Laun dry**	**Toilet**	**Bathing**	**Car Wash**	**Irrigation**
Mean	15.3	18.7	15.3	56.4	43.1	49.8	3.7	78.2
Std Deviation	7.4	14.3	9.9	38.6	32.8	31.0	7.3	218.9

Table 4.11: Covariance Matrix of the domestic activities performed by the Township residents

	Cooking	Clean_Hse	wash utensils	Laundry	Toilet	Bathing	Car	Irrigation
Cooking	55.29	25.51	27.55	97.74	71.87	78.73	13.55	248.28
Clean_Hse	25.51	203.72	38.06	227.47	133.26	99.00	20.58	853.40
wash utensils	27.55	38.06	98.07	110.89	77.48	122.96	6.57	62.27
Laundry	97.74	227.47	110.88	1490.67	585.45	548.05	65.72	2799.45
Toilet	71.87	133.27	77.47	585.45	1075.63	687.35	-4.81	107.74
Bathing	78.73	99.00	122.96	548.05	687.35	963.12	21.78	767.38
Car	13.55	20.58	6.57	65.72	-4.81	21.78	52.64	913.14
Irrigation	248.28	853.40	62.27	2799.45	107.74	767.38	913.14	47891.44

The diagonal elements (shaded cells) of the Table 4.11 show the covariance of each variable with itself which is equivalent to the variance. The other values give the covariance of different variables. The Variance indicated for cooking is **(55.29)** while the variance indicated for washing utensils is **(98.07)**. The covariance between them is (**27.55)** and this indicates a positive relationship. All the variables have positive relationships between them as seen in Table 4.11 and are indicative of the high correlations between the different domestic activities in Magadi households.

Table 4.12: Table of Eigen values of covariance matrix

	Eigen value	Difference	Proportion	Cumulative
1	48542.06	40538.31	0.813	0.813
2	8003.76	6187.24	0.134	0.945
3	1816.51	1088.75	0.030	0.977
4	727.77	407.81	0.012	0.989
5	319.96	155.69	0.005	0.995
6	164.27	86.82	0.003	0.998

7	77.45	36.81	0.001	0.999
8	29.04		0.001	1.000

The Eigen values explain the variability inherent in each of the principal components and provide information about the patterns in the data. From Table 4.12, the first principal component describes **81.28%** of the data while the second principal component describes **13.40%.** Together, they account for **94.68%** of the information in the data. Eigen vectors show the extent of loading of each component. The loadings can either be positive or negative as seen in Appendix 7. This can also be interpreted by the scree plot in Figure 4.5 below which displays the Eigen values on the vertical axis and the principal component number on the horizontal axis.

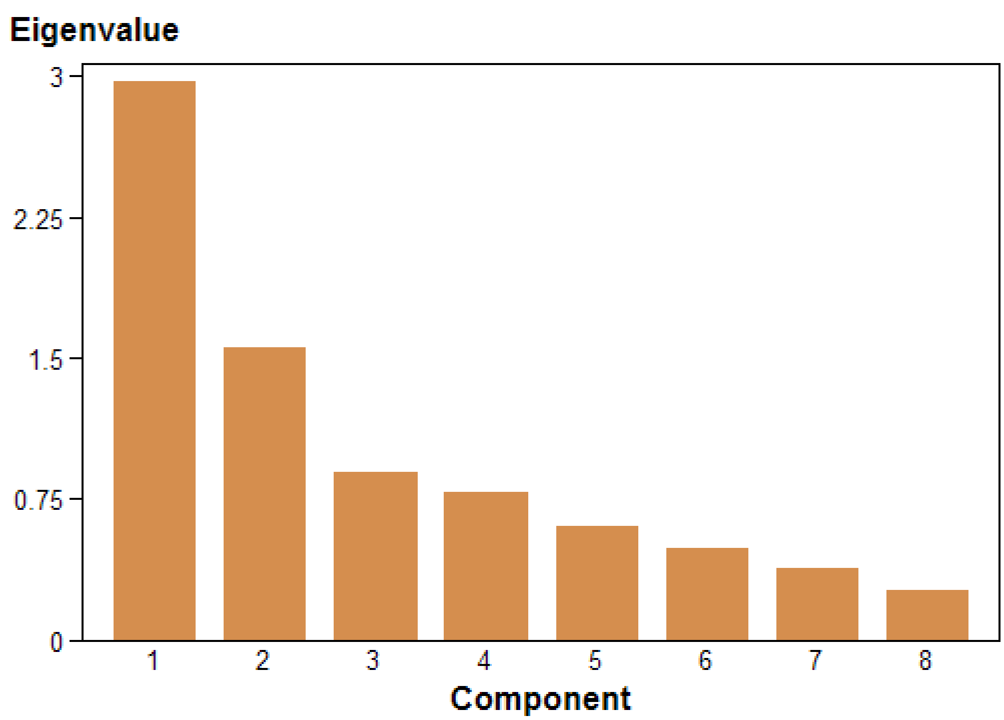


Figure 4.5: Scree plot showing the Eigen values versus principal components in a Principle Component Analysis

When plotting vector plots, the first principal component value is plotted along the y axis (vertically) and the second principal component is plotted along the *x* axis (horizontally). A scree plot is useful in determining the appropriate number of components that need to be interpreted. A gradual decrease in Eigen values is observed in Figure 4.5. The contributions are relatively low after the second component which agrees with the preceding conclusion that the first two components provide a reasonable summary of the data.

In Figure 4.6, each vector corresponds to one of the analysis variables and is proportional to its component. Bathing, toilet flushing and laundry load heavily on the first component while car wash and irrigation load heavily on the second component. This information reveals that car washing and irrigation consumed more water daily despite the fact that few households own cars or gardens. Bathing, laundry and toilet flushing are daily activities performed by all occupants in the Township that consume more water than cooking and washing utensils.

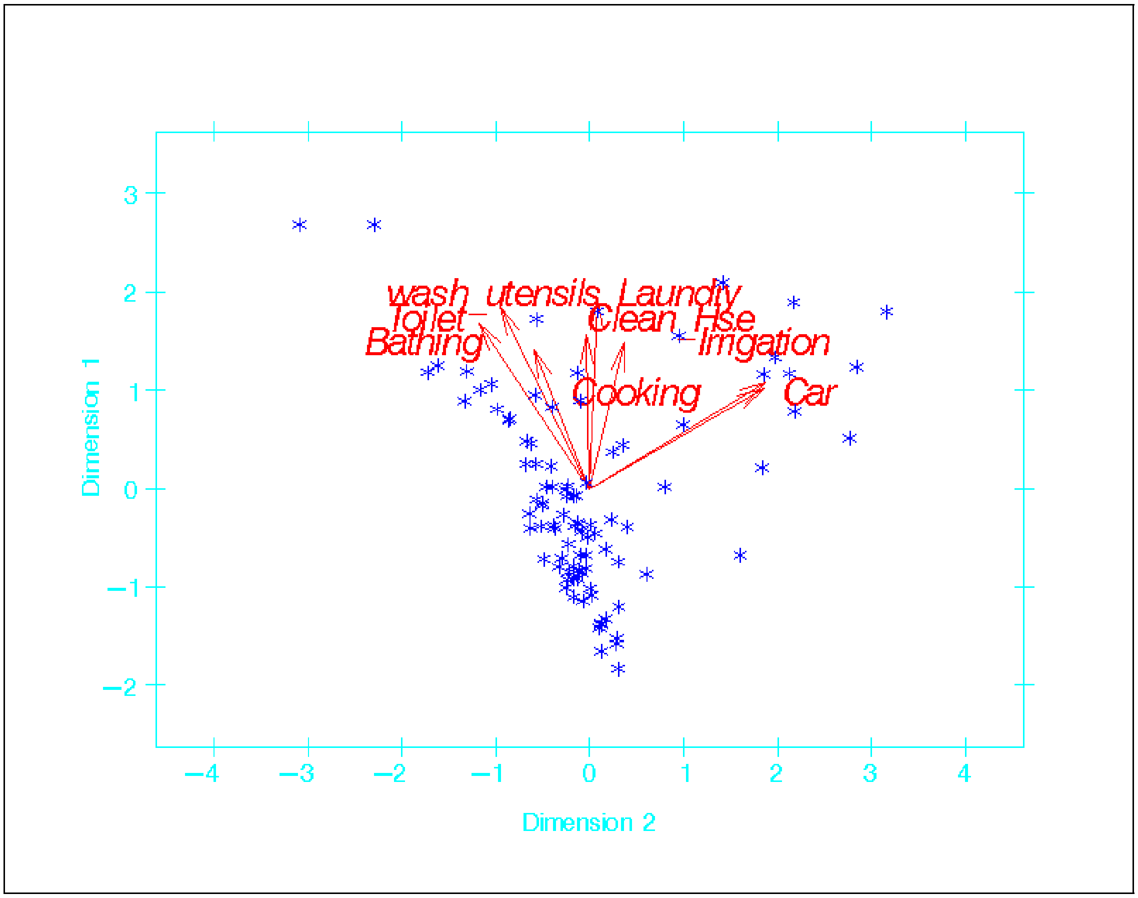


Figure 4.6: A vector plot showing the principal components

4.6 SITE REPORT

A site visit was an important aspect of this study because physical observation was used as a means of data collection. Site visits provided a clear impression on the current water situation in Magadi from the sources to the points of use. Most of the site visits were as a result of the informal interviews conducted with the company representatives.

A visit to the source of water revealed massive soil erosion along the banks of the stream (Figure 4.7). This may be as a result of deforestation that has been caused by cutting down trees to provide firewood by the local community. If this is not prevented, the soil will end up in the stream blocking the supply of water to the reservoir.

Figure 4.7: Massive soil erosion along the banks of Oloibortoto Stream

Water wastage

When the supply of water to the Township is stopped, most residents leave their taps open. When the supply is resumed, the water is left running as can be seen in Figure 4.8.

Figure 4.8: Clean water flowing in a surface water run-off drain

Overflowing sewage

Since there are no sewage plants in Magadi to process sewage, the septic tanks work at maximum capacity (Figure 4.9). A visit to the site showed sewage which overflowed into the lake and is a potential source of pollution to the environment.

Figure 4.9: Overflowing sewage from a septic tank in Magadi.

CHAPTER 5: DISCUSSION

5.1 WATER USE IN MAGADI

This study looks at the consumption of water in Magadi Township. Since MSC is unable to meet the current demand of water required for its residents, current water use has to be managed and other alternative sources of water have to be considered to increase supply to the Township. Table 5.1 shows a summary of the data collected on the total amount of water consumed/day/class of housing in the sampled households in Magadi Township. The total daily amount in table 5.1 does not correspond with the total in table 1.6. This difference could be attributed to the estimates that the respondents were giving during interviews.

Table 5.1: The total daily water consumption in the three classes of housing in Magadi Township for sampled households

Housing Class	**Total water consumed in litres/day**
Upper Class	4,305
Middle Class	12,561
Lower class	10,755
Total	**27,621**

During the study, a number of drawbacks were encountered. First and foremost, the study coincided with a period where the company was accommodating a large number of guests, therefore, stretching the existing accommodation facilities at the company's guesthouses. This limited the site visits and interviews to two weeks.

Since MSC has not installed any water meters along their pipelines for monitoring the water supply and consumption, it was very difficult for the respondents to quantify the amount of water consumed daily in their households. An estimate was made using the number of 20-litre buckets or jerry cans used during each domestic activity. This could have led to inaccurate estimates which may account for the outlying points in Figure 4.3. Lack of proper and updated records on the consumption of water and the number of residents of the Township respectively made it difficult to acquire as much accurate information as possible from the company. Finally, due to the limited amount of time, the respondents had no time to prepare for answers. However, one advantage was that the respondents could not compare their answers with neighbours. Limited research funds restricted the study to a single trip.

5.2 COMPARING THE MEAN DAILY WATER CONSUMPTION IN THE THREE HOUSING CLASSES

The daily consumption of water in each of the three classes of housing differed according to ANOVA analysis (Table 4.3). The upper class households had a significantly higher mean compared to the middle class and the lower class households. In general, all the comparisons on the total consumption of water between the different classes of housing were significantly different. The lower and middle classes house the highest number of occupants while the upper class houses the least number of occupants in Magadi. The daily amount of water consumed across these three classes differed significantly with the upper class seemingly consuming more water daily per household than the middle and lower class of housing. Irrigation of gardens could be one of the factors that influenced the high daily consumption in the upper class households. MSC should therefore consider installing flow meters along the pipelines to monitor the amount of water consumed in the Township. An emphasis should be put on the upper class household who seem to use a larger amount of water on irrigation.

It is important to note that a difference existed between the total daily amount of water consumed per class and the mean daily amount of water consumed per household in the three classes of housing in Magadi (Figure 5.1).

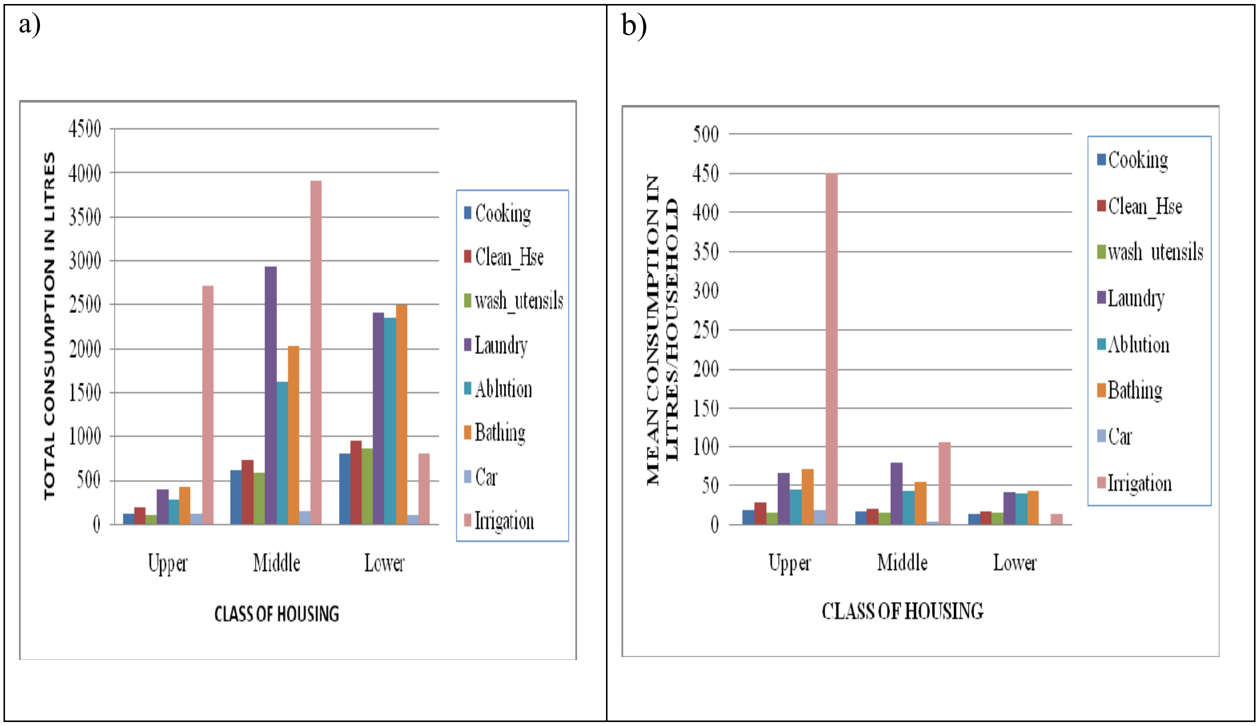


Figure 5.1: A comparison between the total daily amount of water consumed/class and the mean daily amount of water consumed/per individual/class in Magadi Township

The graph in Figure 5.1(a) illustrates that occupants in middle class households consume the highest total amount of water daily in Magadi Township compared to the lower and upper class households. However, Figure 5.1(b) corresponds with Table 4.2 and indicates that the mean consumption of water per household is highest in upper class households.

5.3 INVESTIGATING THE EFFECT OF THE NUMBER OF OCCUPANTS IN EACH HOUSEHOLD ON THE DAILY CONSUMPTION OF WATER

The relationship between the daily consumption of water and the number of occupants in each household was calculated based on the consumption of water in the different classes of housing in Magadi using correlation (Table 4.5). The upper and lower class households, showed strong positive correlations between the daily consumption of water and the number of occupants living in each household (Figure 4.2). This showed that an increase in the number of occupants living in a household increased the amount of water consumed daily. On the other hand, the middle class estate showed a weak correlation between the two variables. As a result of this, it was concluded that the number of occupants in the households did not necessarily dictate the daily amount of water consumed. One reason would be that the occupants living in these households were economical with water. In conclusion, an increase or decrease in the number of occupants in the lower class and upper class would increase or decrease the daily consumption of water but would probably not cause a significant difference in the middle class (Figure 4.2).

When all the three classes of housing were considered as a whole, the mean daily amount of water increased with an increase in the number of occupants in a household. Households with 5, 6 and 10 occupants showed the highest rate of consumption while houses with one occupant showed the least consumption rate of water in Magadi Township. Despite having a large number of occupants, households with 8 occupants showed less consumption of water. This could probably be caused by the small sample interviewed during the study or inaccurate estimates of water given by the respondents.

5.4 PREDICTING OF THE DAILY AMOUNT OF WATER CONSUMED IN MAGADI TOWNSHIP BY LOOKING AT THE ASSOCIATION BETWEEN THE CLASS OF HOUSING AND THE NUMBER OF OCCUPANTS IN A HOUSEHOLD

The *p*-value **(0.0001)** obtained from the regression analysis showed that there was a significant association between the total daily consumption of water and the number of occupants in each household and the class of housing. Therefore, the number of occupants in each household sampled and the class of housing they belonged to were good predictors of the daily amount of water consumed.

The number of occupants in each household and the class of housing predicted the daily consumption of water in Magadi Township. An increase in the number of people in the lower class and middle class households would increase the daily amount of water consumed since a large percentage of water is used in cooking, bathing, washing utensils, laundry and general housekeeping. On the other hand, an increase in the number of people in the upper class households would probably not have any effect on the daily consumption of water since irrigation accounts for the largest percentage of water in these households as opposed to mainstream domestic activities like cooking and general housekeeping.

5.5 TOTAL DAILY CONSUMPTION OF WATER IN TWO DIFFERENT SEASONS.

The WDC requested an investigation to determine whether the daily amount of water consumed during the dry season was higher than that consumed in the wet season. A two sample t-test was used to establish this difference. Since the water supplied to the Township is mainly used for domestic activities, the total daily consumption of water is perceived to be the consistent throughout the wet and the dry season. However, the range of daily consumption in the wet season is limited as compared to the dry season (Figure 4.4). A possibility would be that during the wet season, households do not practice irrigation.

5.6 CONSUMPTION OF WATER IN DOMESTIC ACTIVITIES

Different household activities use different amounts of water daily. Table 4.10 outlines the mean daily consumption of water for different domestic activities in Magadi Township. Residents use the least amount of water on cooking and washing utensils while the highest daily amount of water is consumed by laundry, toilet flushing, irrigation and bathing. Bathing, cooking and washing utensils are some of the activities performed daily which require potable water while toilet flushing, irrigation, carwash and laundry are activities performed daily by the residents which do not necessarily require potable water for use. Recycled water can be used as an alternative source for these activities and this would contribute to savings of potable water. The study revealed that 60% of the residents interviewed practised small scale recycling. The residents used the wastewater from laundry activities in housekeeping, flushing toilets and irrigation.

Table 5.2 shows the percentage of water used in each domestic activity in Magadi households. If recycled water is used for irrigation, car wash and toilet flushing, potable water savings of approximately 44% can be achieved.

Table 5.2: Total daily consumption of water for each domestic activity in Magadi Township households

Domestic Activity		Cooking	House keeping	Dish washing	Bathing	Laundry	Toilet	Car wash	Irriga tion	Total
Total Daily Consump tion	m^3	1,517	1,847	4,964	1,520	5,753	4,235	355	7,430	**27,621**
	%	5.5	6.7	18.0	5.5	20.8	15.3	1.3	26.9	**100**

The shaded areas are those domestic activities where recycled water could be used

5.7 WATER MANAGEMENT IN MAGADI

A Water Development Committee was formed in 2005 to come up with sustainable solutions that assist in balancing the water demand and supply in Magadi. A report on the short term action for water sustainability in Magadi Soda Company revealed that the current water demand exceeded the current supply creating a deficit that was brought about by an increase in the consumption of water by the processing plants (Table 5.3). This means that water abstracted from the Oloibortoto stream and the FSW should be properly managed to avoid a crisis in future.

Table 5.3: The supply and demand of water in Magadi (Magadi Records, 2007)

Water Source	Required water (m^3/day)	Current Supply (m^3/day)	Deficit (m^3/day)
Oloibortoto Stream	**1577.06**	**1254.72**	**(- 322.34)**
Fish Springs Water	**6093.83**	**5760**	**(-333.83)**

During the study, the following issues were raised during interviews with the company representatives;

1. **Water wastage**

Water wastage was one of the biggest problems currently facing water supply to Magadi Township. The introduction of the water rationing program worsened the situation because residents left their taps open throughout the rationing period and once normal supply resumes, water flows freely from the open taps (Figure 4.8). In Cyprus, the water board introduced a program where pressure in the water pipelines was reduced and this consequently reduced the amount of water lost as a result of leakages (Charalambous, 2001). However, the WDC proposed the installation of “push” taps in Magadi as one of the ways in which water wastage can be prevented.

2. **Reclamation of wastewater**

Greywater and sewage water are readily available in the Township and are reliable sources of water as they are generated daily from the households. The water can be reclaimed and used in the Township for both potable and non-potable uses. Reclamation of water in Magadi could be performed on greywater and sewage water which accounts for almost 50 - 80% of all residential wastewater (Eriksson *et al*., 2002). Water generated from laundry and bathing could be reclaimed and reused in ablution facilities, housekeeping, irrigation and car wash and this could lead to potable water savings of approximately 44% in each household (Table 5.2).

Treatment of sewage water should be very effective as it involves the removal of disease causing pathogens and it also reduces pollution of the lake. Another challenge of using reclaimed sewage water would be the perception of the residents towards using this type of reclaimed water.

Increasing the water supply by reclaiming sewage water using artificial wetlands was another of the issues raised during the interviews. MSC has 36 septic tanks with a total capacity of 1493.5 m^3 (Appendix 8) and no sewage plant to process sewage. The septic tanks operate at maximum capacity and sewage overflows into the lake (Figure 4.9). Construction of a sewage plant or artificial wetlands will reduce the environmental pollution and provide an alternative source of water for non-potable use in the Township such as irrigation of gardens and decorative plants and toilet flushing. The cities of Bulawayo and Brisbane in Zimbabwe and Australia respectively have reclaimed sewage water for landscaping and toilet flushing (Taigbenu and Ncube, 2005; Jeppesen, 1996).

3. Exploitation of alternative water sources in Magadi

These are unconventional sources of water which can be developed to provide alternative sources of water in Magadi. Water from these sources can be recycled by using several water treatment methods and supplied to the Township for potable and non-potable use. During the study, the sources of water identified were stormwater, groundwater and the lake. The success in exploiting these sources of water is dependent on the cost of abstraction and treatment, the availability, reliability and the public perception towards the use of recycled water.

Storm water is one of the alternative sources of water that can be developed to supplement the supply of potable water. However, it is unreliable as Magadi has experienced a prolonged dry spell since 2000. The absence of roof gutters on Magadi buildings indicated that Magadi does not collect stormwater during the rainy season. The costs incurred in the collection of storm water would include the installation of the equipment used to collect and distribute the storm water as no treatment of the water may be required before use. One advantage of using storm water is that it may be readily accepted by the Township residents as opposed to greywater and black water.

The use of water from the FSW was another possibility identified to increase the potable water supply in Magadi. The water is currently used without treatment in the processing plants as well as in most toilet facilities in Magadi. FSW can be treated using the existing RO treatment plant in Magadi. However, this is only possible if surplus energy can be generated from the power plant.

The groundwater and lake water are both brackish in nature and desalination would be the ideal method for its treatment. However, the prohibitive costs of constructing and operating a desalination plant would inhibit the development of such plants in Magadi. Furthermore, abstraction of water could affect the quantity of the soda ash extracted from the lake thereby decreasing production and consequently, affecting the main source of income for the company. The most important factors to consider while setting up a desalination plant are the location of the plant, disposal of the brine and energy consideration. In Magadi, there are two possibilities of disposing the brine.

- Dispose the brine into the lake as the concentration of the salt compounds in the lake is similar to the content of the brine.
- Dispose the brine in the evaporation pans where it is evaporated to produce salt.

Energy in the form of hydroelectric power is tapped from the national grid and is therefore not a reliable source of power because of frequent rationing schedules in Kenya. Solar power could be considered as an additional source of energy since Magadi experiences long sunlight hours throughout the year. However, the cost of installation is high and this may present a problem in adopting solar as an alternative source of power. A summary of the factors which are likely to influence the exploitation of wastewater for reuse in Magadi are outlined in Table 5.4.

Table 5.4: Factors influencing the exploitation of alternative sources of water in Magadi

Source	**Reliability**	**Availability**	**Costs**	**Public perception**
Greywater	High	High	Medium – High	Low
Sewage	High	High	Medium – high	Low
Storm water	Low	Low	Low	High
Brackish water	Medium-high	Medium to high	High	High

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

Human demand accounts for the largest percentage of water usage in Magadi (Table 1.3) therefore, water management practices should focus on the consumption of water by residents. MSC needs to develop policies that focus on Integrated Water Resources Management to meet the increasing human and industrial demand for water. Such policies have been successfully implemented in water scarce countries like Kuwait and Namibia (Hamoda, 2001; Harhoff and Van der Merwe, 1996).

Proper planning and future water demand and supply management is essential in this developing region in Kenya. Van Zyl (2006) points out that a key input in water management and planning is estimating present and predicting future water demand. These water demand estimates are used to calculate the peak water demand and sewer flows which determine infrastructural requirements. This will in turn impact on the budget and capital investment needs of the company. Inaccurate estimates lead to inadequate service and inequitable water distribution (Van Zyl, 2006). Better planning involves having reliable data on the population, water consumption, all water inflows, outflows and storage on which to base estimates within Magadi. This knowledge will progressively lead to better management of the water demand and supply in Magadi.

Magadi Soda Company has an open door policy and therefore does not impose access restrictions on the local surrounding community and extended families of the Township residents. This allows for the movement of people and animals in and out of the Township. This aggregation of people increases the number of occupants in the households, which corresponds to an increase in the amount of water consumed in each household. Introduction of measures such as educating residents to create awareness on the proper use of water should be initiated as it would be difficult to control the population growth in the Township or limit the number of occupants living in each household as a result of migration to the town.

A water management program has the potential to act as a catalyst for change in water use resulting in more sustainable use of the limited resource. The process of organizing the implementation of water management programmes for the Township can be a starting point from which future development initiatives can follow (Davis and Garvey, 1993). Since the interviews were conducted during the day, the majority of the respondents were women who were the major users of water as they performed most of the household chores. Therefore, the WDC should involve women in the process of developing a water management program in Magadi which currently does not have any women representatives.

The water management approach currently adopted by Magadi can be termed as a reactive rather than a proactive approach. Water rationing has achieved desirable results because a constant supply of water to the processing plants has been achieved. Water is also wasted when normal supply is resumed because taps in the households are left turned on during rationing. Creating awareness and increasing knowledge among the residents on the importance of conserving water and the consequences for irresponsible use of water could be a good management strategy. Township meetings can be held to inform residents on water use efficiency which include conservation and recycling of water. Giving public lectures in schools is also another way of creating awareness on proper use of water. Seminars can be conducted in the workplace to sensitize the employees on the importance of conserving water. Incase

MSC does not introduce charges for water use, a penalty or fine could be imposed on residents who use water irresponsibly.

Given the current difficulty in quantifying the amount of water used, Magadi should consider installing water/flow metres along its pipelines. Water metres show the actual amount of water used in each household enabling the company to manage the water demand and supply as it is impossible to "manage what has not been measured".

Proper management of water should begin with the proper management of the water source. Since Magadi abstracts its potable water from Oloibortoto Stream, the management of this resource should be included in the water management program. A water catchment authority is responsible for the conservation and protection of the water resource. Massive soil erosion along the banks of the stream (Figure 6.1) was observed and this may in future, block the flow of water from the stream to the reservoir where water is collected before abstraction (Figure 1.7a). Another possibility is the accumulation of silt in the stream which reduces the quantity of water the stream holds and this is a major cause of flooding during heavy rains. The catchment can be managed by:

- Stabilizing the banks by planting trees on the banks of the river to prevent soil erosion.
- Desilting the stream regularly to maintain its holding capacity and prevent flooding during the rainy season.

According to the amended Water Act no. 8 of 2002, the catchment authority formulates a catchment management strategy for the management, use, development, conservation, protection and control of the resources within each catchment area. An advisory committee is appointed by the minister and comprises of representatives (Section 1.8.2) who are responsible for management of the catchment. MSC can partner with the government through the water catchment authority to manage the catchment as part of its Corporate Social Responsibility (CSR).

One concern raised by the WDC was the consumption of water during the dry and wet seasons. Since the mean amount of water consumed during the wet season and the dry season in Magadi is not considerably different (Section 4.1.4), MSC should manage and monitor the use of water throughout the year to identify any abnormal occurrences in consumption patterns.

Rainwater harvesting is another source of water that could supplement potable water. Although this is not practiced in Magadi, it is important to explore the possibility of collecting rainwater from roofs and surface run offs for use in the Township. Roof gutters, tanks, storm water drains should be installed or constructed for collection of rain water. Harvesting of rain water would be very effective in estates with multi-storey buildings (Majengo, Uhuru and Maringo) which accommodate the largest population in Magadi.

FSW is an additional source of water in Magadi which is used in the processing plants and in ablution facilities in the administrative buildings, educational institutions and a number of Township houses. This water could be reclaimed through Reverse Osmosis (RO) technology to provide potable water to the township residents. Some setbacks that are expected when using RO include:

Availability of energy: RO should be operated if a surplus of electrical power from the power station occurs or if an alternative power supply is identified.

Brine disposal: This has serious effects on the environment. However, in Magadi, the presence of a salt lake provides a favourable environment for disposing the brine as it has the same concentration as the lake. The brine can be disposed in the salt plant for the production of salt and this forms an extra source of income for the company. Further research should be conducted to determine the effect of the brine on the quality and quantity of the trona extracted from the lake.

Maintenance, servicing and replacing of the water infrastructure should be frequently performed to avoid leaks and unaccounted spills of water from faulty taps and worn out pipelines. Since the cost of replacing worn out water plumbing appliances in all households in Magadi Township could be high, it is advisable to progressively install or replace the appliances through repairs and maintenance as this will ease the financial strain on the company's budget. In the event that additional residential houses are constructed to accommodate the rising population growth, it would be feasible to install the improved fittings and appliances in the houses during construction.

6.1 WATER MONITORING PROGRAM

Salmon (2007) describes a water monitoring program (Figure 6.1) as a tool which forms the basis for water resource planning and management by assisting in the collection, management, and delivery of data on the quantity and quality of water. Monitoring can be performed manually through physical observation or automatically by the automation of the water distribution infrastructure. Physical observation is labour intensive and time consuming and more often than not, incorrect data may be recorded through typographical errors or complacency of the data entry person(s) resulting in inaccurate estimates of the consumption of water in the Township. Automation of the water infrastructure would be a good strategy as it enables early detection of faults and leaks and prevents the possibility of capturing incorrect data.

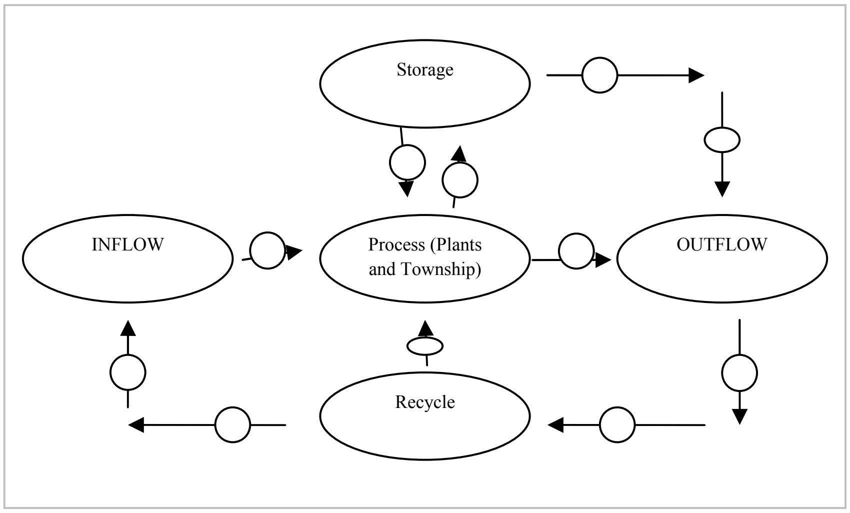


Figure 6.1: A hypothetical representation of a water monitoring program
◯ Indicates a monitoring point

6.2 WATER BALANCE SYSTEM

A water balance system manages water supply by ensuring conservation and sustainable water use. Since balancing water supply and demand in regions where fresh water is scarce like Magadi is challenging, it is important to develop a better water resource planning and management strategy to reduce the risk of supply shortage. A water balance (Figure 6.2) should be implemented by MSC to determine the amount of water inflows, storage and outflows. The inflows could include: Water from Oloibortoto Stream and FSW, storm water and brackish groundwater while the outflows may include; sewage, greywater and industrial effluent. In Magadi, large-scale recycling of wastewater is not practised. Households practice recycling by using the water that has been used for laundry in flushing and washing the toilets. The use of water in the processing plants, surrounding community and the Township should be incorporated in the water balance system to ensure its effectiveness. This will enable the company identify the opportunities available for water use efficiency and recycling.

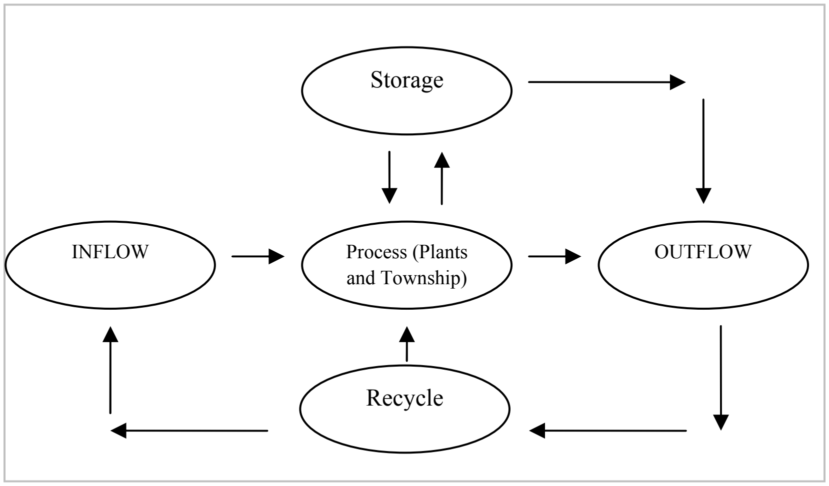


Figure 6.2: A hypothetical representation of a water balance model

The main conclusions of the study are as follows;

- There is strong evidence that water demand increases as a result of an increase in the number of occupants per household in Magadi Township.
- There seems to be no notable difference between water consumption during the wet and dry seasons.
- The average daily consumption of water per class of housing in Magadi is not similar.
- It is possible to recycle wastewater for non potable uses in the Township like irrigation and carwash.

6.3 RECOMMENDATIONS FOR FUTURE WORK

6.3.1 Educational Campaigns

Since no other sources of water in Magadi have been exploited, the company should manage the existing amount of water supplied to the residents, company and local surrounding community. This can be done by creating awareness on the efficient use of water and advantages of water conservation by;

- Holding meetings in the Township to educate residents on the importance of proper use of water.
- Giving public lectures in schools to educate the children on proper use of water both at home and in school.
- Holding seminars for employees to create awareness on the water crisis the company faces and give solutions on conserving water.
- Distributing pamphlets, fliers, notices and posters throughout the township on proper use of water and the consequences of irresponsible use of water.

6.3.2 Developing and implementing a water monitoring program and water balance system

The implementation of a water balance and a water monitoring program for better management of water supply and demand in Magadi is highly recommended. A conceptual water balance is initially developed to give information on the inflows, outflows and storage in Magadi. These inflows and outflows are monitored to determine the quantity and quality of water that flows into Magadi. Finally, an operational water balance system could be developed and used as a water management tool.

6.3.3 Identifying opportunities for water recycling

Identifying methods and opportunities available for recycling water is another solution for alleviating the water scarcity issue in Magadi. The most apparent sources are processing plant water, storm water, swimming pool water and household effluent. It is recommended that Magadi explores the possibility of introducing the use of reclaimed wastewater in the Township. A social research on the perception of the residents in the use of reclaimed wastewater for non-potable uses can be conducted.

The viability of collecting storm water should be investigated as Magadi is generally an arid area which receives low amounts of rainfall annually. A centrally located car washing bay should be constructed in the Township. The water used can be collected and recycled for reuse in the car washing bay (Hamada and Miyazaki, 2005). This will limit the impact of wastewater on the environment as well as conserve potable water for other uses.

6.3.4 Construction of wetlands

Since the greywater is not collected separately from the sewage water, construction of wetlands for reclamation of sewage water is highly recommended. Magadi Township has an existing sewage and drainage system. Overhauling this system and establishing a separate greywater system would be a very expensive and impractical exercise. The wetlands can also be used for collecting wastewater from overflowing septic tanks which flow into the lake.

The location of an artificial wetland should be carefully selected to avoid the contamination of the land by the sewage overflowing into the lake. The effect of the high evaporation rates in Magadi on the wetland should be investigated to establish the sustainability of using these wetlands in reclaiming wastewater.

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APPENDICES

Appendix 1: Magadi weather station

Note the buildings (old fly ash plant) in the background and a section of Lake Magadi.

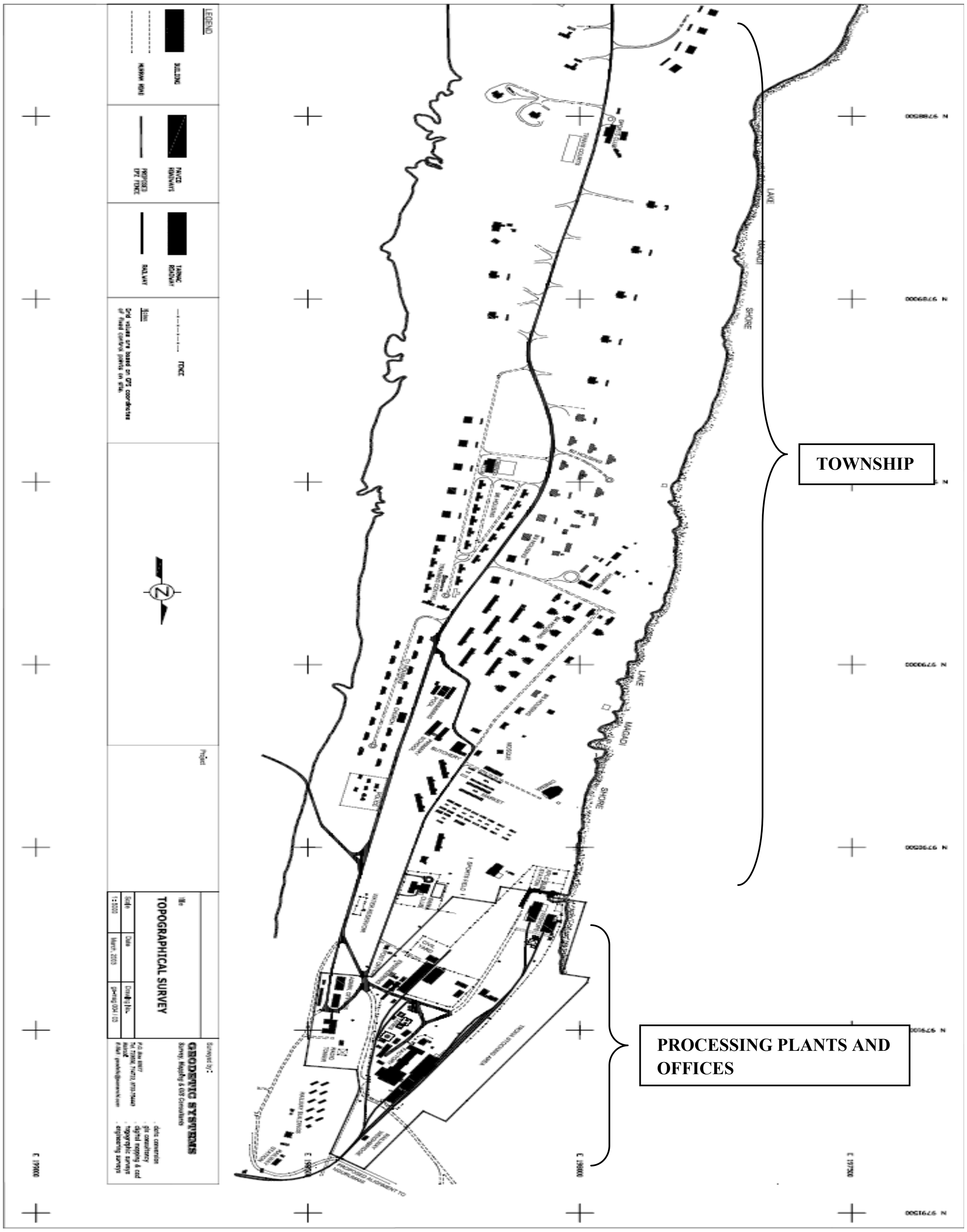
Appendix 2: Comparison of census data between 1997 and 2000 (Magadi Records, 2007)

	YEAR 2000 CENSUS							YEAR 1997 CENSUS					
CATEGORY	NO.	SPOUSE	CHILDREN	DEPND & RLTVS[11]	CHILD DEPENDANTS	TOTAL		NO.	SPOUSE	CHILDREN	DEPND & RELATIVES	CHILD DEPENDANTS	TOTAL
MSC EMPLOYEES (MR+MSC)[12]	286	127	462	297	28	1200		415	425	1537	605	122	3104
PIECE-RATE WORKERS	85	8	5	13	2	113		0	0	0	0	0	0
CONTRACTORS AND WORKERS	102	22	55	27	3	209		97	34	88	42	0	261
TEACHERS (PRM& SEC)[13]	25	6	30	27	0	88		28	14	62	11	0	115
TRADERS /BUSINESSMEN	36	8	39	31	0	114		63	36	156	76	8	339
CHURCH CLERGY	11	2	13	7	0	33		11	4	10	11	0	36
POLICE	9	2	1	0	0	12		15	5	13	4	0	37
STUDENTS (BOARDING)	14	0	0	0	0	14		29	0	0	0	0	29
GROUP RANCHES	14	4	26	49	7	100		0	0	0	0	0	0
CO-OPERATIVE EMPLOYEES	12	4	6	11	0	33		11	5	16	20	0	52
APPRENTICES	4	2	5	3	0	14		0	0	0	0	0	0
ADMINISTRATION	1	0	2	2	1	6		0	0	0	0	0	0
SPORTS CLUB EMPLOYEES	6	2	3	3	0	14		8	4	27	15	0	54
GOVERNMENT	3	1	5	0	0	9		12	6	31	19	12	80

[11] Dependants and relatives
[12] Magadi Railway and Magadi Soda Company
[13] Primary and Secondary

EMPLOYEES													
N.G.OS[14]	2	0	1	3	0	6		21	31	62	64	3	181
TELKOM/POSTA EMPLOYEES	5	2	8	1	0	16		5	2	4	0	0	11
AKAMBA BUS EMPLOYEES	4	0	0	0	0	4		5	4	7	2	0	18
PATIENTS	11	0	0	0	0	11		22	0	0	0	0	22
GUEST HOUSES	9	0	0	0	0	9		8	1	1	0	0	10
OTHER	15	0	0	0	0	15		0	0	0	0	0	0
TOTALS	**654**	**190**	**661**	**474**	**41**	**2020**		**750**	**571**	**2014**	**869**	**145**	**4394**
	Grand Total					**2020**		**Grand total**					**4394**
	Add 30% degree of error					**2626**		**Add 30% degree of error**					**5600**

[14] Non Governmental Organizations



Appendix 3: Layout plan of Magadi Soda Company (Magadi Records, 2007)

Appendix 4: Questionnaire

QUESTIONNAIRE

WATER USE IN MAGADI TOWNSHIP

1. Name of estate

2. Marital status

Single	Married	Married but living alone

3. Number of occupants in the household.__________________-

4. How many taps do you have in the house?

   No of those working_________

   No. of those not working_________

5. Is the water quality good?

Yes	**No**

6. Have you experienced poor water quality?

Yes	**No**

   If yes, how many times

7. Can you estimate the amount of water you use on a day to day basis using jerry cans, buckets or other storage containers for the following?

Activity	**Amount of water**
Cooking	
Cleaning the house	
Washing utensils	
Laundry	
Ablution (Toilets)	
Bathing	
Storage	

8. Which day is the consumption of water the highest?

Sunday	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**

Explain your answer

9. How long does it take to fill up a bucket /Jerry can from your taps?
(Please measure the duration it takes to fill a bucket using your watch)

10. Do you have storage tanks in the house?

Yes	**No**

If yes,

No. of tanks	
Capacity	
No of days it lasts	

11. Do you store water?

Yes	No

If yes, how many Jerry cans / buckets do you use to store water?

12. Do you recycle water in your house?

Yes	No

If yes, please explain.

13. Do you have a garden?

Yes	No

If yes, what time of the day do you irrigate?

Morning	Afternoon	Evening	Night

How many hours do you irrigate?

14. Are there any leaking or faulty taps and faucets in your house?

Yes	No

If yes, how long does it take for them to be repaired?

Promptly	Delayed	Never

Appendix 5: Sample of the data collected during the study

Estate	Code	Class	occupants	No of taps	water quality	Freq_poor_H20	Cooking	Clean_Hse	wash_utensils	Laundry	Toilet	Bathing	Storage	Car	Irrigation	Daily_total	Amount_H20_stored	Recycling	Irrigation	Length_irrigation
Tanganyika	2	Middle	3	3	Good	Low	20	10	10	20	0	20	0	0		80	5	Yes	Evening	4 hours
Uhuru	2	Middle	4	4	Good	Low	10	5	15	60	20	80	50	20	0	260	100	Yes		
Uhuru	2	Middle	5	4	Good	None	10	20	15	20	10	40	20	0	0	135	60	No		
Maringo	3	Lower	5	1	Good	Low	10	40	50	100	50	100	80	20	0	450	80	Yes		
Maringo	3	Lower	3	1	Good	Low	10	20	25	60	10	30	110	0	0	265	110	No		
Kenyatta	2	Middle	2	5	Good	Low	5	20	10	25	30	20	100			210	100	No		
Uhuru	2	Middle	5	4	Good	Low	20	10	10	20	25	50	400	10	0	545	500	No		
Uhuru	2	Middle	1	3	Good	Low	5	5	10	20	10	20	80	0	0	150	80	Yes		
Uhuru	2	Middle	5	3	Good	None	20	10	20	100	20	40	140	0	0	350	140	No		
Uhuru	2	Middle	6	3	Good	None	5	25	10	150	30	120	120	0		460	120	No	Night	2 hrs
Uhuru	2	Middle	4	4	Good	Low	20	10	30	100	20	100	200	0	0	480	200	No		
Uhuru	2	Middle	5	3	Good	None	20	15	10	25	20	100	300	0	0	490	300	Yes		
Uhuru	2	Middle	4	3	Good	None	15	15	15	80	20	20	100	0		265	100	Yes		
Uhuru	2	Middle	6	4	Good	Low	40	30	20	60	30	60	200	0	0	440	200	No		
Harambee	1	Upper	2	4	Good	None	20	10	10	80	20	20	60	0	0	220	60	Yes	Night	2 hrs
Tanganyika	2	Middle	6	2	Good	Low	20	25	15	200	200	120	270	0	0	850	470	Yes		
Kenyatta	2	Middle	4	5	Good	None	25	60	20	200	20	20	200	10	0	555	200	Yes		
Kenyatta	2	Middle	4	1	Good	Low	10	5	20	8	5	80	60	0	0	188	100	Yes		
Kenyatta	2	Middle	3	4	Good	Low	5	10	10	120	10	60	100	0	0	315	100	Yes		

Kenyatta	2	Middle	3	4	Good	None	15	10	15	100	30	60	200	0	0	430	200	Yes		
Harambee	1	Upper	3	8	Good	None	20	20	20	100	60	100	200	10	100	630	200	No	Morning	5 hrs
Tanganyika	2	Middle	5	3	Good	None	20	20	15	60	25	50	200	0	0	390	200	Yes		
Maringo	3	Lower	1	1	Good	None	5	0	5	10	20	10	0	0	0	50	0	No		
Maringo	3	Lower	6	1	Good	None	20	10	15	60	30	40	40	0	0	215	40	No		
Maringo	3	Lower	3	1	Good	None	10	10	10	30	30	30	60	0	0	180	60	No		
Ole sayanka	3	Lower	5	3	Good	None	15	20	10	60	50	50	200	0	100	505	200	Yes	Evening	2 hrs
Ole sayanka	3	Lower	7	3	Good	None	20	30	20	100	70	70	200	0	100	610	200	Yes	Evening	2 hrs
Ole sayanka	3	Lower	6	3	Good	None	15	20	10	60	50	50	200	0	100	505	200	Yes	Evening	2 hrs

Appendix 6: Results of Regression diagnostic test

Observation	Residual	Leverage	Covratio	DFFITS
1	-363.5238	0.0209	0.9826	-0.2194
2	-234.5708	0.0171	1.0198	-0.1268
3	-410.6178	0.0191	0.9620	-0.2371
4	145.1035	0.0186	1.0397	0.0817
5	62.1974	0.0202	1.0508	0.0365
6	-182.4769	0.0304	1.0454	-0.1330
7	-0.6178	0.0191	1.0516	-0.0004
8	-191.4299	0.0456	1.0599	-0.1738
9	-195.6178	0.0191	1.0308	-0.1117
10	-136.6647	0.0268	1.0496	-0.0930
11	-14.5708	0.0171	1.0494	-0.0078
12	-55.6178	0.0191	1.0499	-0.0316
13	-229.5708	0.0171	1.0211	-0.1240
14	-156.6647	0.0268	1.0463	-0.1066
15	-172.4769	0.0304	1.0473	-0.1257
16	253.3353	0.0268	1.0246	0.1731
17	60.4292	0.0171	1.0475	0.0325
18	-306.5708	0.0171	0.9991	-0.1662
19	-128.5238	0.0209	1.0445	-0.0768
20	-13.5238	0.0209	1.0535	-0.0081
21	-54.2451	0.0756	1.1141	-0.0652
22	-155.6178	0.0191	1.0384	-0.0887
23	-50.7086	0.0448	1.0785	-0.0454
24	-140.9435	0.0264	1.0485	-0.0952

25	-22.8026	0.0202	1.0526	-0.0134
26	200.1035	0.0186	1.0294	0.1128
27	203.0096	0.0399	1.0511	0.1714
28	149.0565	0.0264	1.0472	0.1007
29	44.0565	0.0264	1.0585	0.0297
30	730.1035	0.0186	0.7858	0.4305
31	226.1505	0.0165	1.0213	0.1201
32	-24.8965	0.0186	1.0508	-0.0140
33	-32.8026	0.0202	1.0523	-0.0192
34	28.2444	0.0296	1.0626	0.0203
35	-30.7086	0.0448	1.0794	-0.0275
36	2.1974	0.0202	1.0529	0.0013
37	-358.0374	0.0592	1.0220	-0.3786
38	-64.8965	0.0186	1.0488	-0.0365
39	-213.0374	0.0592	1.0697	-0.2236
40	266.1505	0.0165	1.0108	0.1416
41	67.1974	0.0202	1.0504	0.0394
42	-13.8495	0.0165	1.0488	-0.0073
43	-17.8026	0.0202	1.0527	-0.0104
44	-42.8026	0.0202	1.0519	-0.0251
45	8.1035	0.0186	1.0511	0.0046
46	244.7079	0.0717	1.0751	0.2870
47	-468.1981	0.0852	0.9953	-0.6166
48	315.7549	0.0756	1.0556	0.3832
49	383.6610	0.0736	1.0256	0.4603
50	524.7079	0.0717	0.9514	0.6280
51	-5.7086	0.0448	1.0799	-0.0051

52	-75.7086	0.0448	1.0766	-0.0678
53	184.0565	0.0264	1.0408	0.1245
54	-3.8495	0.0165	1.0489	-0.0020
55	105.1035	0.0186	1.0451	0.0591
56	199.8686	0.1149	1.1389	0.3106
57	95.1035	0.0186	1.0462	0.0535
58	26.1974	0.0202	1.0525	0.0154
59	78.2444	0.0296	1.0597	0.0561
60	48.2444	0.0296	1.0618	0.0346
61	-12.8026	0.0202	1.0528	-0.0075
62	177.1974	0.0202	1.0357	0.1042
63	-28.0374	0.0592	1.0960	-0.0293
64	20.1035	0.0186	1.0509	0.0113
65	-60.9435	0.0264	1.0575	-0.0411
66	-96.9904	0.0399	1.0691	-0.0817
67	-3.8495	0.0165	1.0489	-0.0020
68	-27.8026	0.0202	1.0524	-0.0163
69	-79.8965	0.0186	1.0476	-0.0449
70	-57.8026	0.0202	1.0510	-0.0339
71	-150.6178	0.0191	1.0393	-0.0858
72	-73.5238	0.0209	1.0506	-0.0439
73	-170.6178	0.0191	1.0358	-0.0973
74	-127.4769	0.0304	1.0548	-0.0928
75	-262.6178	0.0191	1.0143	-0.1503
76	-316.6647	0.0268	1.0051	-0.2170
77	-405.8526	0.1149	1.0582	-0.6383
78	-164.5708	0.0171	1.0348	-0.0887

79	-295.6178	0.0191	1.0045	-0.1695
80	-248.7587	0.0593	1.0602	-0.2618
81	1055	0.0171	0.5519	0.6318
82	549.3822	0.0191	0.8949	0.3210
83	670.4292	0.0171	0.8231	0.3755
84	518.3353	0.0268	0.9175	0.3607
85	521.4762	0.0209	0.9111	0.3187
86	-52.8026	0.0202	1.0513	-0.0310
87	14.2914	0.0448	1.0798	0.0128
88	-41.7556	0.0296	1.0621	-0.0299
89	-26.7556	0.0296	1.0627	-0.0192
90	-92.8026	0.0202	1.0482	-0.0545
91	-148.8495	0.0165	1.0369	-0.0788
92	-143.8495	0.0165	1.0377	-0.0762
93	31.0096	0.0399	1.0739	0.0261
94	-74.5708	0.0171	1.0465	-0.0401
95	-181.4299	0.0456	1.0620	-0.1647
96	-122.8026	0.0202	1.0446	-0.0721
97	-52.8026	0.0202	1.0513	-0.0310
98	-23.8495	0.0165	1.0486	-0.0126
99	-100.6178	0.0191	1.0461	-0.0573
100	8.2444	0.0296	1.0630	0.0059

The values which do not lie within the specified ranges of the diagnostic tools are said to be influential. The shaded values in the table show influential points in covratio and leverage.

Appendix 7: Eigen vectors and their interpretation

	PRIN1	PRIN2	PRIN3	PRIN4	PRIN5	PRIN6	PRIN7	PRIN8	PRIN9
Cooking	0.005793	0.031732	0.035549	-.001646	0.017304	0.098113	0.403661	0.660648	-.623193
Clean_Hse	0.018387	0.026696	0.107167	-.079032	-.104579	0.945204	-.276684	0.010372	-.014464
wash_utensils	0.001660	0.015213	0.086058	0.002716	0.170590	0.262185	0.841192	-.393184	0.179757
Laundry	0.062407	0.177210	0.576327	-.779476	0.068425	-.138612	-.032370	-.004756	-.001393
Ablution	0.005130	0.143316	0.592834	0.425466	-.656928	-.084657	0.078532	-.015654	0.042742
Bathing	0.019384	0.174140	0.460508	0.451008	0.721055	0.006777	-.179167	0.032908	-.025954
Car	0.019010	0.001444	-.000604	-.012950	0.034331	0.041009	0.116215	0.637844	0.759116
Storage	0.102820	0.950091	-.289390	0.005514	-.047359	0.002021	0.008090	-.021459	0.014306
Irrigation	0.992167	-.114482	-.020649	0.039164	-.009192	-.010499	0.003429	-.013652	-.012048

- ❖ The table of eigenvectors reveals that the first eigenvector has a large loading on irrigation. This suggests that the first component is primarily a measure of irrigation.
- ❖ The second eigenvector has high positive loadings on the variables storage.
- ❖ The third eigenvector has high positive loadings on the laundry, ablution and bathing.
- ❖ The fourth principal component has negative loadings on laundry.
- ❖ The fifth principal component has a negative loading on bathing and ablution
- ❖ The sixth principal component has a positive loading on cleaning the house.
- ❖ The seventh principal component has a positive loading on washing utensils.
- ❖ The eighth component has a positive loading on cooking and washing the car
- ❖ The ninth component has a positive loading on the car wash and a negative on the cooking.

Appendix 8: Sewage capacity in Magadi (Magadi Records, 2007)

MAGADI SEPTIC TANK CAPACITY							
Location	**Number**	**Size**	**Length (m)**	**Width (m)**	**Height (m)**	**Volume (m^3)**	**Total Volume (m^3)**
Management houses	21	Small	1.2	1.9	2.4	5.472	**114.912**
Sports club	2	Big	2.3	2.3	2.4	12.696	**25.392**
B2 houses	1	Big	5	8.5	3	127.5	**127.500**
B4 houses	1	Big	11.7	14.6	3	512.46	**512.460**
Repair shop and Majengo estate	1	Big	7.2	11	3	237.6	**237.600**
Power house	1	Small	2.3	7.4	3	51.06	**51.060**
Civil yard and Simba club	1	Medium	2.7	7.7	3	62.37	**62.370**
Engineering offices	1	Big	2.7	2.9	3	23.49	**23.490**
Ash plants	1	Big	2.1	5.1	3	32.13	**32.130**
Administration offices	1	Small	1.9	2	3	11.4	**11.400**
Commercial offices	1	Small	1.9	2	3	11.4	**11.400**
Personnel and laboratory	1	Small	1.5	2	2.4	7.2	**7.200**
Railways houses	1	Big	4.7	8	3	112.8	**112.800**
Salt plant	1	Medium	2.5	6.8	3	51	**51.000**
Police post and Hospital	1	Big	4.7	8	3	112.8	**112.800**
Total	**36**					**1371.378**	**1493.514**