WATER QUALITY AND HEALTH: IMPLICATIONS FOR IRRIGATION MANAGEMENT IN SOUTHERN SRI LANKA

By

Rebecca L. Shortt

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Department of Agricultural and Biosystems Engineering
Macdonald Campus of McGill University
Ste-Anne de Bellevue, Québec, Canada

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ABSTRACT

M.Sc. Agricultural and Biosystems Engineering

Rebecca L. Shortt

WATER QUALTIY AND HEALTH: THE IMPLICATIONS FOR IRRIGATION MANAGAMENT, IN SOUTHERN SRI LANKA

This study was conducted to understand the interactions between irrigation water management and water quality (agro-ecological interactions). The Uda Walawe basin, in Southern Sri Lanka was chosen as the study area. Fluctuations in water quality, especially microbiological water quality, affect human health. Since the source of domestic water (drinking and washing) in this region is from the irrigation system, there is a concern for the human health effects. All the potential water sources and the water use habits of the community were identified. The water quality of these sources was then monitored for a period of 5 months (August-December 2000). Second, the water management of the Uda Walawe irrigation system was linked to the differences in water quality. The best quality water was found to come from the shallow wells (seepage water from the irrigation system). Both quantity and quality of the water were shown to fluctuate with canal construction (earthen or concrete) and irrigation water management.

RÉSUMÉ

M.Sc. Génie rural, et des biosystèmes

Rebecca L. Shortt

SANTÉ ET QUALITÉ DE L'EAU: LES IMPLICATIONS AU NIVEAU DE LA GESTION DE L'IRRIGATION AU SUD DU SRI LANKA

Cette recherche a été effectuée afin de comprendre les interactions entre la gestion des systems d'irrigation et la qualité de l'eau (interactions agro-écologiques). Le bassin Uda Walawe, dans le sud du Sri Lanka, a été choisi pour cette recherche. La santé humaine est affectée par les changements en qualité de l'eau, à cause de la présence de nombreux agents infectieux. Puisque les systèmes d'irrigation servent souvent de source d'eau potable, il y a des risques pour la santé humaine. En premier lieu, toutes les sources d'eau, ansi que les habitudes d'utilisation de l'eau de la communauté ont été identifiées. Pendant une période de 5 mois (août-décembre 2000) la qualité de l'eau de ces sources a été mesurée, puis un lien a été établi entre la gestion du système d'irrigation et les changements et différences en qualité de l'eau. Les résultats démontrent que l'eau de la meilleure qualité se trouve dans les puits de surface (approvisionnés par l'écoulement du system d'irrigation). Les changements en quantité et en qualité de l'eau ont été reliés au type de canal d'irrigation et à la gestion de l'eau d'irrigation.

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List of Symbols and Abbreviations

APHA	American Public Health Association
BOD	Biological oxygen demand
Chi-Square	statistic for the Chi-Square distribution
COD	Chemical oxygen demand
DALY	Disability-adjusted life years
df	Degrees of freedom
E. coli	*Escherichia coli*
EC	Electrical conductivity
F	statistic for the F distribution
FAO	Food and Agriculture Organization
GLM	General Linear Models
IDRC	International Development Research Centre
IIMI	International Irrigation Management Institute
IWMI	International Water Management Institute
JBIC	Japanese Bank for International Cooperation
LSD	Least Squares Difference
MCM	Million cubic meters
mS	millisiemens
NGO	Non-governmental organization
P	Probability
ppm	Parts per million
T	statistic for the student t distribution
ThCU	Thermotolerant coliform unit
UNCED	United Nations Conference on the Environment and Development
UNDP	United Nations Development Program
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
WARDA	West Africa Rice Development Association
WHO	World Health Organization

1. INTRODUCTION

Water scarcity and water pollution are two major present day concerns (Postel, 2001; Gleick, 2001). Some countries will not have enough water to provide the basic necessities for their people. Water pollution will render some of the sources unusable, thereby diminishing the already scarce supply. Drinking water and water for personal hygiene are seen as the number one priority uses of water, although many other sectors compete for this resource. Major water use sectors are: agriculture, industry, hydropower, navigation and sustenance of the environment. As water resources have become scarcer, fears have grown that water may become yet another commodity manipulated by the rich, and that those in the most need, the poor, will be denied this basic necessity. The United Nations (UN) has attempted to safeguard the use of water resources and made this declaration at the 1977 Mar del Plata conference:

> *...all peoples, whatever their stage of development and their social and economic conditions, have the right to have access to drinking water in quantities and of a quality equal to their basic needs.*

There is an abundance of water on earth; however, the vast majority is saline. The oceans contain most of the world's water (97.5%) and, of the remaining fresh water, two thirds (1.67% of the total) is captive in the polar ice caps and glaciers. Rainfall, the renewable portion of freshwater, amounts to only 0.000 008% of all water on earth. Of the rest, one third is found in freshwater lakes and rivers and two thirds is in subterrainian aquifers (Postel, 1996; Canadian Broadcasting Association, 2001). World freshwater resources are limited and by no means evenly distributed. In arid regions many people experience water scarcity, where they lack enough water for drinking and bathing. This leads to disease and hardship for the community. According to the World Watch Institute, 21 countries, as of 1995, were already in a state of water scarcity (Postel, 1996). Water demand is increasing due to our ever growing population and an increase in affluence creating a rise in demand per person. Water availability around the globe is diminishing. The International Water Management Institute (IWMI) estimates that by the year 2025, 1.8 billion people will live in regions of absolute water scarcity (International Water Management Institute, 2000).

The number one consumer of fresh water is agriculture. This sector is viewed as being a water waster with efficiency rates of only 40% (Postel 1996). Inefficiencies in irrigated agriculture are mainly attributed to seepage and evaporation losses (Rajkumar et al. 1999; Phogat and Malik, 1997). These losses may occur through the application method, or through the distribution system. Water is quickly being siphoned out of agriculture and into other, higher value sectors such as urban supply and industry. However, food is also a necessity of life. In underdeveloped countries, water scarcity and the resulting prospect of having to import food may be detrimental, impacting especially on the poor. Already, 24 countries import more than 20% of their grain to feed their people and livestock which cannot be sustained by their limited water resources (Postel, 1996). Water scarce regions will have difficult choices to make.

Waterborne diseases are primarily the product of both water scarcity and pollution. More than 4.0% of world mortality and 5.0% of world morbidity are caused by contaminated water (WHO, 2000b). For domestic purposes, a clean supply of water in adequate quantities is crucial for the health of every community. In many developing countries where domestic water supply is lacking, irrigation has served as the main water source for domestic purposes (including drinking water). Both the quantity and the quality of water have a direct influence on people's health, especially in regards to waterborne diseases. Although irrigation water may be perceived as poor quality for drinking by the developed world standard, it may constitute the only option for some communities in regions of water scarcity. Drinking water is often drawn from irrigation systems either directly, or from areas of seepage into shallow ground water. Sri Lanka is an example of this phenomenon. In many arid regions of the world, deep ground water is brackish or contains high iron or fluoride levels. In these regions of acute water scarcity, the only alternative water source for domestic purposes is the water originating from the irrigation system.

Management of irrigation systems can affect both the availability and the quality of domestic water. A direct correlation between water management and water quality has been shown in Pakistan (Jensen et al. 1998; van der Hoek et al. 2001). Large surface irrigation systems are often designed, leaving out adequate consideration for the living conditions of the people within those systems. By studying the impact of water management on the quality of water used for domestic purposes, improvements in the health of rural communities in developing countries may be achieved.

1.1 Objectives

The objective of this research project was to study the interaction between the irrigation water management and water quality (agro-ecological interactions). The parameters studied were those related to microbiological quality of domestic water.

The specific aims were to:

1. identify all the potential water sources and the water use habits of a small community in the Uda Walawe irrigation scheme (southern Sri Lanka)
2. monitor the water quality of the different water sources over a 5 month period
3. compare the water quality of the different water sources in terms of thermotolerant coliform units (ThCU), electrical conductivity (EC), pH and temperature
4. relate the water quality differences to climatic changes and the irrigation system management (type of canal construction, water issuing schedule, position along canal: head/tail)
5. investigate water quality differences due to other parameters such as well head protection, bathing activities, sun/shade, topography and proximity of wells to canals, latrines and refuse heaps

1.2 Scope

A discussion of world water resources is vast, and includes issues of scarcity, quality and resulting human and ecosystem health implications. Water management affects all aspects of human life, from domestic uses to power generation, industry, food production and ecosystem maintenance. Water is a precious resource required for life in every part of the world. This study was conducted in the Uda Walawe irrigation scheme of southern Sri Lanka to determine the quality of water for domestic use and the implications of irrigation system management on the availability and quality of water sources in the region. Data were collected over a 5-month period from August to December 2000, from the distribution area of two irrigation canals, MD17 and BBD5, which flanked the village of Suriawewa. The distribution areas of each canal were approximately 1.5 km^2 and 3.0 km^2, respectively. The results of this study are locally applicable. However, the concept of interactions between water management and human health have the potential to be applied to other large scale irrigation projects, within Sri Lanka or in other developing countries.

1.3 Limitations

This study was limited by the financial resources and time allocated through the project. In rural Sri Lanka, the availability of laboratory support, supplies and equipment are also significant limitations. The results are limited to a specific region of the world and a specific region of Sri Lanka.

2. LITERATURE REVIEW

In developing countries, irrigation systems, which are built for agricultural purposes, serve also as a source of domestic water supply. This review of the literature of this practice highlights some of its benefits and detriments with respect to water quality and its subsequent implications for human health.

2.1 History of water resources

Water is essential for all life. The issues surrounding water and its availability, quality and distribution are gaining importance in the public eye. For people living in an environment of water scarcity, these have always been crucial issues. For the overwhelming majority of people in developed countries, the adequacy of the water supply and its quality have been taken very much for granted since the proliferation of municipal water systems.

The second World Water Forum held in the Hague, March 2000, brought the world's attention to water as a global issue. However, the crisis is not new. Even before modern times people struggled to gain control of water resources. Our primary needs are ample clean water for basic survival, drinking and hygiene. As people moved to an agrarian existence, water for agriculture became important. Food production is necessary for survival and irrigation became necessary for food production as people began to live in regions where rainfall was lacking. Industry was the next sector to develop and it also laid claim to water resources. As the world population has expanded, humans have begun to consume so much water that there is no longer any left for other ecosystem participants. Today, domestic uses, irrigation, industry and environment compete for this vital resource.

2.2 Water scarcity

Every living being depends on water for survival. The sustainability of human activity and of ecosystems depends on wise management of the world's water. Today, the world faces an ever increasing shortage of water due both to the depletion of water quantity and the deterioration of water quality (World Water Commission, 2000).

The present definition of water scarcity is somewhat arbitrary. Most discussions of water scarcity are based on calculations by the hydrologist Malin Falkenmark which set water scarcity at 1,000 cubic meters per year per person and water stress at 1,700 cubic meters per year per person (de Villiers, 1999). Countries with less renewable runoff than 1,000 cubic meters per year per person are therefore water scarce. Today, most countries in the Middle East and North Africa are considered to have absolute water scarcity (International Water Management Institute 2000). IWMI predicts that this will rise, and by 2025, 1.8 billion people will live in countries with absolute water scarcity (International Water Management Institute 2000). This will increase the competition for water between the various sectors: domestic, industrial, environmental and agricultural most likely leading to a reduction of water allocated to the environment and agriculture (Burt et al. 1997; Gupta, 1999). Other countries will face economic water scarcity, where water is potentially available, but the cost of developing these water resources will be prohibitive (International Water Management Institute, 2000). Large water development schemes, such as dams, or extensive ground water extraction will be necessary to provide water. However, many countries, especially those in sub-Saharan Africa, will lack the finances to make these developments (International Water Management Institute 2000). There are many estimates about future water scarcity. For example the UNFPA (1999) predicts that 1 person in 4 may face water shortages by 2050. Regardless of the actual number of people affected in the future, the world is already affected by water shortages. Even at the beginning of the 21st century there are certain regions of the world where water demand exceeds the sustainable supply.

Water scarcity is a fact of life in many of the world's river basins, and may lead to international conflicts. Several international conflicts have arisen over water from numerous rivers including the Nile, Jordan, Tigris, Euphrates, Ganges, Amu Dar'ya and Sry Dar'ya (Postel, 1996). Self-interest will make it difficult for countries to share this precious resource. Water withdrawals at the head end may deplete rivers so that tail end users are left with nothing. In some basins, water withdrawals have been so great that even massive rivers such as the Yellow River and the Colorado, now run dry at their tail ends due to over consumption in the upstream regions (Postel, 1996). This raises the question of water sharing and if downstream users have rights to certain volumes of water.

Rivers are not the only water source suffering from damaging water volume withdrawals. Aquifers are also shrinking. Underground water levels are declining as humans extract more water than is naturally recharged each year. Monitoring programs in the High Plains Aquifer System of Texas, California, Southwest Arizona, the Arabian Peninsula, North Africa (Lybia), Israel, Gaza, Spain, Punjab (India), and Northern China have recorded decreases in the level of their water table between 40 m and more than 120 m (Postel, 1999). Cities, such as Bankok and Mexico City, are subsiding as aquifers underneath them are pumped dry (Postel, 1999). Already, the evidence of our declining water resources is clear.

At the beginning of the 21st century, the world population is more than 6 billion, and is expected to rise, at a rate of 1.8%, to 8.9 billion people by the year 2050 (UNFPA, 1999). This means that more water will be required for humans' basic domestic needs such as drinking and bathing. This creates greater demand for water in cities and will increase the competition between farmers and urban populations. This is already apparent in China, California, and South East Asia, where cities are redirecting water away from agricultural lands (Gleick, 1998). However, with rising populations, food consumption will also rise, and food production requires water. It is estimated that the human population in 2050 will consume twice the number of calories as in 1999 (UNFPA, 1999). The production of one ton of grain requires one thousand tons of water (Postel, 1999). The countries of the Middle East already import more than 30% of their grain since limited water resources restrict their capability to be self sufficient in food (Postel, 1999). Not only is the population rising, but also the affluence of the world is rising and this puts further pressure on water resources. Diets traditionally based on grains and legumes are shifting to higher meat consumption, which requires more water to produce the necessary increase in grains to feed livestock (Kirpich et al. 1999).

Energy production consumes water also. For example, approximately 10 litres of water is required to manufacture 1 litre of gasoline (Canadian Broadcasting Association, 2001). The production of hydropower impounds or diverts rivers often causing conflicts between sectors and between countries. The conflict over the flow of the Tigris and the Euphrates rivers is only one example of this water conflict. Turkey wants to expand its hydropower, and Iraq and Syria do not want to be left high and dry without water to grow food and supply cities with potable water (UNFPA, 1999). Many other industries use astronomical volumes of water. For example, approximately 324 litres of water are required to produce 1 kg of paper and 95 litres of water are required to produce 1 kg of steel (Canadian Broadcasting Association, 2001). Generally, for each unit of water used in industry greater economic value is produced than could be generated from agricultural production using that same unit of water. As a result, governments tend to direct water into industry and leave less and less for agriculture.

World-wide increases in population and in the level of development have caused the overall per capita water withdrawals to rise from 250m^3/yr in 1900 to over 700m^3/yr in 2000 (Canadian Broadcasting Association, 2001). The implications of increasing world wide water scarcity are vast and difficult to envision. Water managers have a great responsibility in the decisions of water allocation for today and the future.

2.3 Water pollution

Water scarcity is a matter for global concern. Water pollution from industry, agriculture and urban waste is only aggravating the water crisis. Not only are we living with water scarcity, we are rendering much of the water that we do have, unusable. The problems of water pollution have begun to be addressed by the international community. Both remediation and prevention of water pollution are being promoted (Global Water Partnership, 2000). Water pollutants may be classified under several general categories, such as: fertilizers, pesticides, sediment, organic matter (BOD, COD), heavy metals, synthetic organic chemicals, salinity, microorganisms, acidifying compounds and macropollutants (large debris) (Thornton et al. 1999). In 1998 the U.S. Environmental Protection Agency reported to Congress that of its surface waters assessed, 35% of rivers, 45% of lakes and 44% of estuaries were polluted. In Canada the Agriculture and Agri-Food Canada Research Branch has reported widespread pollution resulting from suspended sediments, nutrients, pesticides, pathogens, and metals. Large numbers of water bodies have experienced environmental degradation due to pollution by phosphorus and nitrogen causing problems of eutrophication throughout the world (Sims et al. 1998; U.S.Environmental Protection Agency, 1996; Heinzmann and Chorus, 1994). The health implications of water pollution are vast and the population affected includes those from all regions of the world. It is important to have some understanding of the most relevant issues, however, the focus of this thesis is the microbiological aspects of water pollution.

2.4 Ecosystem approach to human health

In view of our diminishing water resources, society has begun to realise that there can be impacts on human health caused by a degraded environment. Agro-ecosystems are of particular interest when discussing water resource issues. Food is a basic requirement for healthy people. However, food alone does not ensure human health. A multitude of factors present in our environment affect human health. Therefore, a broad scope is required when approaching health issues. Hence, an ecosystem approach to human health has developed in which the ecosystem is managed for the improvement of human health. This concept began with the World Health Organization (WHO) in 1976 redefining health as "a state of complete physical, mental and social well-being", not merely the absence of disease or infirmity. This broader vision of health was continued by the 1992 United Nations Conference on the Environment and Development (UNCED) which began reflections on the relationships between human health and the changing environment, and the specific links between health and development, poverty and environmental degradation (Forget et al. 1999). In 1998 the International Development Research Centre (IDRC) pioneered the ecosystem approach to human health by initiating dialogue and cooperation between different sectors. for example. agriculture and health. Many organizations have been calling for interdisciplinary approaches and research. but in reality this is an extremely difficult task. In terms of water resources it entails bridging two domains, the water specialists and the health specialists. Collaborations would include hydrologists, irrigation engineers, agronomists, public health officers, research scientists, physicians, community development workers. politicians, etc. (Peden. 1998)

What does ecosystem approach to human health mean? First, an ecosystem is the complex of all biotic and abiotic elements within a boundary and includes the interactions between these elements. The boundary is arbitrary and is determined for the convenience of the researcher. It is understood that all the elements in the ecosystem interact and have an effect on the system as a whole. Second. the traditional definition of health. the absence of disease, has been replaced by a broader view of health as: the sustainable maintenance of productivity and integrity (Waltner-Toews. 1996). An important concept in this definition is that health is a scale: it is a measure of the ability we have to maintain productivity. If we bring together these two concepts. ecosystem and health. then we can begin to address the concept: what is a healthy ecosystem? This is a more difficult concept. An ecosystem may be considered healthy if it is capable of maintaining a dynamic equilibrium in which all the elements (participants) maintain sustainable productivity (health) from the available resources. At an individual level. elimination from the ecosystem is detrimental, but at the ecosystem level this might be beneficial. A healthy ecosystem is one in which there exists a certain level of diversity and healthier ecosystems have greater diversity. Ecosystem health may be measured on the relative richness of resources available for productive use. Healthy ecosystems have the ability to exploit, conserve, release and re-organize. They require integrity, the capacity to respond, efficiency and effectiveness. Health of an ecosystem includes the capacity to withstand stress, ability for self-renewal and the ability to respond to unwanted, catastrophic changes. The difficulty in defining ecosystem health lies in the fact that health is a combination of value judgements followed by scientific assessment and is based on the values and ideologies of humans. A complete definition of ecosystem health requires the community to determine which ecosystem components or services are valued most by society. By that token, a healthy ecosystem is one that is most conducive for human flourishing. As some aspects of an ecosystem seem detrimental to humans, the instinct is to eliminate them. However, we must be cautious in eliminating these "unwanted" aspects as they often have indirect effects, which are beneficial. The stewardship of our ecosystems is not an easy task, but through wise management and the subsequent maintenance of a healthy ecosystem, the level of human health may be increased.

The ecosystem approach to human health is different from other health initiatives as it seeks to include all the elements (participants) in the ecosystem, because we know that all elements interact and have an effect on each other. Of course, we are incapable of dealing with the infinite complexities of ecosystems, however, this approach tries to incorporate all interactions in the ecosystem, although in reality, we will omit many. The approach emphasizes the inclusion of more of the ecosystem participants (elements), and seeks to include participants which might normally be excluded from a study due to the researcher's particular expertise or specialization. This can be achieved through the incorporation of many disciplines from the conception of the project, thereby fostering an intersectorial view of the problem.

Why is the ecosystem approach to human health important ? Humans are involved in a variety of activities that disrupt the balance of our ecosystems. Before making interventions, society should try to gain some understanding of the consequences of our actions since changes in our ecosystem have an effect on human health. In the past, the choices made in managing ecosystems have created many unsustainable systems. The ecosystem approach may help society make appropriate management choices. Establishing good ecosystem health should be society's goal when trying to achieve good human health (IDRC, 1999; Smit et al. 1998; Waltner-Toews, 1996; Waltner-Toews and Wall, 1997).

How can the ecosystem approach to human health be implemented? Interdisciplinary ecosystem level research is expensive and thorough studies are time consuming due to the quantity of parameters and the complexity of interactions existing in an ecosystem. Two methods have been suggested for implementation of this approach. First, the inclusion of human health research in ongoing or planned ecosystem level studies, and second, community or non-governmental organizations (NGO) research. The local research entails a modest scale and examination of agroecosystems with the intent of identifying, understanding and testing interventions that may result in improved human health. Some key elements of the concept are interdisciplinary, knowledge intensive, community based and management approach (Peden, 1998).

A good example of the ecosystem approach to human health is the IDRC project "Assessing the health risks of rice growing in Africa". The increase of irrigated rice farming in West Africa was seen as an amplifier of the human malaria problem. However, the results of the ecosystem study showed that malaria was not increased by the introduction of irrigated rice production. The increased productivity of the region meant more disposable income for families allowing them access to drugs, which encouraged them to seek timely malaria treatment. As well, the mosquito population was increased, due to impounded water in rice paddies. This reduced the life span of individual mosquitoes and therefore reduced the malaria transmission (WARDA, 1999). Through the efforts of an interdisciplinary team looking at the broad issues and complex interactions, an ecosystem management plan could now be put into effect to benefit the health of the community. The ecosystem approach to human health is still developing, as researchers and managers begin to implement it and realise the potential benefits.

2.5 Human health and water quality

Water contaminated by faecal matter becomes a reservoir of infectious agents and may cause diseases if the contaminated water is used for domestic purposes. Waterborne diseases are caused by pathogenic bacteria, viruses, protozoa or helminths' eggs, which are released in faeces from infected individuals and/or animals. The pathogens may re-infect a new host after ingestion of contaminated water. It is a process known as faecal-oral transmission. Water of poor quality may lead to diarrhoea and dysentery (bloody diarrhoea). Examples of specific waterborne diseases include cholera, hepatitis A, typhoid fever, *Cryptosporidium*, *Giardia*, etc. The WHO estimates that in 1999 diarrhoeal disease accounted for 2.2 million deaths or 4.0% of the total world mortality (WHO, 2000b). More than 45% of these deaths occurred in South East Asia (WHO, 2000b). The WHO calculates Disability-Adjusted Life Years (DALYs) to measure the morbidity impact of a disease. For diarrhoeal disease the WHO estimated 72,063 DALYs lost in the world; which represented 5% of the world morbidity burden in 1999. More than 47% of this morbidity was experienced in South East Asia. In 1999, there were 254,310 cases of cholera with 9,175 fatalities reported to the WHO. In particular Sri Lanka reported 108 cases of cholera, with 5 casualties. The estimated number of cases for hepatitis A in the world in 1990 was 1,399,000 (WHO, 2000c). Outbreaks of waterborne disease are not only restricted to the developing world. In North America there have been two recent waterborne disease outbreaks: the 1993 outbreak of *Cryptosporidium* in Milwaukee (U.S.A.) where more than 100 people died and 404 thousand people became ill, and the 2000 outbreak of pathogenic *E. coli* in Walkerton (Ontario) where 6 people died and 2.3 thousand became ill (Gleick, 1998; Verma and Donovan, 2000; Kondro, 2000). These disasters demonstrate that even in the developed world, vigilance of the water systems is necessary to avoid widespread waterborne disease. Thus, it is clear that the improvement of water quality, which breaks disease transmission cycles, could vastly reduce global morbidity and mortality.

Recent studies have shown that in order to reduce diarrhoeal diseases, water quality is of lower importance when compared to the improvement of water quantity, sanitary facilities and personal hygiene (Esrey et al. 1991; Kolsky, 1993; Mertens et al. 1990). However, the improvement of water quality can significantly reduce diarrhoeal diseases if adequate water supply and sanitation are already present (VanDerslice and Brisco, 1995).

2.6 Water supply and sanitation

The incidence of diarrhoeal diseases may be reduced by improving the existing water supply and sanitation facilities (WHO, 2000a). However, 1.1 billion people (18% of the world population) still live without adequate water supply and 2.4 billion people (40% of the world population) lack sanitation facilities (WHO, 2000a). In Sri Lanka 17% of the population lack adequate water supplies and sanitation facilities (20% of rural residents and 9% of urban residents) (UNICEF, 2000). A simple effort to increase the access to clean water and sanitation facilities could reduce the disease burden and thereby reduce health care expenditures for a country where already 8,273 million Rupees (5.2% of total government revenues) are spent annually on health care (Department of Census and Statistics, 1995). The Global Water Partnership (2000) estimates that in rural communities potable water can be supplied at a cost of $15 US/person, and sanitation facilities at $10 US/person (Global Water Partnership, 2000). In order to reduce morbidity and mortality, the WHO declared the years 1980 to 1990 as the International Drinking Water Supply and Sanitation Decade. Although significant progress has been made since that decade, water and sanitation are still lacking for many people in developing countries. New innovations in the provision of sanitation facilities and water supply systems are needed urgently.

2.7 Irrigation water usage

Approximately 70% of the world's freshwater withdrawals are used for irrigated agriculture (World Water Commission, 2000). The Food and Agriculture Organization of the United Nations (FAO) estimates that in 1998 world irrigation was at 271.4 million ha. In terms of number of irrigated hectares, the top 10 countries of the world are India, China, U.S.A, Pakistan, Iran, Mexico Thailand, Indonesia, Russia and Uzbekistan (Postel, 2001). Irrigated agriculture produces

40% of the world's food from only 18% of the world's cropland (Postel, 2001). Major issues in irrigation management include salinization, and issues pertaining to water scarcity. Salinization, the rising of salts to the soil surface causing infertility, is exacerbated by irrigation and currently affects an estimated one third of irrigated lands (Kijne et al. 1988). Increasing water scarcity has raised the issue of poor efficiency in irrigation systems where only 40% of irrigation water is actually used by crops (Postel, 1996; Burt et al. 1997). Decreasing water tables due to over extraction of water from aquifers is now putting into question the sustainability of irrigated agriculture in regions that depend on ground water (Postel 1996). To combat scarcity new initiatives have begun in recycling of urban wastewater to be used for irrigation. In Israel, 30% of irrigation depends on urban effluents (Postel 2001). As the world's freshwater resources dwindle, the competition between irrigated agriculture, industrial purposes, domestic uses and environment will increase (Bakker et al. 1999). As the world population increases, food demand is also increasing, creating more need for irrigated (highly productive) agriculture (Kirpich et al. 1999). Thus, many people believe that improving the efficiency of irrigation systems is necessary in order to "save water" which can then be used for other purposes. As two-thirds of all irrigated land is situated in developing countries (Kirpich et al. 1999), the competition for water between irrigation/other uses is only more poignant (Biswas, 1999). The conflict over water allocation between agriculture and cities such as Bankok, Jakarta, Manila, Los Angeles, San Diego, Tianjin, Beijing, and West Java (Postel, 1999; Kurnia et al. 2000; Wang et al. 2000) are typical examples of this conflict. To solve problems of water scarcity, many irrigation specialists are proponents of water saving techniques (Kirpich et al. 1999; Wu, 1999; Gupta, 1999; Rajkumar et al. 1999; Phogat and Malik, 1997). However, the re-allocation of water must be further researched and its impact on different water use sectors should be investigated before any interventions are put into practice.

2.8 Multiple uses of irrigation water

Recent studies have shown that irrigation water is an important source of domestic water in some rural areas (Bakker et al. 1999; Meinzen-Dick and

Bakker, 1999; van der Hoek et al. 1999; Jensen et al. 1998; Konradsen et al. 1997; Meinzen-Dick, 1997; Steele et al. 1997). Grenney et al (1998) noted the multiple use of irrigation water in Egypt during the course of a cost allocation study for the operation, maintenance and rehabilitation of the irrigation system. Among others, rural water supply was identified as one of the main non-agricultural uses for irrigation water. Laundering and bathing directly in irrigation canals has been observed in irrigation systems across the country in Sri Lanka (Meinzen-Dick, 1997; Bakker et al. 1999; Steele et al. 1997; Meinzen-Dick and Bakker, 1999). Irrigation authorities have become aware of this practice, and, as a result, have provided steps and washing slabs to provide easy access to concrete lined canals (van der Hoek et al. 1999). In addition, during the inter-cropping seasons (period of canal closure), the irrigation authorities have issued water in the canals once every two weeks for domestic consumption (Meinzen-Dick and Bakker, 1999; van der Hoek et al. 1999). In Pakistan and Sri Lanka, seepage water from the canals and fields recharges shallow aquifers that supply shallow wells used for all domestic purposes, including drinking (Jensen et al. 1998; Bakker et al. 1999; Meinzen-Dick and Bakker, 1999; Meinzen-Dick, 1997; van der Hoek et al. 1999). A few municipal water supply systems provide the only alternative for domestic water supply. However, the origin of this water is generally irrigation canals or tanks (reservoirs). In Sri Lanka there are some alternatives; deep groundwater sources are also used for municipal supply (Meinzen-Dick, 1997; Meinzen-Dick and Bakker, 1999; Bakker et al. 1999; van der Hoek et al. 1999).

The use of irrigation water for domestic purposes is by no means a new concept. The 1978 publication "Environmental effects of arid land irrigation in developing countries" by UNESCO highlighted potential benefits to communities by the provision of domestic water through the irrigation system. Unfortunately, their suggestion to include the concept of multiple use of irrigation water during development of irrigation systems has been overlooked for many years. An interdisciplinary approach is needed where irrigation engineers, community planners and health specialists will work together in designing irrigation systems.

These issues were addressed in the 1995 consultation, "Integrated Rural Water Management", hosted by the WHO, which brought together the FAO, UNICEF, UNDP and the World Bank. Its purpose was to highlight the similarities between water supply and irrigation sectors and provide opportunities for collaboration between the two sectors.

Health planners often disregard irrigation water as a potential domestic water source due to the perception of it being of poor quality. Koegel (1985) discourages the use of surface waters and warns against the use of any shallow wells as he considers these sources to be of very poor quality. However, studies such as those by the IWMI in Pakistan and Sri Lanka, have shown that in some regions irrigation systems are the only possible water source for all domestic uses (van der Hoek et al. 1999; Jensen et al. 1998). Particularly in arid areas, where water is very scarce, an irrigation system can provide easily accessible, adequate water for domestic purposes (UNESCO, 1978). As mentioned previously, numerous studies have found that in impoverished communities, the quantity of water provided (not the quality) is crucial for the reduction of disease (especially diarrhoeal diseases and water contact diseases)(Kolsky, 1993). Low, or seasonal rainfall, and poor quality of deep ground water force communities to draw domestic water from the irrigation system. Deep ground water may be non-potable due to high fluoride levels, as reported in Sri Lanka, Kenya and India (Steele et al. 1997; Dissanayake, 1991; Gikunju et al. 1992; Ahmed and Murali, 1992; Sarma and Rao, 1997); high arsenic levels, as in Bangladesh (Masibay, 2000; Anonymous1996); or high salt content, as in Pakistan and Sri Lanka (Ahmad et al. 2000; Meinzen-Dick, 1997; Jensen et al. 1998; Bakker et al. 1999; van der Hoek et al. 1999). Multiple use of irrigation water is possible but can it be done safely? This research project will investigate further the health implications of using irrigation water as a domestic water supply.

2.9 Microbiology of waterborne diseases

Poor quality water can cause diseases by acting as the vehicle of transmission. Infectious agents from humans or animals are passed by excretion of faeces into water and then ingested by a new host (faecal oral contact). Ingestion of infectious agents may occur by drinking water, washing food with contaminated water or by washing with contaminated water. Such pathogens are classified as either bacteria, viruses, protozoa, or helminths. Considering human health, the most important pathogens found in water are listed in Table 2.1.

Table 2.1 Major waterborne pathogens affecting human health (WHO, 1996).

Bacteria	Viruses	Protozoa & Helminths
Salmonella spp.	Adenoviruses	*Giardia* spp.
Shigella spp.	Enteroviruses	*Cryptosporidium* spp.
Campylobacter coli	Hepatitis A	*Entamoeba histolytica*
Vibrio cholerae	Hepatitis E	*Dracunculus medinensis*
Yersinia enterocolitica	Norwalk virus	
Campylobacter jejuni	Rotavirus	
Pathogenic *Escherichia coli*	Small round viruses (other than Norwalk virus)	

It is important to mention the helminth, *Schistosoma* spp., which is a water washed pathogen transmitted by direct contact with the aquatic larvae (cercariae) that penetrate the skin. Schistosomiasis is largely associated with irrigation systems and has received much attention as a negative health impact of irrigation development (UNESCO, 1978; WHO, 1992).

Numerous environmental factors affect the survival of pathogens. Some pathogens may be more robust and resistant to adverse environmental conditions than others. For example, pathogens are highly sensitive to extreme temperatures, although some may thrive at very high or very low temperatures. Chlorine is deadly to many pathogens, however *Giardia* spp. and *Cryptosporidium* spp. are highly resistant to chlorine due to their formation of cysts or oocysts. Most infectious agents are photosensitive and can be destroyed by UV irradiation

(WHO, 1996). Some infectious agents have an increased ability to persist in water, particularly those that form spores, eggs, cysts, or oocysts (WHO, 1996).

The virulence of an infectious agent varies from one infectious agent to another. Very virulent pathogens may cause disease from the ingestion of only one organism. Mildly virulent pathogens require the ingestion of high doses of organisms to cause disease (WHO, 1996).

2.10 Water quality assessment and monitoring

To determine the safety of a particular water source, water quality tests and standards are used.

Disease is caused only when a certain dose of pathogens is ingested. The required dose to cause infection will depend on the state of the immune system of the individual and the virulence of that pathogen. Since only one pathogen can cause infection and disease, the acceptable water quality standard is zero (absence of pathogens) (WHO, 1996). Infectious agents may be difficult to measure as they are discrete and may be clumped or adhered to suspended solids (WHO, 1996). Many of the pathogens are detectable in water samples. However, it is impractical to test for every possible pathogen, as this group is very broad and diverse. Therefore, the accepted standard tests are those that indicate faecal contamination since most pathogens causing disease are transmitted in faeces (WHO, 1996).

To determine if there has been faecal contamination an indicator organism is used. The chosen indicator organism must be found in high numbers in the faeces of warm-blooded animals and not found in waters free of contamination. The indicator organism must be easily detectable. Also, the indicator organism must have the same level of persistence in water and resistance to treatment methods as the more robust waterborne pathogens. The classic indicator organism of water contamination is the thermotolerant coliform group. The test for thermotolerant coliforms is the basis for the WHO water quality standards. These bacteria are gram-negative non-spore forming rods which are capable of fermenting lactose at 44-45 °C. The dominant species of this group is *Escherichia coli*, which is indicative of faecal contamination (Csuros and Cusuros, 1999). Thermotolerant coliforms also include species of *Klebsiella*, *Enterobacter*, and *Citrobacter* (WHO, 1996). These species may be of origin other than faeces, such as industrial effluents. decaying plant materials or soil. However, they are found less frequently than *E. coli* (WHO, 1996). Direct testing for only *E. coli* would be the best option, however, rapid and reliable methods to do so are not available yet, and are not as well standardized as the tests for the entire thermotolerant coliform group (WHO, 1996). Other possible tests may detect total coliforms, faecal streptococci, sulfite-reducing clostridia and coliphages. Total coliforms (of which the faecal coliforms are a part) can be an indication of faecal contamination but may also originate from nutrient rich water, soil, or decaying plant material. Therefore, a positive result is not necessarily indicative of faeces-derived waterborne organisms. Faecal streptococci are of human or animal origin. However, they are mainly indicative of human faecal contamination. This test is therefore useful to determine the extent of human faecal pollution versus that of other animals. It is important to differentiate between human and animal contamination as animal faeces contain infectious agents, of which only some are human pathogens. Some diseases may be transmitted between humans and animals, and they are called zoonosis. Sulfite-reducing clostridia are extremely persistent in water (long lived) and are resistant to disinfection. Thus, they are useful for detection of old or distant contamination but are not suitable for regular monitoring. Bacteriophages are not numerous in human or animal faeces, however, they are abundant once in sewage. They are persistent and easy to detect. This makes them appropriate to use as a further test criterion (WHO, 1996).

2.11 Testing for thermotolerant coliforms

Assays for the thermotolerant coliforms include Membrane Filtration, Delayed Incubation Membrane Filtration, Most Probable Number (MPN), and MUG (4-methylum-belliferyl- -D-glucuronide) (Csuros and Cusuros, 1999). The WHO drinking water quality standards are based on thermotolerant coliform counts from either membrane filtration tests or MPN tests (WHO, 1996). Both tests are standardized by the International Standards Organization (# 9308-11990 and # 9308-21990). Standard procedures are also outlined by the American Public Health Association (APHA-AWWA-WPCF, 1998) and the United Kingdom Department of Health and Social Security. Further Details for the execution of these tests may be found in popular texts such as Microbiological Examination of Water and Wastewater (Csuros and Cusuros, 1999).

2.12 Water quality standards for thermotolerant coliforms

The WHO is the main source of water quality standards although most countries have also established their own standards that are generally based on the WHO guidelines. For drinking water, the WHO states there should be zero thermotolerant coliform units (ThCU) in a 100ml sample. For water destined to be used as a raw water source for a conventional treatment plan, (pretreatment, coagulation/settling, rapid filtration, terminal chlorination) an average loading of 1,000 ThCU/100ml (with an allowable maximum of 10,000 ThCU/100ml) is recommended by the WHO. For simple treatments, the water supply should have average loads between 3-1,000 ThCU/100ml depending on the treatment (see Table 2.2). Simple treatments include boiling, disinfection (chlorination), slow sand filters (with or without gravel pre-filters) or plain sedimentation (WHO, 1996).

Table 2.2 Limits for Thermotolerant Coliform Units (ThCU/100ml) in raw water sources to be treated by various simple methods (WHO, 1996)

	Disinfection	Slow sand filter	Gravel pre-filters (3-stage)	Plain sedimentation
Average loading	<3	50	500	1,000
Maximum loading	25	500	5,000	10,000

Sri Lankan standards somewhat resemble the WHO standards and recommend levels of zero ThCU/100ml for drinking water, 2,000 ThCU/100ml for raw water used in a conventional treatment plant and 20 ThCU/100ml for raw water used with simple treatment (such as boiling) (Democratic Republic of Sri Lanka, 1983; Democratic Republic of Sri Lanka, 1985). The Sri Lankan standards recommend the use of the MPN test. For bathing waters the Sri Lankan standard is 1,000 ThCU/100ml (Democratic Republic of Sri Lanka, 1985). The WHO has outlined guidelines for bathing waters with a standard for marine waters at 1,000 Faecal Streptococci/100ml as the threshold for immediate investigation. Guidelines for fresh waters have not been formulated at this point. For fresh waters, the WHO recommends that Thermotolerant Coliform Units (ThCU) are a more appropriate measure than Faecal Streptococci counts, and the upper limit should be lower than 1,000 organisms/100ml (WHO, 1998). For standards relating to the use of wastewater for agriculture, the WHO refers to the book Guidelines for the Safe Use of Wastewater and Excreta in Agriculture and Aquaculture (Mara and Cairncross, 1989). For irrigation water, the contamination should not exceed 1,000 ThCU/100ml. To put these standards into perspective we have looked at some typical ThCU/100ml values from tropical countries. Studies compiled by Cairncross and Feachem (1983) have found that for surface waters, values ranged from 0 to 3,100,000 ThCU/100ml. For open wells, values ranged from 8 to 100,000 ThCU/100ml. For boreholes, values ranged from 0 to 60 ThCU/100ml (Cairncross and Feachem, 1983).

2.13 Chemical water quality and health

Water may contain many chemicals causing detriments to human health. These substances may occur naturally or may exist as a result of human activities. The full range of water quality parameters will not be discussed here, however, a few parameters will be highlighted. The pH is a basic measurement used for quantification of water quality. Water with extreme pH will cause skin or eye irritation and can permanently damage these tissues (WHO, 1996). Both the sodium concentration and the amount of total dissolved solids (TDS) are parameters that represent the level of salts in the water. High salt concentrations are linked to hypertension and high blood pressure, and aggravate chronic congestive heart failure although the actual causal action has not been proven (WHO, 1996). High salt levels in drinking water may lead to dehydration. Young children, especially infants, are particularly at risk (WHO, 1996). Parameters of particular importance in terms of natural contamination of ground waters are iron, fluoride and arsenic. Iron overloads may cause haemorrhagic necrosis and sloughing of areas of mucosa in the stomach with extension into the submucosa, sometimes leading to death. However, iron is a necessary element for human health (WHO, 1996). Fluoride, in high concentrations, causes a malformation of tooth enamel and in severe cases may affect the formation of bones, leading to superfluous calcium deposits and in extreme cases, spinal cord fusion (skeletal fluorosis). Children whose teeth and bones are still forming are more susceptible to damage by high fluoride levels (Gikunju et al. 1992; Sarma and Rao, 1997; WHO, 1996). Arsenic is present in the ground waters of Bangladesh, it causes serious skin lesions and may lead to cancer (Masibay, 2000; WHO, 1996). The hazardous health effects of chemical contaminants are generally slow to manifest. However, they can be as severe as the consequences of microbiological contamination.

2.14 Water quality standards for chemical properties

The WHO guidelines for drinking water recommend a pH of 6.5-9.5 (WHO, 1996). In Sri Lanka standards are a pH of 6.5-8.5 for drinking water, a pH of 6.0-8.5 for bathing and water destined for simple treatment and a pH of 5.0-8.5 for water destined for conventional treatment (Democratic Republic of Sri Lanka, 1985). The WHO salinity guidelines prescribe 200mg/l of sodium or a total dissolved solids (TDS) of 1000mg/l (WHO, 1996). In Sri Lanka, standards are expressed as electrical conductivity (salts increase the conductivity of a solution), and desired levels of electrical conductivity are 0.750 mS/cm, with an acceptable limit of 1.3 mS/cm (note: 1 mS/cm = 1,000 µmhos/cm) (Democratic Republic of Sri Lanka, 1985). The WHO recommends 2 mg/l of iron in drinking water.

Complaints of poor taste usually start at iron levels of 0.3mg/l (WHO, 1996). Generally, water becomes unpalatable due to iron and salts before concentrations reach levels detrimental to health. Therefore, high levels of iron and salts are generally not considered an important public health risk. However, contaminants such as fluoride and arsenic are more dangerous as they are tasteless and odourless. The WHO guideline is 1.5 mg/l for fluoride and 0.01 mg/l for arsenic. Acceptable limits of fluoride should be lowered, especially in hot regions, where greater volumes of water are consumed (WHO, 1996).

2.15 Irrigation management and its implications for water quality

Opponents of irrigation development contest that bringing in large amounts of contaminated water causes health problems within the irrigated areas (El Gaddal, 1985). However, as mentioned previously, water quantity, not water quality, is more crucial in the incidence of diarrhoeal disease. Due to dirty hands and food, direct pathways are created for faeces to mouth contact. The transmission of diseases via this direct pathway may be reduced by the provision of a greater quantity of water, of unimproved quality, which is easily accessible to the household (Kolsky, 1993). Enough water, regardless of it's quality, is therefore more important in the reduction of diarrhoeal disease as the provision of ample water leads to better hygiene (Esrey et al. 1991). In many areas, the irrigation system serves as the only water source, providing quantities of water necessary for survival (Pulido-Bosch and Sbih, 1995; UNESCO, 1978; van der Hoek et al. 1999; Meinzen-Dick, 1997; Steele et al. 1997; Bakker et al. 1999; Jensen et al. 1998; Konradsen et al. 1997). IWMI's research project in the Punjab (Pakistan) identified all possible domestic water sources as being derived from the irrigation system. The various water sources were, direct canal water, irrigation seepage water extracted from wells, municipal water supply schemes fed by canals and village storage tanks (diggi), which are also filled by the canal (Jensen et al. 1998; van der Hoek et al. 1999). IWMI has identified a similar situation in Sri Lanka where the major water sources also originate from the irrigation system. The water sources were, direct canal water, irrigation seepage water extracted from wells and municipal water supply schemes filled by tanks (irrigation reservoirs). The region, however, does not completely rely on the irrigation system for domestic water. There are some deep groundwater sources that are extracted by hand pumps or serve as the source for municipal water supply schemes (Meinzen-Dick and Bakker, 1999; Meinzen-Dick, 1997; Bakker et al. 1999). The rainfall in the dry zone of Sri Lanka is significantly higher than that in Pakistan and could be sufficient to provide another water source through rainwater harvesting programs (Lanka Rain Water Harvesting Forum Secretariat, 1996; Lanka Rain Water Harvesting Forum, 1999; Ariyabandu et al. 2000). Since communities are almost completely dependent on the irrigation system for water, they face extreme water shortage when the canals are closed (Jensen et al. 1998; van der Hoek et al. 1999; Meinzen-Dick, 1997; Meinzen-Dick and Bakker, 1999). Methods to improve irrigation efficiency, such as canal lining, further reduce the amount of water available for households by eliminating the seepage water, and with it, the shallow freshwater aquifer (Jensen et al. 1998; Meinzen-Dick and Bakker, 1999; Meinzen-Dick, 1997; Bakker et al. 1999; Pulido-Bosch and Sbih, 1995). Studies by the IWMI in Pakistan have shown that from all available water sources, irrigation seepage water has the best bacteriological quality. This places further importance on the availability of seepage water and presents an argument against lining of the canals, which may reduce or eliminate this water source (Ensink et al. 2001; van der Hoek et al. 2001). The dependence of communities on the irrigation system for domestic water supply raises issues of how this resource can be managed to benefit both agricultural production and domestic supply.

3. MATERIALS AND METHODS

3.1 Sri Lanka

Sri Lanka is an island located off the south east coast of India (Figure 3.1). It has an area of 65,609 km^2 with a population of 19.04 million (Central Bank of Sri Lanka, 1999). Its major exports include textiles and garments, tea and other industrial products (Central Bank of Sri Lanka, 1999).

The country is characterized by mountains in the south central region, with a wet zone extending south west and dry zone plains to the north and south east (Figure 3.1). This topology causes its dual monsoon climate with the first bringing rain to the south western corner during May-August and the other bringing rain to the north and south east during October-February. These monsoons establish two growing seasons: the Yala (May-Aug.) and the Maha (Oct.-Feb.) (Japan International Cooperation Agency, 1993).

Rice paddy cultivation, irrigated by large surface irrigation schemes, has been prevalent in Sri Lanka since ancient times. Today, systems of tanks (irrigation reservoirs) both modern and ancient, irrigate agricultural lands. In 1990, 47.8% of the employed population in Sri Lanka worked in the agricultural sector, with the major products being tea, rubber, coconut and paddy (Central Bank of Sri Lanka, 1999). The agricultural sector contributed 16.9% of the GNP in 1999. In the same year, paddy production was 2.89 million MT over an area of 781 thousand hectares (483 ha in Maha, and 298 ha in Yala) contributing 3.5% of the GDP (Central Bank of Sri Lanka, 1999).

3.2 Uda Walawe irrigation system

The Uda Walawe basin is located in the southern region of Sri Lanka. The area straddles the wet zone/ dry zone boundary. It is dominated by the surface irrigation scheme fed by water from the Uda Walawe reservoir (Figure 3.2). The reservoir was constructed and the irrigation system was developed between 1967 and 1977. The basin is 2,442 km^2 in area and serves to irrigate an area of 16,444

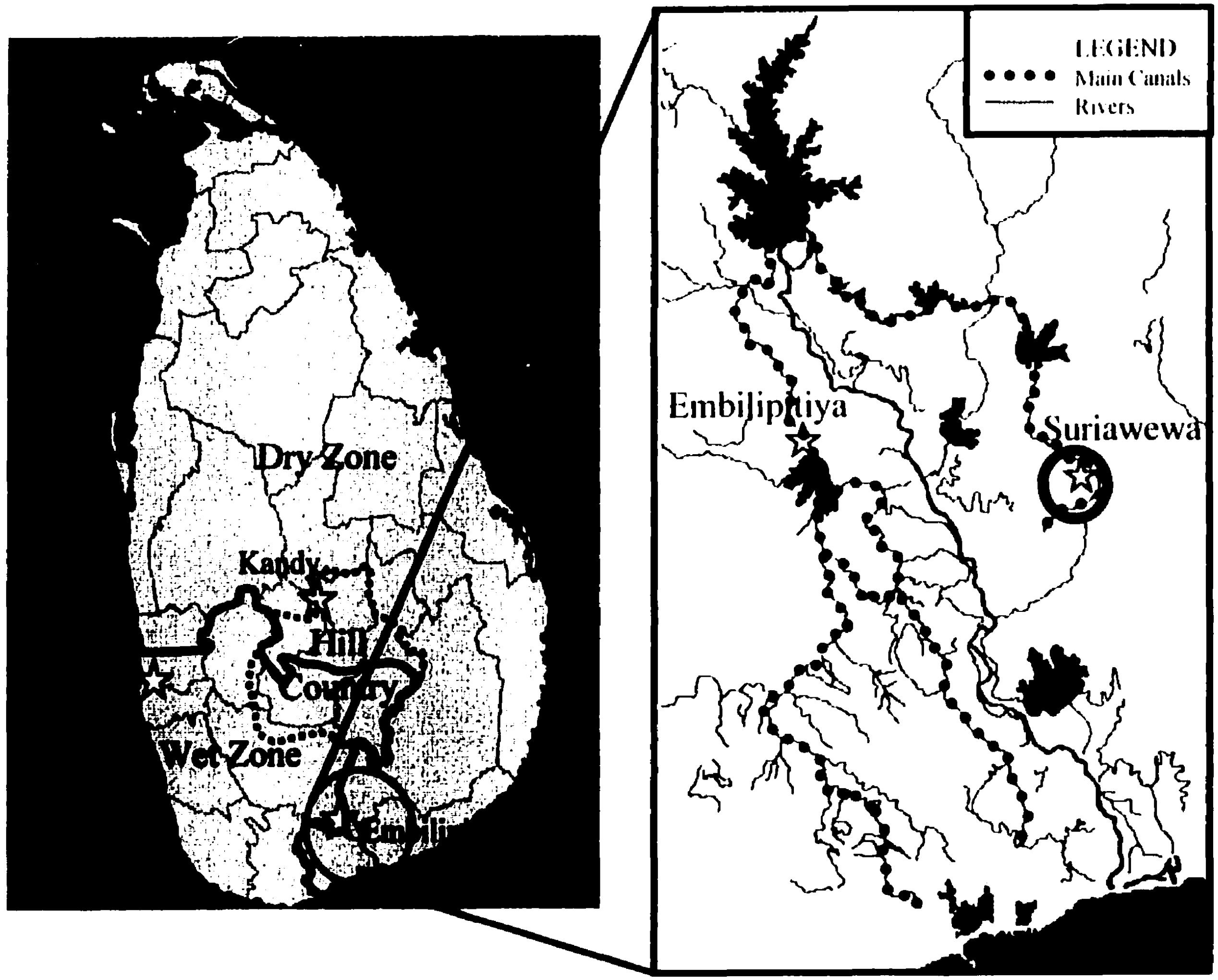


Figure 3.1 Sri Lanka, and Uda Walawe Irrigation System

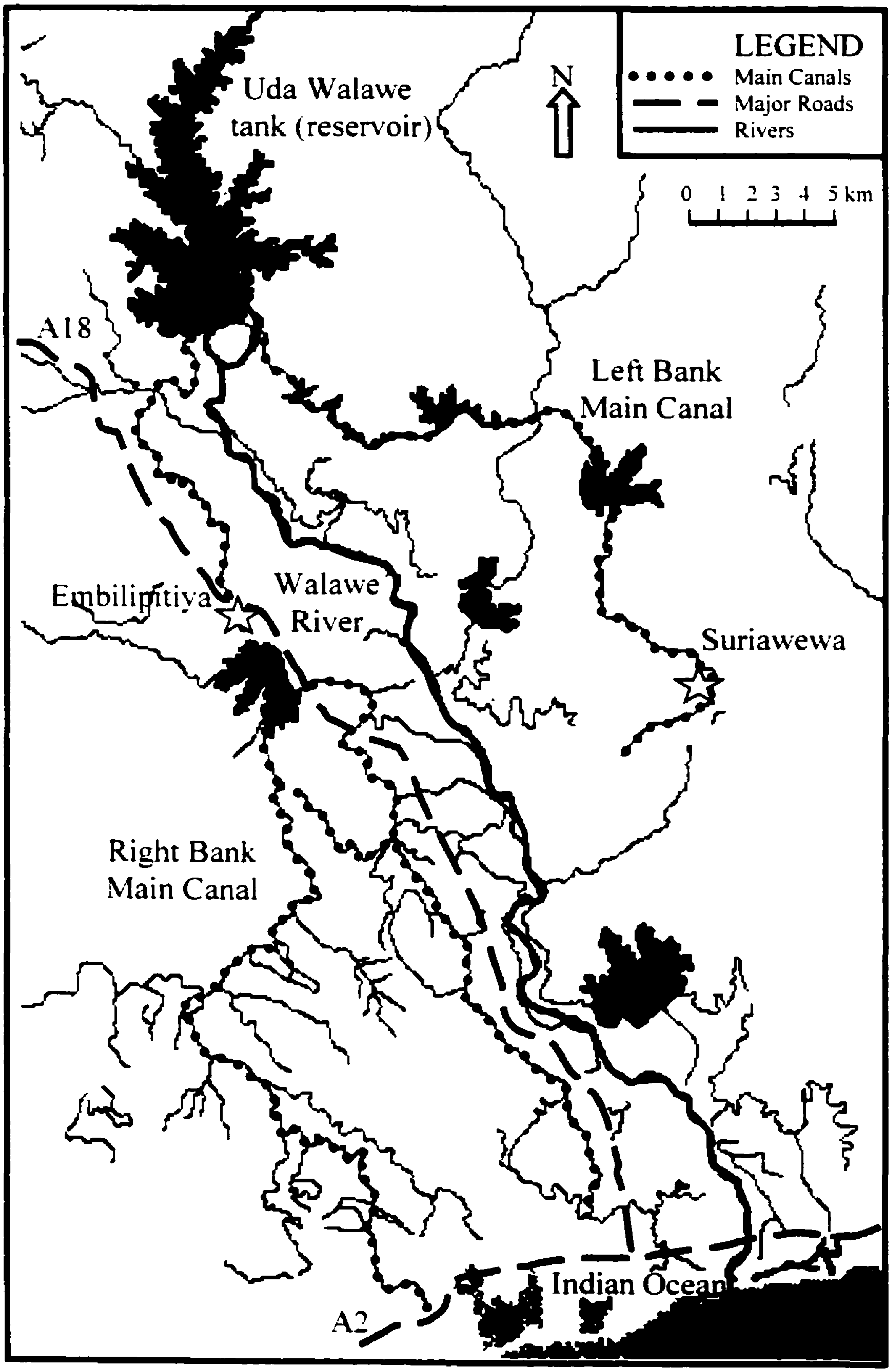


Figure 3.2 UdaWalawe Irrigation System

ha. The reservoir itself has a capacity of 268 million m^3 and feeds two main canals, the right bank, which irrigates 11,444 ha and the left bank, which irrigates 5,000 ha. Both canals are single banked (irrigate only to one side) and drain into the Walawe River. Although the canals are seen as serving a single purpose (agriculture), certain points have been constructed with steps allowing access to the water for washing and bathing purposes. The system consists of numerous linked tanks (irrigation reservoirs), the largest of which are the Chandrikawewa (immediately south of Embilipitiya), Ridiyagama, Mahagama, Kiri Ibban wewa, Habarall and Suriawewa (Gal wewa). These intermediate reservoirs are used as volume control devices (Godaliyadda and Renault, 1999). The primary crops grown in this region are rice and bananas. Other fruits and vegetables are often cultivated in home gardens (Japan International Cooperation Agency, 1993). The village of Embilipitiya is the major urban/ economic centre of the region, and is located along highway A18 between the Uda Walawe reservoir and the ocean. Embilipitiya is approximately 25 km north of the coast.

The Mahaweli Authority manages the Uda Walawe irrigation system through a central office in Embilipitiya and 7 block offices located throughout the region. Distributor canals are double banked and the local block office of the Mahaweli authority controls the water supply. There is low concern about sedimentation and salinity, and no conjunctive use (use of well water and surface water) (Godaliyadda and Renault, 1999).

3.2.1 Climate

The Uda Walawe area is generally considered a dry zone region, receiving rain during the Maha (Oct.-Feb.) monsoon season.

There are 23 rainfall-monitoring stations in the Uda Walawe area. Rainfall varies throughout the area diminishing towards the south and the east. Average annual rainfall for the upper basin is 4,500 mm. At the Uda Walawe dam, rainfall amounts to 1,500 mm, and in the coastal area 1,000 mm. The mean annual rainfall of the entire Uda Walawe river basin is 2,047mm (Japan International Cooperation Agency, 1993).

There are 5 meteorological observatories in the Uda Walawe area, the Sugar Research Institute (SRI), Hambantota, Agricultural Research Station (ARS), Rice Research Station (RRS) and MEA. The SRI and Hambantota observatories may be used as representatives of the northern and southern regions of the basin, respectively (Tables 3.1 and 3.2) (Japan International Cooperation Agency, 1993).

Table 3.1 Climatic data, Sugar Research Institute (SRI) observatory

Parameter	Annual Mean	Mean Maximum	Mean Minimum
Temperature (°C)	28.2	32.6	23.6
Relative Humidity (%)	75.6	82.8	69.2
Evaporation (mm)	1,871.9/yr	195.8/month	116.4/month
Sunshine Duration (hrs)	2,447.4/yr	231.6/month	175.6/month
Wind Velocity (km/hr)	4.9	8.6	2.4
Rainfall (mm)	1,411.3/yr	276.3/month	28.7/month

Table 3.2 Climatic data, Hambantota observatory

Parameter	Annual Mean	Mean Maximum	Mean Minimum
Temperature (°C)	27.2	30.2	24.1
Relative Humidity (%)	78.9	81.3	76.5
Sunshine Duration (hrs)	2,482/yr	254.2/month	174.0/month
Wind Velocity (km/hr)	4.9	8.6	2.4
Rainfall (mm)	1,075.5/yr	187.5/month	42.2/month

3.2.2 Geology and soils

The Walawe basin is divided based on two geological hard rock formations, the Highland and Vijayan rock groups. The division between the two regions is approximately defined by the Walawe River, the Highland rock groups being in the west, and the Vijayan rock groups in the east. The Vijayan rock group consists of migmatic gneisses, granitic gneisses and charnokitic gneisses, whereas the Highland rock group consists of charnockites, marble/calogneisses, quartz and feldspar (Silva, 1984). A fault line runs along the Walawe River. This fault contains serpentine, iron and sulfite deposits, with fluoride concentrations from 100-200 ppm and consequently, groundwater from these regions contains high fluoride levels posing possible health risks (Steele et al. 1997). The terrain of the northern region is undulating with slopes ranging from 0-4 %. The southern region is rolling with slopes ranging from 0-3%. The drainage in the northern region is excellent due to the deeply incised water courses. This is not true for the southern region, so drainage may be more difficult (Jayaweera et al. 1960). The northern region of the basin is covered by a thick soil layer, whereas the southern region has a thinner soil cover with rock outcrops (Silva, 1984). There are five major soil types in the Uda Walawe area, the Walawe, Walawe Rolling, Malabotu, Rana, and Siyambala series. These soils are mainly reddish brown earths and some alluvial soils and pockets of erosional remnants (high proportion of quartz or iron) (Soil Map, 1967). Further details of the Walawe Rolling series, and Malabotu series will be discussed in the Suriawewa section.

3.2.3 Ground water resources

Ground water in the region is scarce and often saline. The resources are limited and localized due to the hard fractured rock. In the Uda Walawe region there are three main ground water quality concerns: salinity in the southeast, fluoride in the northeast and iron in the southwest. However, these problems are not restricted to those particular areas and may be found over the entire region (Amarasekara, 1992). More than 60% of the region has poor quality deep ground water. Salinity can reach levels of 3.00 mS/cm and fluoride up to 19 ppm. Near rivers, streams and tanks, ground water tends to be of better quality with reduced incidence of salinity in areas of higher elevation (Silva, 1984).

3.2.4 Water supply schemes

There are 5 municipal water supply schemes in the Uda Walawe area. All five schemes use water from the irrigation system as their raw water source (Table 3.3).

Table 3.3 Municipal water supply schemes in the Uda Walawe region

Water Source	Villages Served
Uda Walawe tank	Uda Walawe
Chandrikawewa/right bank main canal	Embilipitiya
Suriawewa tank (Gal wewa)	Suriawewa
Walawe River	Ambalantota, (Hambantota)
Kattakadua tank	Ranna, Hungama

The Embilipitiya water supply system produces 2,730 m^3 water/day and serves 4,684 connections, of which 67 are public stand posts. The Suriawewa water supply system produces 850 m^3 water/day and serves 1,244 connections, of which 2 are public stand posts. Private connections are expensive (pipeline installation fee and fee/volume consumed) and the water supply distribution systems are restricted to the area around the towns. The Suriawewa system does provide browser service (water trucks) to the outlying areas however, this browser service is irregular. Water supply to private connections or stand posts is often insufficient, and water may be available for only a few hours per day. The water quality from the distribution system is monitored and results respect the Sri Lankan norms for drinking water. The chemical water quality is measured monthly and the bacteriological water quality is measured twice monthly. Chlorine, turbidity, pH and salinity are measured at two-hour intervals. The chlorination gives water a bad taste and therefore many people choose not to drink water from the water supply systems.

The Asian Development Bank (1984) determined that there was a lack of domestic water supply facilities in the region. The Suriawewa facility has been added since that time, however, this scheme services few people and many regions are still without adequate water supply. The result is that many people use water from irrigation canals for domestic purposes. Therefore, between the two cropping seasons when the canals are officially closed, large amounts of water must be diverted to the canals to sustain these people and the municipal water supply systems. This impedes the ability to do routine repair and maintenance of the canal infrastructure. Domestic purposes are considered priority water uses and are therefore allocated 0.89 MCM/week of irrigation water (46.2 MCM/year). This allocation is also used for industry as they are supplied by the municipal water supply systems (SAPI Team for Japanese Bank For International Cooperation (JBIC), 2000).

3.2.5 Water pollution

Water quality degradation in the region may be due to both industrial and agricultural wastes. The main industry in the region is a sugar mill in the north east (Left Bank). This mill does not produce effluent; by-products are used as fertilizer or as fuel (bagasse) to power the mill. The region did have a distillery and a paper factory although both are now closed. These two industries were releasing effluent into the Walawe River. The effluent of the paper mill consisted of wash water and cooking water that contained high organic mater, COD, BOD, sodium hydroxide (2.2g/l), caustic soda and lignin. Agricultural pollution consists of inorganic basal mixtures, urea, herbicides (MCPA, 3-4 DPA, Macheet, Saturn, Grammoxone, Diuron), pesticides, organophosphates and carbamate (organic manure is rarely applied) (Amarasekara, 1992).

3.3 Suriawewa (Sooriawewa)

The project area was situated along the left bank canal near the town of Suriawewa. The public institutes in the town of Suriawewa are: a hospital, police station, DSD secretariat, National School and the Suriawewa Block Office (irrigation administration). An agricultural training centre was opened at the end of August 2000, however, programs had still not begun by December 2000. In

Suriawewa the major industries are a garment factory and the Hanjun concrete canal sections factory.

Two distributor canals were selected for this water quality study, the MD17 earthen canal with its offtake located above the Suriawewa town and the BBD5 concrete lined canal with its offtake located below the Suriawewa town (Figure 3.3).

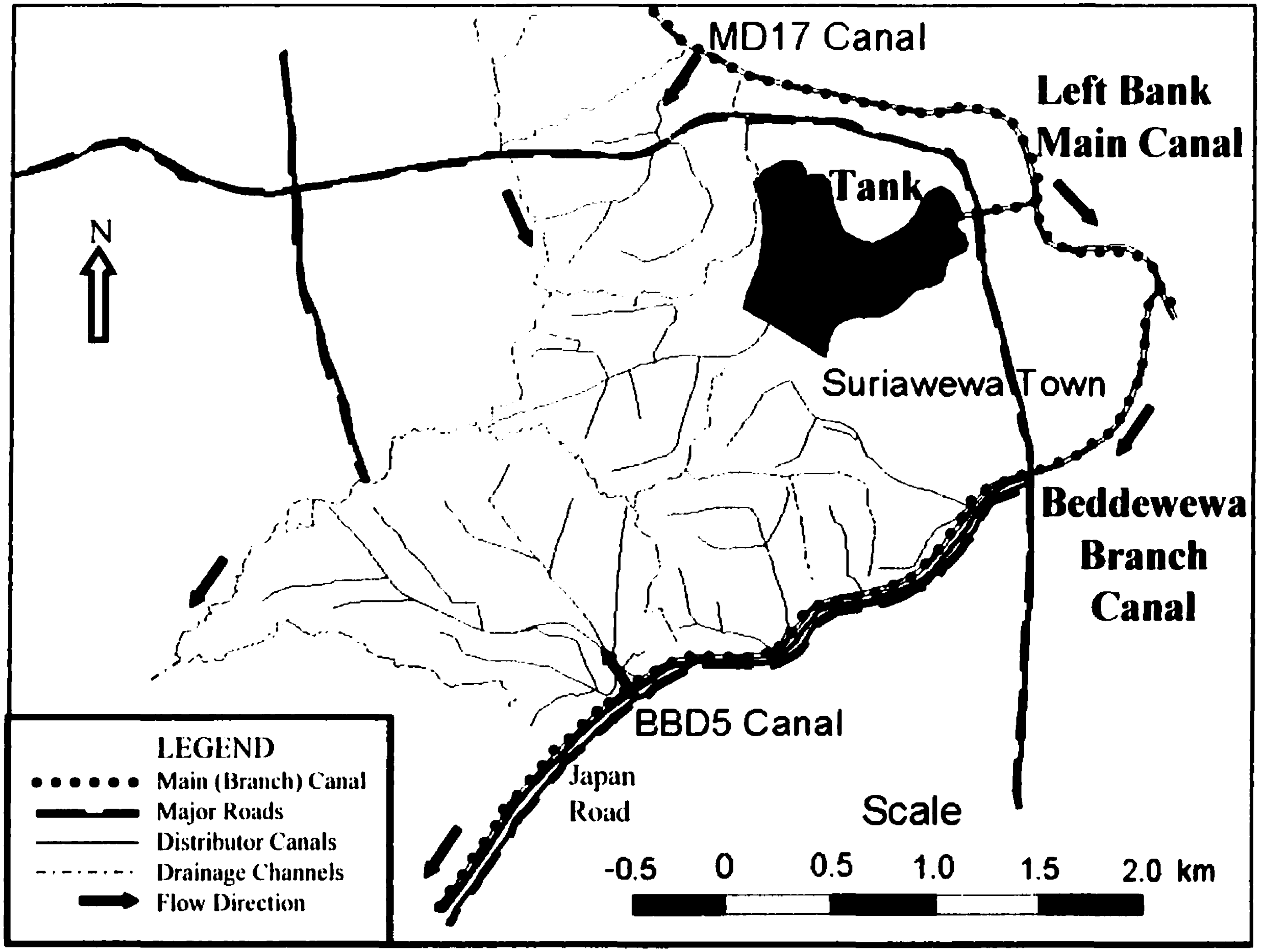
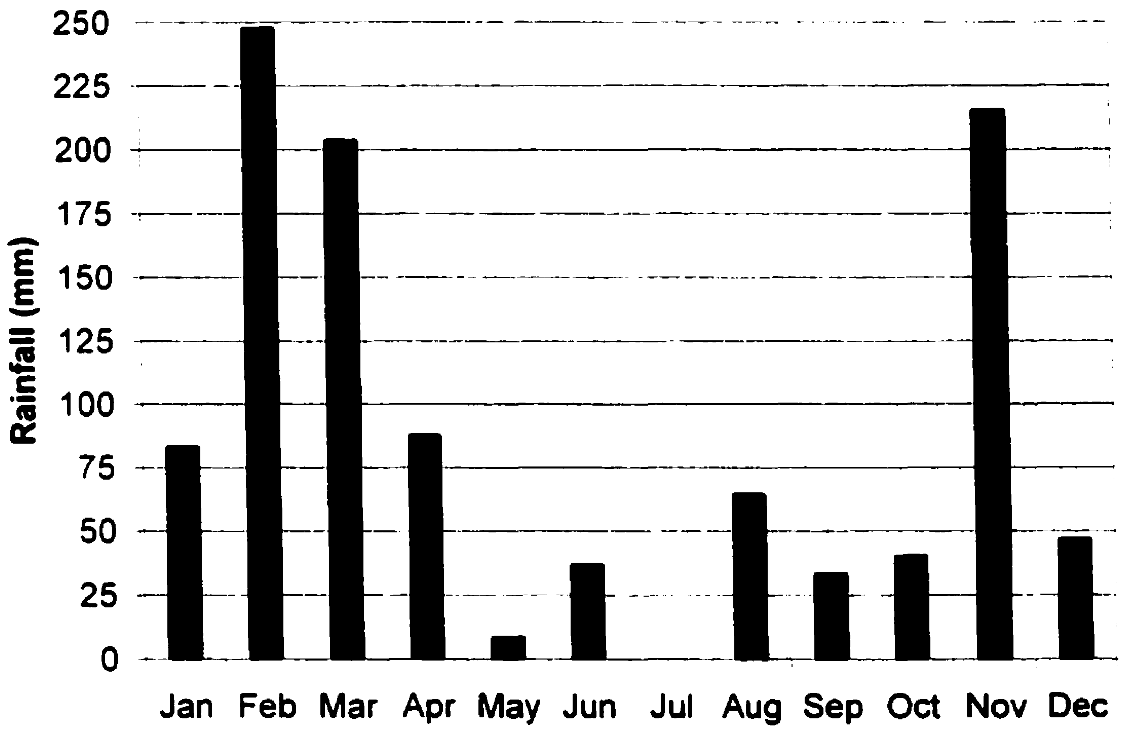


Figure 3.3 Study area: MD17 canal, BBD5 canal and Suriawewa town

3.3.1 Rainfall, geology and soils of the study area

The Suriawewa region receives the majority of its rainfall during the Maha season, which occurs between October and March. A total of 1070 mm of rain fell in the year 2000. The Mahaweli Authority recorded rainfall at the Block Office in Suriawewa. Rainfall by month for the year 2000 is shown in Fig. 3.4.

Figure 3.4 Rainfall in Suriawewa region during 2000



The geologic formations underlying the two selected canals are dominantly biotite and Hornblende gneisses.

The two soil types that are found along the two canals are the Walawe association rolling phase and the Malabotu association. The Walawe association rolling phase is a well-drained, deep, reddish brown, moderately fine soil. It has a good moisture supplying capacity with a pavement of stone and gravel at an average depth of 71cm, and has a moderately high fertility (Table 3.4). The erosion hazard for this soil is somewhat high and it is generally found on slopes of 4-6%. The Malabotu association is a slow drained soil with obvious iron and manganese concretions. It has a large capacity to supply moisture and high fertility (Table 3.4). There is no erosion hazard and it is generally found on flat lands with slopes of 0-1%. Without adequate drainage, this soil may experience problems of alkalinity or salinity. The Walawe association Rolling phase is best suited for rain fed crops such as maize, sorghum, groundnut, pigeon pea, vegetables, etc. Rice and surface irrigation are not recommended, as it destroys the soil structure. The Malabotu association is excellent for rice cultivation as long as adequate drainage is supplied (Jayaweera et al. 1960).

Table 3.4 Major soil cations (ppm) in the study area.

Site	P	K	Mg	Ca	Na	Fe
MD17 Head	25	32	720	2380	538	10
MD17 Tail	25	88	538	1756	88	19
BBD5 Head	384	32	308	928	25	20
BBD5 Tail	4	50	352	2144	112	78

3.3.2 Waterborne disease

Data relating to the incidence of waterborne disease in Suriawewa were collected from the Medical Officer of Health (MOH) and the hospital. Records used were the MOH notifiable disease records and the hospital inpatient records. These were checked for cases of dysentery, bloody dysentery, typhoid, and food poisoning. Records were similar between the two agencies demonstrating good administrative connections. The Suriawewa hospital provides service to approximately 35 000 families. Dr. Gamini Ranasinghe (the hospital's doctor) commented that diarrhoeal disease had decreased in Suriawewa area due to education and chlorination programs. During the period from January 2000 to November 2000 there were 229 cases of waterborne disease (see categories above) requiring overnight hospitalization. 96.9 % of cases were dysentery or bloody dysentery, with 1 case (0.4%) of typhoid. There was no difference in number of cases between genders (female 49.8%, male 48.9%). The majority of the cases were in young children (65.5% of cases were from children aged 0-5 years). The incidence of disease was low during most of the year, with a peak occurring in August (78.2 % of cases). To control this outbreak the MOH visited various communities to educate people about boiling water and to chlorinate shallow wells. The hospital records give an underestimation of the burden of disease as many people will treat mild cases of diarrhoea in the home. Although the hospital is free and all drugs administered in the hospital are free it may be preferable to treat patients at home to avoid the costs of travelling to the hospital and waiting in the long lineups.

3.3.3 Municipal water supply system

There is a municipal water supply system in Suriawewa. The system produces 850 m^3 water/day and supplies water to 1,134 domestic connections, 60 public service and government buildings, 46 commercial connections, 2 industrial connections, 2 stand posts and also browser water truck supply. Supply is intermittent and households complain about getting water only during the night, and that chlorine makes water unpalatable. The raw water for the system comes from the Suriawewa tank (irrigation reservoir).

3.3.4 Suriawewa tank (irrigation reservoir)

The Suriawewa tank or irrigation reservoir is located beside Suriawewa town. It is fed by the Left Bank main canal and serves as the source for the municipal water supply system and one distributor (MD18). The tank is shaped approximately like a horseshoe and is 1 km wide by 1 km long at the widest and longest points. The tank is earthen with an earthen berm at the southern end to retain the water (Figure 3.5).

3.3.5 Wells

Tube wells, sometimes called boreholes, are deep wells (generally >20m) drilled by mechanical equipment and fitted with well casing and a hand pump (Figure 3.6). During the 1980s the Sri Lanka federal government commissioned the construction of tube wells across the country in order to provide domestic water

Figure 3.5 Tank irrigation reservoir

Figure 3.6 Tube well

for the population. Both the Water Supply and Drainage Board and the Water Resources Board were responsible for the construction of tube wells.Residents of the greater Suriawewa region spoke poorly of the water quality from tube wells. Specific complaints were high levels of iron, salt and fluoride (causing mottling of children's teeth). Dependence on tube well water decreases near the irrigated areas, as water from the canals or shallow wells (seepage from canals and paddy) is abundantly available. Physical characteristics are listed in Table 3.5 for two of the three tube wells sampled in this study.

Table 3.5 Physical characteristics of tube well 1 and tube well 2

	Tube Well 1	Tube Well 2
Total Depth	24 m	36 m
Casing Length	14.9 m	12 m
Depth of Fresh Water	15.1 m	20.3
Depth of Hard Rock	13.7 m	10.2

Shallow wells dug by hand are abundant within the irrigated areas. There are 81 shallow wells within the MD17 distribution area and 79 shallow wells within the BBD5 distribution area. The wells are on average 2.7 m deep with a water level of 1.0 m from the edge of the well structure. A typical well is unlined, with a ring of stones and logs defining the edge of the well as illustrated in Figure 3.7. In this area, 23 of the wells (15 %) are protected by a concrete lining and wall extending above the ground. The protective concrete lining is made of bricks and mortar clad with concrete as illustrated in Figure 3.8. Most wells (70%) are located in settlement land and the others are found in the paddy fields or banana groves. Almost every household in the MD17 or BBD5 canal area has its own well. Wells that are easily accessible, or perceived as having higher quality water will also be visited by other families. Some wells receive as many as 200 families per day to withdraw drinking water. The MD17 area has families coming for

Figure 3.7 Shallow well, no protective wall

Figure 3.8 Shallow well, with protective wall

drinking water from the non-irrigated areas to the east of the main canal and the non-irrigated areas located west along the road. Some families travel as far as 4 km to take water from shallow wells in MD17. The BBD5 area has families coming to the tail end of the system from non-irrigated areas to the north (Hathporua).

3.3.6 Canal infrastructure and operation

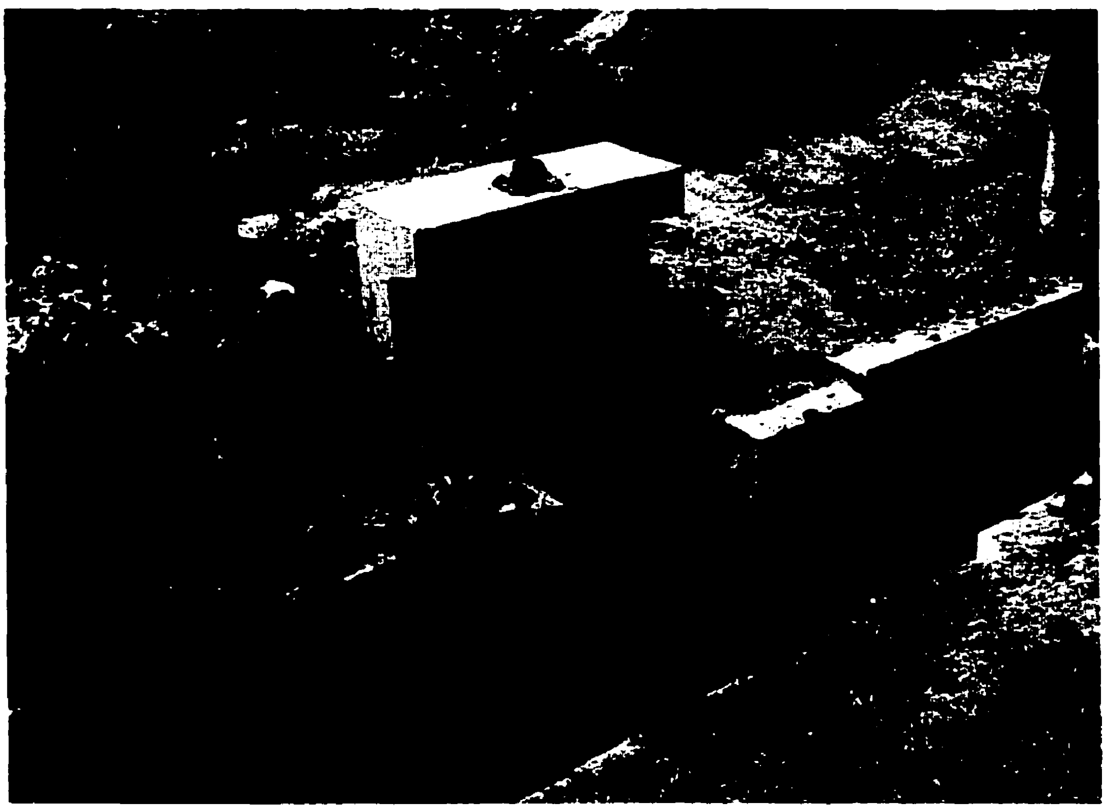
The MD17 canal is earthen and approximately 1.5 km long, irrigating an area of 1.5 km^2. It has 4 field canals and crosses the Suriawewa-Mahagama road near the 11-mile post. At the head (upstream) end of the canal, it is approximately 0.5 m deep, 2.5 m wide and is U shaped (Figure 3.9). The canal dimensions decrease along its length. The control structure at the head (inlet) end is an undershot gated offtake, opened and closed manually in-situ by the Mahaweli Authority. The opening mechanism is padlocked to prevent unauthorized operation. The water supply to the farm outlets is controlled by the individual farmers. These outlets are usually earthen ditches or pipes and the discharge is controlled by earthen embankments alone or in combination with pieces of wood. Disputes arise between farmers about water allocation. Tail end farmers lose out when head end farmers take a larger share of the water. There are numerous concrete drop structures along the canal although many are not serving their intended purpose as the stream has washed a pathway around them. Simple canal maintenance such as the clearing of weeds is done by the farmers. There is a farmers' organization for the MD17 canal. This organization is used to mediate disputes about water allocation between the farmers and is also used to represent the farmers' interest to the regional block office (Mahaweli Authority). On two occasions during the Yala 2000 growing season (May-Sept.), the MD17 farmers asked for and were granted more water for cultivation. The Yala 2000 growing season began May 1st. Initially, water was issued every day. After the planting and sprouting, water was issued in rotation 4 days out of 7; water was issued at a rate of 0.076m^3/sec. Water issuing stopped September 30th.

The Mahaweli Authority is presently involved in a project to rehabilitate existing canals. This involves the lining of canals with concrete and replacing control structures. The purpose of the rehabilitation is to increase the efficiency of the Uda Walawe basin by reducing canal seepage losses. The BBD5 canal was rehabilitated during September 1999 to February 2000.

The BBD5 canal is concrete lined and approximately 2.0 km long, irrigating an area of 3.0 km^2. It has 10 field canals and begins from the Beddewewa Branch canal (Japan road). At the head (upstream) end of the canal it is approximately 1 m deep, 1.04 m wide and is square shaped. The canal dimensions diminish along its length to approximately 0.2 m deep by 0.2 m wide. The control structure at the head (inlet) end is an undershot gated offtake, opened and closed manually in-situ by the Mahaweli Authority. Its opening mechanism is also padlocked. Control structures at the head of each field canal are similarly operated by the Mahaweli Authority (Figure 3.10). Farm outlets are pipes, and discharge is controlled by the water level in the field canal. It is easier to regulate the water level in the concrete canals than in the earthen canals due to the functional drop structures. Farmers may also block their outlets by earthen embankments alone or in combination with pieces of wood. The Yala 2000 growing season began May 2nd. Initially water was issued every day. After the planting and sprouting, water was issued in rotation 6 days out of 7. Water was issued at a rate of 0.404m^3/sec; water issuing stopped between the 8th and the 28th of September.

Figure 3.9 Earthen canal (MD17)

Figure 3.10 Concrete canal (BBD5). distributor structure



3.3.7 Social data

The MD17 canal forms part of the village of Samajasevapura. The entire population is Sinhala, Buhddists. Generally, people in this region are literate, as they have access to the Suriawewa government school. The population lives in reasonable sanitary conditions with clean houses, access to ample water and latrines (toilets), and they have access to the Suriwewa government hospital. Additional social data are listed in Table 3.6.

Paddy land accounts for 100 hectares of the region. Other crops include banana, coconut, chilli, papaya, lady's finger (okra), manioc, snake gourd and eggplant. With the exception of banana, these crops are grown on a small scale, often in home gardens. Permanent crops, such as jack fruit, mango, lemon, orange, breadfruit and woodapple are also grown. There is some livestock in the region, including cattle, chickens and buffalo. Agricultural equipment consists of spraying equipment, 2-wheeled tractors, threshing machines and 4-wheeled tractors (village officer data, 1997).

The BBD5 canal forms part of the village of Ali Olu Ara. The living conditions in BBD5 canal are similar to those in the MD17 canal as they also have access to the Suriawewa school and hospital, and have similar sanitary standards. Further social data are listed in Table 3.6. The cropping pattern in BBD5 is also similar to that in MD17.

Table 3.6 Social-economic data from village officers (MD17, 1997 data) (BBD5, June 2000 data) and Mahaweli Block Office (1997)

Village statistics	MD17 village	BBD5 village
Population	920	879
# farmers	72	191
Population who can read	90 %	97 %
Permanent houses	80	26
Semi-permanent and temporary houses	126	161
Permanent toilets	147	53
Temporary toilets	61	138
Employment	**MD17 village**	**BBD5 village**
Paddy farmers	65 %	71 %
Other crop farmers	16 %	2.5 %
Permanent crop farmers	8 %	21 %
Government position	1.5 %	2.5 %
Business	3 %	0 %
Other (self employed, mason, labourer, driver, salesman, carpenter)	5.1 %	3 %

3.4 Experimental design

3.4.1 Shallow wells: physical properties, water use and water scarcity study

A study was performed to determine the water sources and the water use habits in a small community of the Uda Walawe irrigation scheme. In the first stages of the project, during informal interviews with community members, it became apparent that shallow wells were an important water source for the people of the region. A study was developed to determine the uses of shallow wells and their various physical properties. The study was restricted to the MD17 and BBD5 canal areas (bounded by their drainage ditches), covering a total area of 4.5 km^2.

An inventory of all wells along both canals was made. Each well was measured (total depth, water depth and well diameter). The distance from the well to the canal was measured or estimated, and the well construction (protective wall, ring of stones, etc.) was noted. A well user was interviewed to determine the uses for the well water, the number of people using the well and if the well ever fell dry. This inventory was conducted once in late May through June and again in October to confirm the statements concerning the wells that dry up.

Further parameters were measured for the wells selected as part of the water quality study. Distances were measured between the well and the canal, the nearest latrine and the household garbage pile. The amount of sunlight the well received was classified as full sun, sun (part shade), shade (part sun) and full shade. The topography surrounding the well was noted, and classified as being on a hill or in a depression. A well user, generally the woman of the household, was interviewed to determine if bathing activity was carried out near the well. For most wells the responses for these parameters were similar. This helped protect against interference of these factors (contributing effects) on the water quality study.

3.4.2 Thermotolerant coliforms, electrical conductivity, pH and temperature

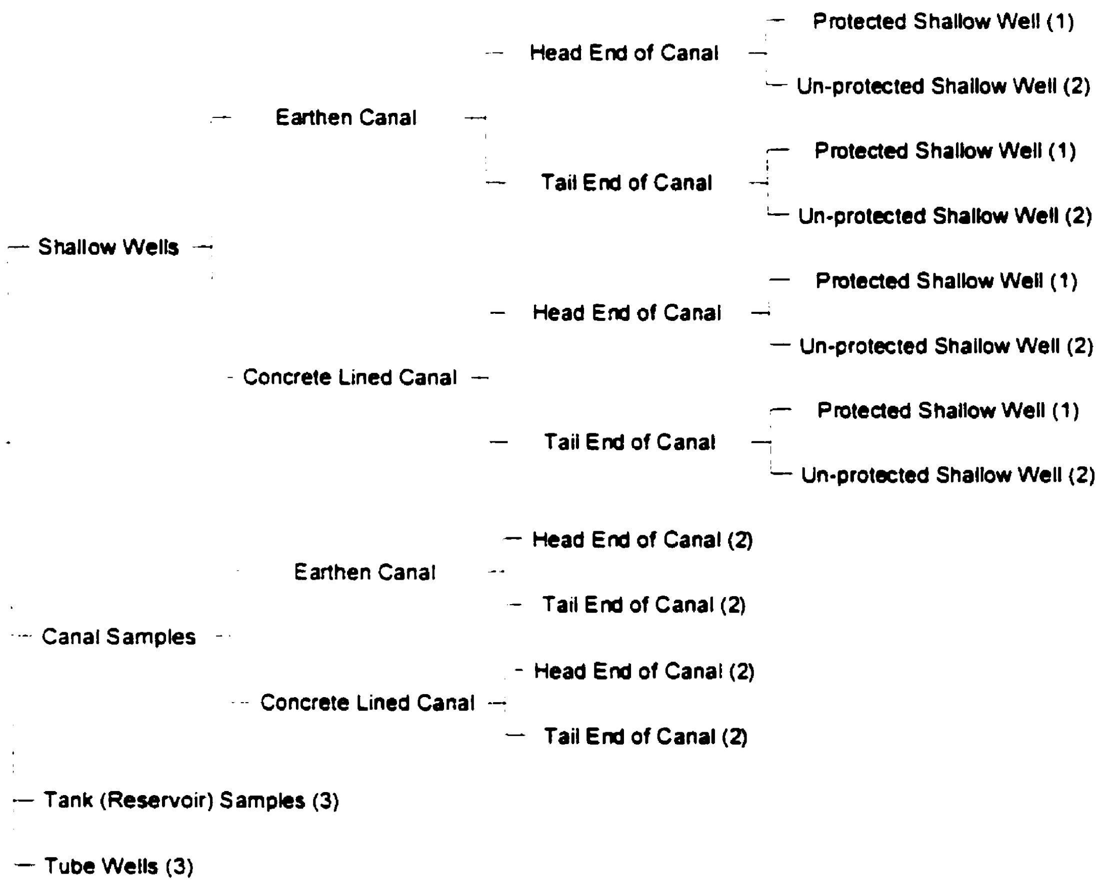
3.4.2.1 Sampling locations

Sampling was executed in an area near the village of Suriawewa, in the Uda Walawe irrigation scheme (see site description). Water samples were taken from 4 different source types:

- Shallow wells (12)
- Canals (8)
- Tank (irrigation reservoir) (3)
- Tube wells (boreholes, deep wells with a hand pump) (3)

Canals were further subdivided into two categories: earthen canals and concrete lined canals. Shallow wells can be classified also by the type of canal to which they are close. Samples from canals and from shallow wells were further classified according to their location along the canal: head of the canal (top end) and tail of the canal (bottom end). Shallow wells were further subdivided into two categories: protected (with a concrete wall preventing the intrusion of runoff) and unprotected (flat to the ground surface). See Fig 3.11, for a tree diagram, and Fig. 3.12 for a map.

Fig 3.11 Tree diagram of sampling locations



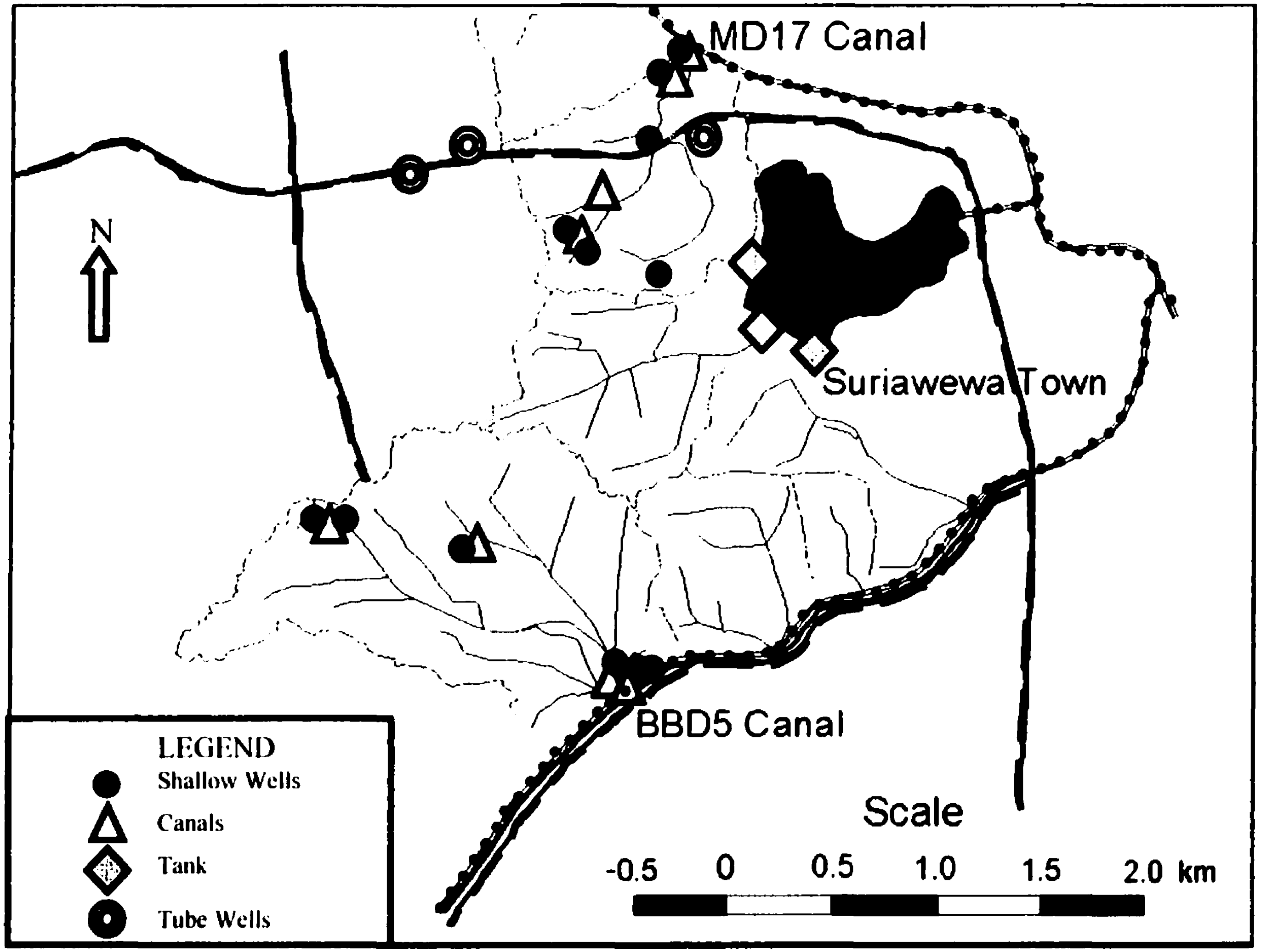


Figure 3.12 Water Sampling Locations

3.4.2.2 Sampling method and times

Sampling of all sites was executed in a period of 5 to 7 days, once per month, and was repeated over a period of 5 months from August to December. Water samples were always collected in the morning using sterile 200 ml plastic bags. All samples were placed in a cool box, transported back to the laboratory, and analyzed within 9 hours of collection. Each sampling day, one sample bag was filled with sterile dilution water and placed into the cool box before leaving the laboratory. This sample was used as a negative control. It was transported to the field and back to the laboratory without opening and then analyzed with the other samples.

For surface water samples, the field worker dipped the sample bag directly into the source, using a dipping stick. In the canal, samples were taken from the centre of the stream, near the water surface. In the tank (irrigation reservoir), the sample was taken 1 m from the edge, near the water surface. For tube wells, water was pumped for one minute, and sample bags were then filled without touching the bag to the mouth of the tube well. For shallow wells, water was drawn using the locally available means, a bucket, and was then poured into the sample bag, taking care to avoid contaminating the sample by touching it with the hands.

Directly after a sample was collected, temperature, pH and EC of the water were measured in the field. The pH meter and EC meter were rinsed with distilled de-ionized water between each site. Once samples arrived at the laboratory they were placed immediately in the refrigerator.

3.4.2.3 pH meter, and electrical conductivity (EC) meter

The pH, electrical conductivity and temperature were measured in the field, and then again in the lab. The pH was measured with a HACH EC10 pH meter. This meter was calibrated at the beginning of each sampling week. Electrical conductivity measurements were made with a UC-35 conductivity meter, Central Kagaku Corp. The meter was calibrated every morning before leaving the laboratory with HACH EC standard solution reading 0.180 mS/cm. Temperature measurements were made with both the pH meter and the EC meter.

3.4.2.4 Membrane filter technique

The samples were analyzed for thermotolerant coliforms using the membrane filter technique as outlined by Csuros et al. (1999) and the APHA et al. (2000). This technique involved filtering water through a membrane that retained thermotolerant coliforms, incubating this membrane on a growth promoting medium and then counting the resultant thermotolerant coliform units (ThCU). The volume of sample passed through the filter ranged from 0.5 ml to 100 ml, where smaller volumes (<25 ml) were mixed with dilution water before filtering. Filtration volume was chosen on the basis of the water source (shallow well, canal, tank or tube well). For example, smaller volumes were filtered for surface water samples because of high numbers of thermotolerant coliforms. The resultant count of ThCU on a filter paper were then multiplied by the dilution factor and reported as number of ThCU per 100 ml. Plated samples were incubated in a water bath (Fisher Scientific ISOTEMP 202S, 2 litres) for 24 hours at 44.5 °C. Plates were counted within one hour of being removed from the water bath. Units were counted without magnification aids. The thermotolerant coliform growth media used was GelmanSciences microbiological media (product # 4390) M-FC broth with rosolic acid (to increase specificity of medium). Petri dishes were GelmanSciences (product # 7245) 50mm, sterile dishes, with absorbent pads. Filter papers were GelmanSciences (product # 66068) GN-6 Merticel® membrane, 0.45 μm, 47mm, S-Pak, sterile and gridded. Filter holders were ADVANTEC MFS, Inc. borosilicate glass (product # 311401 funnel, 311403 clamp, 311402 standard glass frit, 311404 silicone rubber stopper). Dilution water was mixed and sterilized as per Csuros et al. (1999).

3.4.2.5 Sterilization technique

All glassware was rinsed with distilled de-ionized water, wrapped in brown paper, and autoclaved for 15 minutes at a pressure above 15 psi.

3.4.3 *Giardia spp.*, and *Cryptosporidium spp.*

3.4.3.1 Sampling locations and times

For parasite analysis, water samples were collected from one of each of the four water source types: a shallow well, a canal site, a tank (irrigation reservoir) site and a tube well. This was repeated in August, September, and October. Parasite sampling was carried out on the final day of thermotolerant coliform sampling.

3.4.3.2 Sampling method

A large bucket was filled with 49 litres of water from the sample site. Water was pumped (by hand) through a cylindrical filter. The outside of the filter was then scraped to remove all residues. The filter was squirted with distilled de-ionized water and scraped again. This process was then repeated once more. The collected scrapings and water were transferred to 50ml tubes, containing 10ml of 10% formaldehyde.

3.4.3.3 Concentration of specimens

Concentration and analysis of all specimens were done from November 27 to November 29. Without disturbing the deposit on the bottom of the tube, approximately 25 ml were discarded. About 10 ml of the remaining sample were centrifuged at 200g for 10 minutes. The supernatant was discarded and 5 ml of the suspension in the bottom of the tube were kept for analysis.

3.4.3.4 Analysis for *Giardia spp.* cysts

Using a Pasteur pipette, 1 drop (0.1 ml) of the mixture (see above) was placed on 2 microscope slides. A cover slip was placed over the specimens, and they were examined with a light microscope using a 40X objective. A total of 50 fields were selected at random on the 2 microscope slides (25 fields/slide). Positive fields were registered, along with the total number of cysts counted in the selected 50 fields.

3.4.3.5 Analysis for *Cryptosporidium spp.* oocysts

Five ml of sucrose with a specific gravity of 1.103 were pipetted into a 16 ml glass centrifuge tube. Three ml of the suspension on the bottom of the centrifuge tube were concentrated (see section 3.2.2.3). After centrifugation at 200g for 10 minutes, the cloudy layer located at the interface was removed with a Pasteur pipette and used to prepare 2 smears. The smears were allowed to dry at room temperature (23 °C), fixed with methanol and stained with a Ziehl Neeilsen acid-fast stain. They were examined with a microscope at 100X magnification (oil immersion). A total of 100 fields were randomly selected on 2 microscope slides (50 fields/slide). Positive fields were registered along with the total number of oocysts counted in the selected 100 fields.

3.5 Statistical analyses

3.5.1 Thermotolerant coliform units/100ml (ThCU/100ml)

The results of the thermotolerant coliform analysis yielded data that were skewed to the right (positive Skewness), with a few samples having very high levels of ThCU/100ml. This artificially raised the value of the mean, making it a poor indicator of central tendency for the majority of the data set. In this case, a more representative measurement of central tendency was the median, which has been used where indicated (Figures 4.3 to 4.5). For the statistical analysis, the natural logarithm of the ThCUs was taken to redistribute the values into a more normal distribution (Tabachnick and Fidell, 1989). The transformation on the data was ln(ThCU/100ml + 1). The addition of 1 was necessary as some ThCU values were zero. At each sampling site three samples were taken at one time. The average of these three samples was computed and used for the analysis.

To explore variation due to seasonal effects and different water source types the ln(ThCU/100ml) data was analyzed using repeated measures ANOVA. The data analysis was carried out with the SAS proc GLM function. The treatment was water source type. To explore variation due to seasonal effects, canal type, position (head/tail) along the canal and presence of protective wall a second analysis was made using the same method with only the shallow well samples.

The treatments were canal type, head/tail and protective wall. Pairwise comparisons were made using the Least Square Difference (LSD) method.

To explore the effect of time elapsed since last rainfall, the ln(ThCU/100ml + 1) data was analyzed using a linear regression. This was carried out with the SPSS regression: linear function. The factor in the regression was number of days since last rainfall. This was done for the entire data set and with the data broken down into four groups, corresponding to each water source type.

To explore the effect of water level in the canal the ln(ThCU/100ml + 1) canal data was analyzed using a linear regression. This was carried out with the SPSS regression: linear function. The factor in the regression was canal: full/dry.

In order to establish if other factors were affecting the ln(ThCU/100ml) data, a model was built using stepwise regression. This was carried out using the SPSS regression: linear, stepwise function. The factors in the regression were electrical-conductivity, pH, temperature, water source, number of days since last rainfall, canal: full/dry and month (time of year). This was done for the entire data set, and for the canal data and shallow well data separately. Extra factors ware entered when building the model for canal and shallow well data. For canal data the extra factors were canal type and canal position: head/tail. For the shallow well data the extra factors were canal type, canal position: head/tail, protective wall, distance from canal, distance from latrine, bathing activity, sun/shade, distance from refuse pile, and depression (topography).

3.5.2 Parasites

There were two sets of data for each of the two parasites, *Giardia* spp. and *Cryptosporidium* spp.

The first set of data, the number of positive fields in the total (50 or 100) examined, was analyzed using a logistic regression. This was carried out using the SAS proc logistic descending. Factors used in the regression were month (time of year), water source type and ln(ThCU/100ml + 1).

The second set of data, the total number of cysts or oocysts in the fields examined, was analyzed using a linear regression. This was carried out using the SAS proc reg. Factors used in the regression were month (time of year), water source type and ln(ThCU/100ml + 1).

3.5.3 Electrical-conductivity, pH and temperature

At each sampling site three samples were taken at one time. The average of these three samples was computed and used for the analysis.

To explore variation due to seasonal effects and different water source types the EC, pH and temperature data was analyzed using repeated measures ANOVA. The data analysis was carried out with the SAS proc GLM function. The treatment was water source type. To explore variation due to seasonal effects, canal type, position (head/tail) along the canal and presence of protective wall A second analysis was made using the same method with only the shallow well samples. The treatments were canal type, head/tail and protective wall.

To explore the effect of time elapsed since last rainfall, the EC, pH and temperature data was analyzed using a linear regression. This was carried out with the SPSS regression: linear function. The factor in the regression was number of days since last rainfall. This was done for the entire data set and with the data broken down into four groups, corresponding to each water source type.

To explore the effect of water level in the canal the canal data was analyzed using a linear regression. This was carried out with the SPSS regression: linear function. The factor in the regression was canal: full/dry.

In order to establish if other factors were affecting the EC, pH, and temperature data a model was built using stepwise regression. This was carried out using the

SPSS regression: linear, stepwise function. The factors in the regression were electrical-conductivity, pH, temperature, water source, number of days since last rainfall, canal: full/dry and month (time of year). When a parameter was analyzed, it was not used as a factor. For example when electrical-conductivity data was analyzed, electrical-conductivity was not used as a factor in the stepwise regression.

4. RESULTS AND DISCUSSION

4.1 Shallow wells: physical properties, water use and water scarcity study

A study was done to determine physical characteristics, water uses and water scarcity of all shallow wells in the study area (MD17 and BBD5 canal regions, Figure 3.3). There were 81 shallow wells within the MD17 distribution area, and 79 shallow wells within the BBD5 distribution area. The study enabled the researchers to select a few wells for the water quality study which would be representative of the majority of the shallow wells found in the region. The study was also used to demonstrate that shallow wells were important to the community. Water scarcity, in terms of shallow wells going dry, was compared between the two regions MD17 and BBD5 where the canal types were earthen and concrete respectively.

4.1.1 Physical properties of shallow wells

The wells of MD17 and BBD5 regions were, on average, 2.7 m deep with a water level of 1.0 m from the top edge of the well structure (May-June). A typical well was unprotected, with a ring of stones and logs defining the edge of the well (Figure 3.7). In this area 23 (15.1 %) of the wells were protected with a wall extending down into the well (Figure 3.8). Most wells (70.2%) were located in settlement land, the others were found in the paddy fields or banana groves. Settlement land is generally dry, high in elevation and close to the distributor canal or field canals (farm outlets run between settlement lands to the paddy fields below). Paddy fields are flooded for most of the growing season. Banana groves are irrigated but the soil surface is generally dry other than during water application. These physical properties of shallow wells were similar in both regions, MD17 (earthen canal) and BBD5 (concrete lined canal) (Table 4.1).

Well owner households ranged in size from 1 to 10 people, with an average of 5 people. Wells which were easily accessible or perceived as having higher quality water were used by additional families. Some wells received as many as 200 families per day to withdraw drinking water. Around MD17 families came for drinking water from the non irrigated areas to the east of the main canal and the non irrigated areas west along the road. Some families traveled as far as 4 km to take water from shallow wells in MD17. Around BBD5 families came to the tail end of the system, from the non irrigated areas to the north (Hathporua). On average, a well was used by 5 other families.

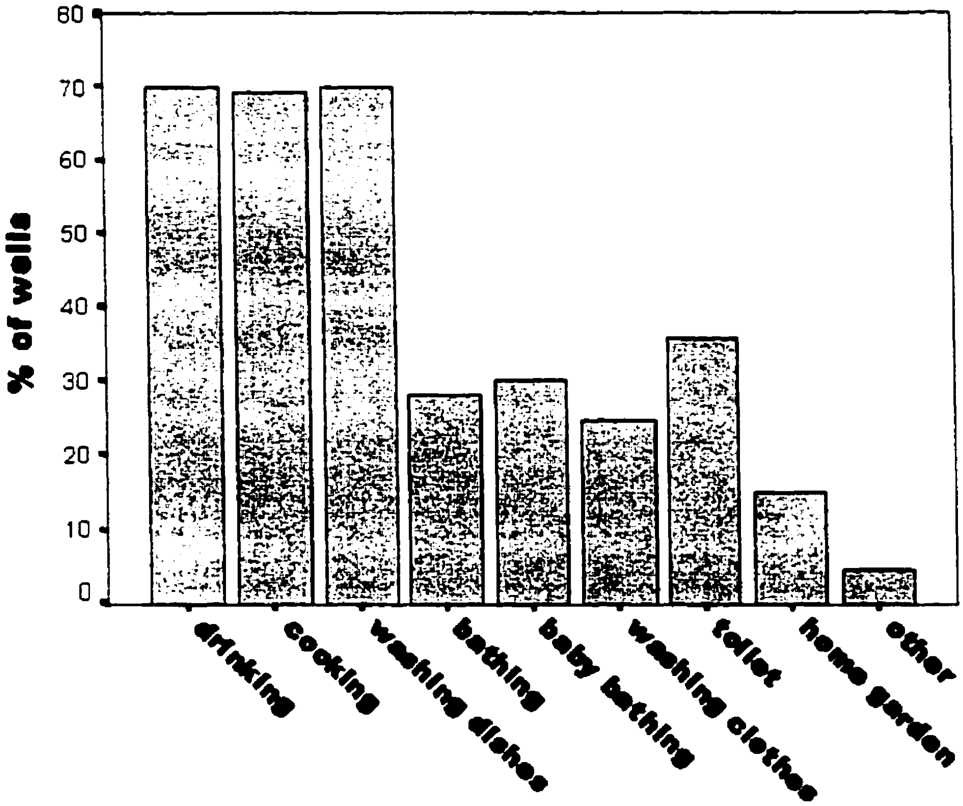
Table 4.1 Comparison of physical properties of shallow wells along two different canal types. Earthen canal (MD17) and concrete canal (BBD5).

	MD17	BBD5
Mean well depth (m)	2.80	2.52
Mean well diameter (m)	1.35	1.25
Mean distance to nearest canal (m)	34.11	24.01
% wells with protective wall	14.8	14.6
% wells going dry	13.6	54.9
% wells located in:		
Settlement land	75.3	62.2
Paddy field	4.9	17.1
Banana field	12.3	15.9
Other crop	2.5	4.9

4.1.2 Water uses of shallow wells

Water from the shallow wells was primarily used for drinking, cooking, and washing household utensils (Figure 4.1). Bathing, the washing of an individual's entire body, and washing of clothes were sometimes done with well water but generally were done directly in the canal or the tank (irrigation reservoir). Generally, water for the toilet was also withdrawn from the canal. Water for toilet purposes was used for anal cleaning and flushing of the toilet in cases where a water sealed latrine was used. If a household had two wells, mostly one was used for drinking, cooking and dish washing, and the other for home garden, bathing and clothes washing. Home gardens consisted of small vegetable patches and flower beds surrounding the home, which were not irrigated as part of the regular irrigation system.

Figure 4.1 Domestic uses of shallow well water by the population of MD17 and BBD5 canals (bars represent % of shallow wells used for each purpose).



The shallow wells were a very important water source in the MD17 and BBD5 canal areas. This was also observed by Silva (1984) who concluded that shallow wells were the main source of drinking water in the district and that generally these wells contained good quality water. Silva (1984) found that shallow wells contained water of better quality when compared to water contained in tube wells. In the present study, the shallow well water was used for all domestic purposes, including drinking. The shallow wells were easily accessible and were also preferred due to the perception that they contained high quality water.

4.1.3 Water scarcity in shallow wells

When the water delivery in the canals was stopped, the water level of the shallow wells decreased. The month of greatest water scarcity was generally August, between the two growing seasons (Yala, and Maha). Silva (1984) also documented shallow wells going dry in the Uda Walawe region during the dry season. He concluded that this caused great suffering for the people as it forced them to travel longer distances to fetch water. In the BBD5, concrete canal area 55% of the people reported wells going dry. This was much more than in the MD17, earthen canal area where only 14% reported dry wells (Figure 4.2). Wells located along the two canals were similar in all respects other than the canal type, either earthen or concrete (Table 4.1). No difference was found in the mean well depth between the two areas (P>F 0.157). A regression analysis was performed to determine the main factors contributing to wells going dry (Table 4.2). The main factors that enable one to predict which wells go dry are the type of canal close to the well and depth of the well. Factors that were not significant in predicting which wells went dry were the presence or absence of a protective wall around the well, the location of the well (settlement land, paddy field or banana grove) and distance between the well and canal.

Figure 4.2 Comparison of number of shallow wells going dry between two canal types.

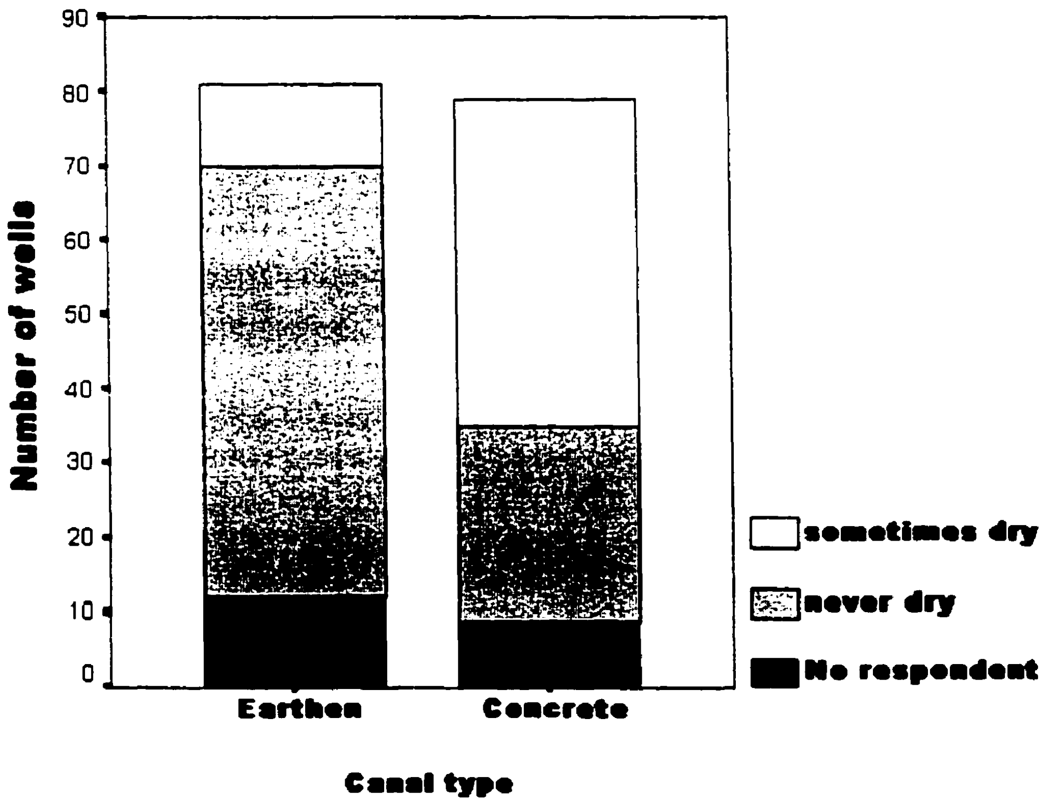


Table 4.2 Regression analysis to determine main effects contributing to shallow wells becoming dry

Source	P>F
Intercept	**0.003**
Canal type	**0.000**
Protective wall	0.469
Well depth	**0.027**
Well location	0.712
Distance to canal	0.800
Model	**0.000**
R^2	0.203
R^2 adj.	0.162

Significant at P<0.05

4.2 Thermotolerant Coliforms (ThCU/100ml)

4.2.1 Time series analysis

The study was conducted over a 5 month period to examine if there were seasonal variations in ThCU/100ml levels. From the Figure B.1 in Appendix B, we can observe little variation over the five sampling months. To determine the importance of time of year on the ThCU/100ml levels a repeated measures analysis of variance was performed (general linear models procedure) (Table 4.3). Effects due to the months were not observed (P>F 0.3677). The ThCU/100ml levels did not vary significantly over the 5 sampling months. As well, there was no observable month x treatment interaction.

4.2.2 Comparison of water sources

The study compared ThCU/100ml between the water source types, shallow well, canal, tank and tube well (Figure 4.3). The dotted line at 1000 ThCU/100ml represents the Sri Lanka limit for bathing waters and the WHO limit of water to be used as a source for a conventional water treatment facility. The different water sources were compared within the repeated measures analysis to identify trends and any significant differences in ln(ThCU/100ml +1). Significant effects due to the water source type were observed for the ThCU results (Tables 4.3 and 4.4). Canals tended to have higher levels of ThCU than all other sources and tube wells tended to have lower levels of ThCU than all other sources (Figure 4.3). Tube wells always had significantly lower (P=0.05) ThCU levels than canals. Shallow wells had significantly lower ThCU levels than canals in 3 of the 5 months. Tank samples also had significantly lower ThCU levels than in canals in 3 of the 5 months. The implication was that tube wells had "the cleanest" water, lowest rates of ThCU and that shallow wells and tank samples were improvements over canal water.

Table 4.3 Repeated measures analysis of variance after logarithmic transformation, for ln(ThCU/100ml + 1).

Source	df	P>F	P>F Adj. [G-G]
Water source	3	**0.0001**	
Month	4	0.3677	0.3607
Month x Water source	12	0.8953	0.8495
Contrasts (compared with Month: December)	P>F Mean	P>F Water source	
Month: August	0.6120	0.8906	
Month: September	0.8914	0.9226	
Month: October	0.4059	0.8456	
Month: November	0.1861	0.6807	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

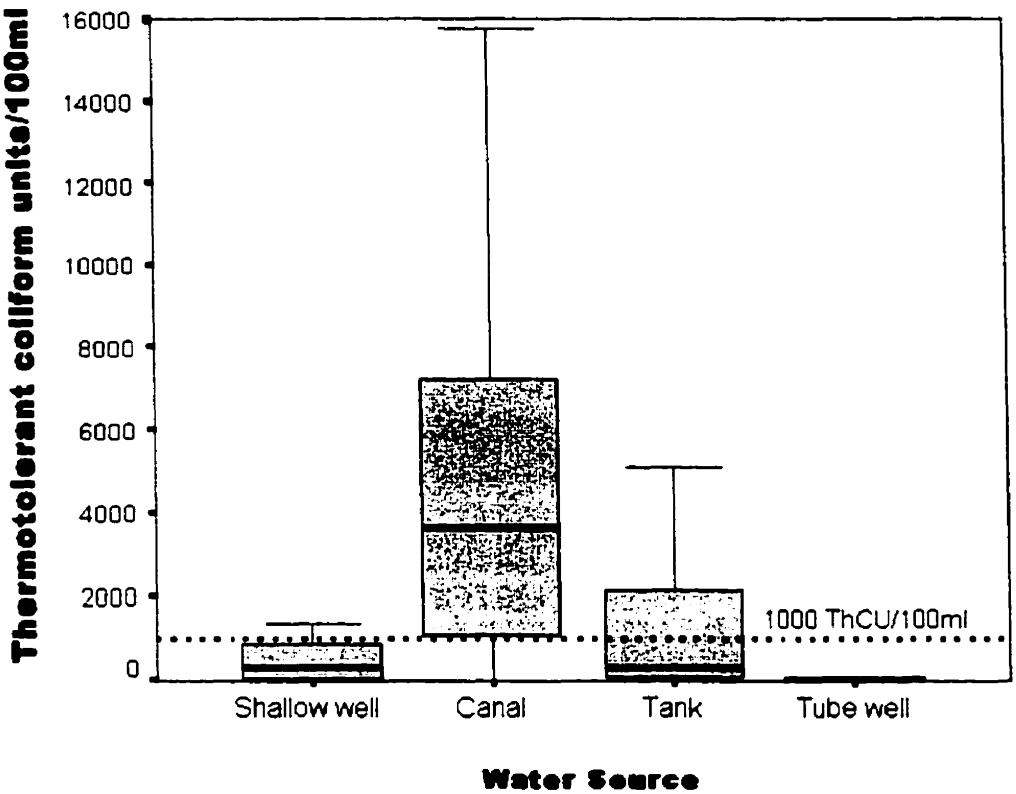
Table 4.4 ln(ThCU/100ml + 1) and significant treatment effects.

Treatment	August	September	October	November	December
Means ln(ThCU/100ml + 1)					
Canal	9.616 a	6.681 a	10.355 a	11.482 a	8.528 a
Shallow well	5.082 b	4.839 a	5.972 b	5.113 b	4.480 ab
Tank	4.132 bc	5.150 a	4.311 bc	4.871 ab	4.884 b
Tube well	1.167 c	0.859 b	1.208 c	2.989 b	0.256 c
P>F					
Treatment	**0.0053**	**0.0258**	**0.0018**	0.1047	**0.0023**
CV%	39.28	44.37	34.38	53.18	41.18
Mean	4.576	4.313	5.237	5.086	4.046

Significant at P<0.05

Means with the same letter, or no letter, are not significantly different (P<0.05, LSD test)

Figure 4.3 Effect of water source types on thermotolerant coliform units/100ml.

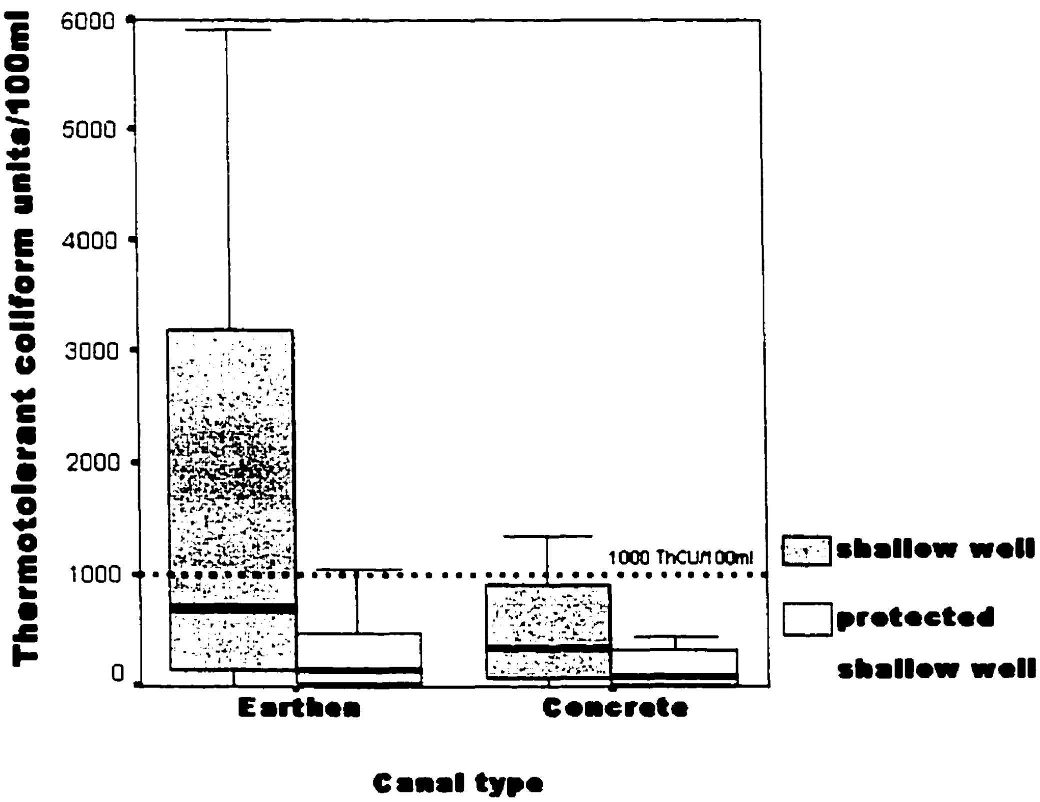


Box plots: shaded area represents 50% of data points, whiskers represent extreme values (excluding outliers) and the darkened line represents the median.

4.2.3 Shallow well data: comparison of canal type, head/tail position and protective wall

Further subdivisons within the shallow wells were analyzed in a separate repeated measures model using only the shallow well data. The study compared ThCU/100ml between shallow wells situated along earthen canals versus concrete lined canals, shallow wells located at the head end versus the tail end of the canal and shallow wells with a protective wall versus those without. A visual comparison is made in Figure 4.4 where ThCU/100ml levels are compared between canal types and presence of a protective wall. The dotted line at 1000 ThCU/100ml (Figure 4.4) represents the Sri Lanka limit for bathing waters and the WHO limit of water to be used as a source for a conventional water treatment facility. A repeated measures analysis of variance was used to determine if there

Figure 4.4 Shallow well samples.
Effect of canal types and presence of protective wall on thermotolerant coliform units/100ml.



Box plots: shaded area represents 50% of data points, whiskers represent extreme values (excluding outliers) and the darkened line represents the median.

study was not significant and there were no significant month x treatment interactions (Table 4.3). There was a significant effect due to the canal type, with the trend being higher ThCU levels in wells located beside earthen canals (Figure 4.4 and Table 4.5). However, there were no differences identified in the comparison least significant difference (LSD) tests (Table 4.6). The effect due to position along the canal (head/tail) was not significant (Table 4.5). There was a significant effect due to the presence or absence of a protective wall (Table 4.5). In October, the LSD comparison test showed higher levels of ThCU/100ml in wells without a protective wall (Table 4.6).

In general, ThCU/100ml levels tended to be higher in wells lacking a protective wall (Figure 4.4). This indicated that the construction of protective walls around

Table 4.5 Shallow well samples.
Repeated measures analysis of variance after logarithmic transformation, for ln(ThCU/100ml + 1).

Source	Df	P>F	P>F Adj. [G-G]
Canal Type	1	**0.0484**	
Head/Tail	1	0.6259	
Protective Wall	1	**0.0074**	
Month	4	0.8334	0.7546
Month x Canal Type	4	0.4491	0.4250
Month x Head/Tail	4	0.3665	0.3596
Month x Protective Wall	4	0.2601	0.2739
Contrasts (compared with Month: December)	P>F Mean		
Month: August	0.7968		
Month: September	0.9997		
Month: October	0.3299		
Month: November	0.9948		

Significant at P<0.05

Table 4.6 Shallow well samples.
ln(ThCU/100ml +1) and significant treatment effects

Treatment	August	September	October	November	December
Means ln(ThCU/100ml + 1)					
Canal, Earthen	5.910	5.684	6.460	5.718	3.901
Canal Concrete	4.253	3.994	5.485	4.507	5.059
Head	5.728	4.441	5.702	4.692	5.400
Tail	4.436	5.237	6.243	5.533	3.560
No Protective Wall	5.554	5.238	6.853 a	6.046	5.120
Protective Wall	4.137	4.041	4.211 b	3.246	4.160
P>F					
Canal Type	0.1137	0.1860	0.3038	0.4795	0.2444
Head/Tail	0.2035	0.5144	0.5594	0.6206	0.0810
Protective Wall	0.1900	0.3624	**0.0230**	0.1448	0.3548
CV%	31.79	41.81	25.74	55.34	35.63
Mean	5.082	4.839	5.972	5.113	4.480

Significant at P<0.05
Means with the same letter, or no letter, are not significantly different (P<0.05, LSD test)

wells might decrease people's exposure to infectious agents in water. Protective walls may have reduced ThCU contamination simply by preventing runoff from entering the well. As rainfall varied between sampling months one might expect to have seen a significant interaction term between protective walls and the month since in rainy months the protective wall would have a greater effect. However, this month x protective walls interaction was not significant (Table 4.5). The lack of significant differences may be attributed to the lower amounts of data available as the data set is broken down into further classifications.

4.2.4 Thermotolerant coliform units correlation with rainfall and other factors

The possibility of a correlation between the time elapsed since the last rainfall and the ThCU/100ml was investigated. Initially, the hypothesis was that more recent rainfall events would have caused runoff thereby increasing the contamination load in the sampled sites. From the scatter plot (Appendix A Figure A.1) it was fairly obvious that there was no correlation between the ln(ThCU/100ml + 1) and the rainfall (number of days since last rainfall). Scatter plots for each water source type were made since it was likely that the rainfall would affect them in different ways (Appendix A.1-A.5). Again there was no obvious relationship between the ln(ThCU/100ml + 1) and rainfall. A regression was run on the ln(ThCU/100ml +1) data to find out if there was a correlation with the time elapsed since last rainfall. There was no correlation found when this regression was run with all the data or when the regression was run for each set of water source data separately (Tables 4.7 to 4.11).

There were many factors that could affect the ThCU/100ml levels. So, a model was built using all other factors that had been recorded in the hopes of determining any cause and effect relationships. The model for the entire data set was built using stepwise regression. Although the results for the final model were significant, the values of R^2 and R^2 adj. were very low and therefore the model describes very little of the sample variation in the ThCU/100ml data (Table 4.12). The variables included in the model based on stepwise regression were EC (mS/cm), pH and water source. The apparent significance of EC (mS/cm) and pH are most likely due to the fact that they mirror the divisions established by water source type (see sections 4.4 and 4.5) and not that they are directly affecting the ThCU/100ml. Water source, as was expected from the results thus far, was the main determining feature in the model. Variables that were excluded were the number of days since last rainfall, temperature, canal: full/dry and month. The regression was not run as a time series since in each month there were too few data points to draw conclusions. However, this is not a misuse of the regression methods as it was demonstrated previously that elapsed time during the study had little effect on the ThCU/100ml regression. A Durbin-Watson test was performed to discover any serial correlation. The resulting statistic was close to 2, which indicated little evidence of serial correlation and therefore the analysis was performed without considering it as a time series data set (Mendenhall and Sincich, 1996).

Table 4.7 All samples. Model building ln(ThCU/100ml +1): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.459
Model Fitting	**df**	**P>F**
Model	1	0.459
R^2	0.005	
R^2 adj.	-0.004	

Significant at P<0.05

Table 4.8 Shallow well samples. Model building ln(ThCU/100ml +1): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.459
Model Fitting	**df**	**P>F**
Model	1	0.553
R^2	0.005	
R^2 adj.	-0.004	

Significant at P<0.05

Table 4.9 Canal samples. Model building ln(ThCU/100ml +1): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.514
Model Fitting	**df**	**P>F**
Model	1	0.514
R^2	0.020	
R^2 adj.	-0.025	

Significant at P<0.05

Table 4.10 Tube well samples. Model building ln(ThCU/100ml +1): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.011**
# days since last rainfall		0.553
Model Fitting	**df**	**P>F**
Model	1	0.553
R^2	0.028	
R^2 adj.	-0.047	

Significant at P<0.05

Table 4.11 Tank samples. Model building ln(ThCU/100ml +1): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.781
Model Fitting	**df**	**P>F**
Model	1	0.781
R^2	0.007	
R^2 adj.	-0.076	

Significant at P<0.05

Table 4.12 All samples. Model Building ln(ThCU/100ml +1): Stepwise regression.

Included Variables	df	P>T
Intercept		0.666
EC (mS/cm)		**0.001**
PH		**0.003**
Water Source		**0.006**
Excluded Variables		
# days since last rainfall		0.722
Temperature		0.185
Canal: full/dry		0.868
Month		0.531
Model Fitting	**df**	**P>F**
Model	3	**0.000**
R^2	0.286	
R^2 adj.	0.226	

Significant at P<0.05

4.2.5 Correlations by analyzing data of each water source type individually

Some analyses were performed taking data of only one water source type at one time. Since each water source type was distinctive it was felt that some factors might be affecting ThCU/100ml in some water source types and not in others. If this is true, analyzing all the data together might mask these effects.

4.2.5.1 Canal samples

For the canal samples it was particularly interesting to see if there were differences between the times when the canal was flowing full (growing season), and when the canal was dry (inter season). Canals were full in August and September, and essentially dry in October, November and December. Note that in 2000, the period of dry canals extended into the usual Maha (November to March) growing season. Few canal samples were collected during the period of dry canals, as there was very little water. Therefore, the statistical tests are lacking in power. However, it was still interesting to compare these two periods as they represented distinctly different situations in terms of available water resources. The model employing only the factor canal: full/dry was significant for predicting ln(ThCU/100ml +1)(Table 4.13). However, the canal: full/dry factor was no longer significant when entered in a stepwise regression with other factors (Table 4.14). This stepwise regression was performed to discover other factors significant in the determination of ln(ThCU/100ml + 1). The main determining factor found from the stepwise regression was the canal type (earthen or concrete)(Table 4.14).

Table 4.13 Canal samples. Model building ln(ThCU/100ml +1): Regression (canal: full/dry).

Included Variables	df	P>T
Intercept		**0.003**
Canal: full/dry		**0.046**
Model Fitting	df	P>F
Model	1	**0.046**
R^2	0.169	
R^2 adj.	0.132	

Significant at P<0.05

Table 4.14 Canal samples. Model building ln(ThCU/100ml +1): Stepwise regression.

Included Variables	df	P>T
Intercept		**0.044**
Canal type		**0.023**
Excluded Variables		
# days since last rainfall		-0.182
Temperature		0.184
Canal: full/dry		0.235
Month		0.227
EC (mS/cm)		0.251
PH		**0.035**
Canal position: Head/tail		-0.267
Model Fitting	df	P>F
Model	1	**0.023**
R^2	0.213	
R^2 adj.	0.177	

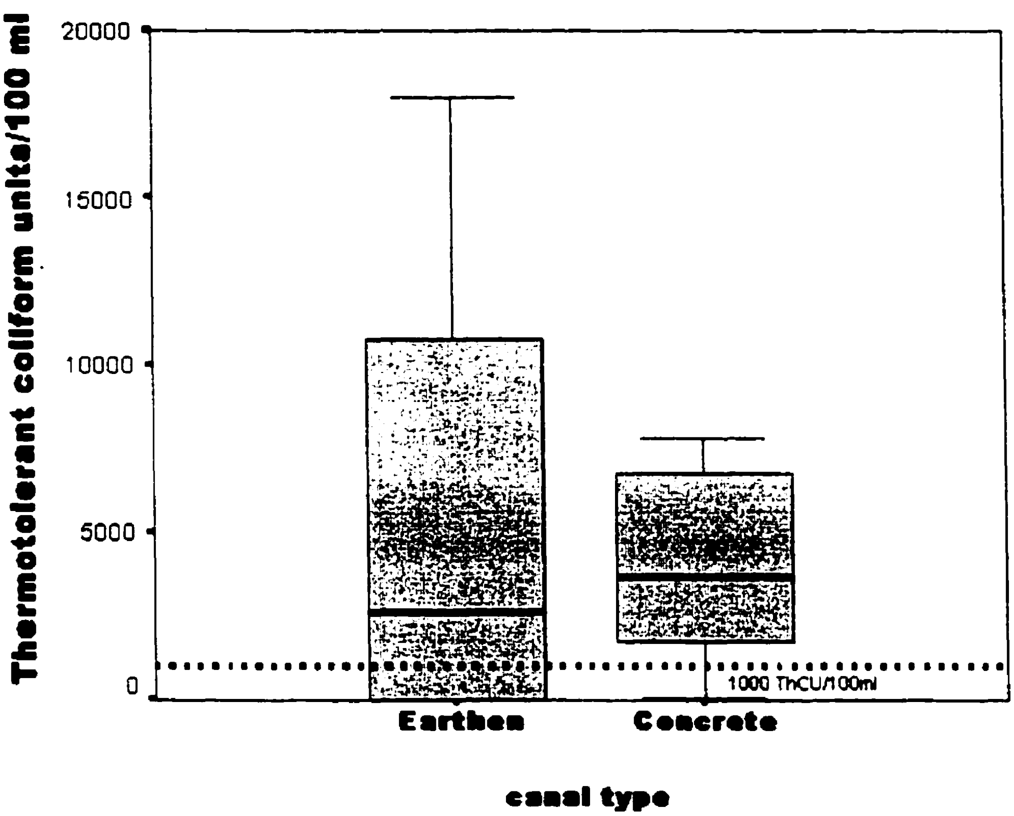
Significant at P<0.05

Figure 4.5 shows that water from concrete canals tends to have higher levels of ThCU/100ml than water from earthen canals. The dotted line at 1000 ThCU/100ml represents the Sri Lanka limit for bathing waters, and the WHO limit of water to be used as a source for a conventional water treatment facility.

Variables excluded from the model were: the number of days since last rainfall, temperature, canal: full/dry, month, EC (mS/cm), pH and canal position (head/tail). Although the model was significant, the R^2 and R^2 adj. values were low and therefore the model describes very little of the sample variation in the canal samples for the ln(ThCU/100ml +1) data.

Figure 4.5 Canal samples.

Effect of canal types on thermotolerant coliform units/100ml.



Box plots: shaded area represents 50% of data points, whiskers represent extreme values (excluding outliers) and the darkened line represents the median.

4.2.5.2 Shallow well samples

Stepwise regression was used to examine the data to fit a model for ln(ThCU/100ml +1) and its possible dependence on various factors. For shallow well samples, the only significant factor was the presence or absence of a protective wall around the well (protective wall)(Table 4.15). The significance of this factor is shown in Figure 4.4 where wells with a protective wall show lower

Table 4.15 Shallow well samples. Model building ln(ThCU/100ml +1): Stepwise regression.

Included Variables	Df	P>T
Intercept		**0.000**
Protective wall		**0.018**
Excluded Variables		
# days since last rainfall		0.897
Temperature		0.214
Canal: full/dry		0.749
Month		0.515
EC (mS/cm)		0.953
PH		0.721
Canal position: Head/tail		0.812
Canal type		0.128
Dist. From canal		0.148
Dist from latrine		-0.124
Bathing activity		-0.105
Sun/shade		0.157
Dist from garbage pile		0.123
Depression		0.233
Model Fitting	**Df**	**P>F**
Model	1	**0.018**
R^2	0.092	
R^2 adj.	0.077	

Significant at P<0.05

levels of ThCU/100ml. Many other factors were thought to possibly affect the levels of ThCU/100ml in shallow wells and so, it was important to try to fit a regression to these factors thereby demonstrating that they were not having an effect on the shallow well data. Variables excluded from the model using stepwise regression were the number of days since last rainfall, temperature, canal: full/dry, month, EC (mS/cm), pH, canal position: head/tail and canal type. Further variables that were applicable only to shallow wells, but were also excluded from the model, were: distance to canal, distance to nearest latrine, bathing activity near well (yes/no), the amount of sun/shade, distance to household refuse pile and the local topography (whether the well is on a hill or in a depression). The exclusion of all these factors demonstrated that ThCU/100ml in shallow wells were not systematically affected by these variables. Again, fractioning the data set into small numbers of data points may be what is preventing the discovery of expected relationships. Many of these other factors would be interesting to explore in a more detailed further study.

4.2.5.3 Tank and tube well samples

Both the tank samples and the tube well samples were subjected to stepwise regression model building. No factors were found to be significant for predicting ln(ThCU/100ml +1) in either tank or tube well samples.

4.3 Parasites

The analysis of the parasite data was somewhat lacking in rigour due to the low number of samples collected. The main observation from this research is that both *Giardia* spp. and *Cryptosporidium* spp. exist in Sri Lanka's irrigation tanks, canals, shallow wells and tube wells and were fairly easily detected with little sampling. Analysis was based on two parameters: the number of fields that were positive for cysts or oocysts from the number of fields examined (50 or 100) and the total number of cysts or oocysts observed in all the fields examined (50 or 100).

4.3.1 Time series analysis

The study was conducted over a 4 month period to examine if there were seasonal variations in parasite abundance. From Figures 4.6 to 4.9 we can observe little variation over the three sampling times, August, September and November. To determine the importance of time of year on parasite abundance, collection month was used as an independent variable in the regression and logistic regression analyses. Months (time of year) were only significant in the logistic regression where the dependent variable was number of positive fields, out of 100 fields, examined for *Cryptosporidium* spp. oocysts (Table 4.17). For the other analyses, *Giardia* spp. number of positive fields, *Giardia* spp. cysts counts and, *Cryptosporidium* spp. oocysts counts, the months were not a significant factor in the regressions (Tables 4.16, 4.18 and 4.19). This was very similar to the ThCU/100ml data that did not vary with the months of sampling either.

4.3.2 Comparison of water sources

The study compared parasite abundance between the water source types, shallow well, canal, tank and tube well (Figures 4.6 to 4.9). Two analyses were performed on each set of parasite data (*Giardia* spp. and *Cryptosporidium* spp.). A logistic regression was performed to link the water source type with the resulting number of positive fields (from a total of 50 or 100 fields respectively). For both the *Giardia* spp. and *Cryptosporidium* spp., the models were significant and a significant correlation was made between the water source types and the number of positive fields (Tables 4.16 and 4.17). The second analysis was a regression to link the water source type with the total counts of cysts or oocysts in the 50 or 100 fields. Again, the water source type was a significant factor in the models to predict counts of these parasite cysts or oocysts (Tables 4.18 and 4.19).

4.3.3 Parasite correlation with thermotolerant coliform levels

Parasite incidence is not necessarily correlated with thermotolerant coliform levels (WHO, 1996). This is due to the formation of cysts or oocysts that are more robust to survive in the environment and are resistant to conventional water treatment such as chlorination. However, in this study, there was a trend for the incidence of parasites to match with that of ThCUs. In the regression analyses, the ThCUs were not a significant factor in predicting number of *Giardia* spp. cysts or *Cryptosporidium* spp. oocysts. However, ThCUs were a significant factor in predicting the number of positive fields for *Giardia* spp. and *Cryptosporidium* spp. (Table 4.16 to 4.19). Further study may be very valuable to demonstrate this link between ThCUs and the incidence of *Giardia* spp. cysts and *Cryptosporidium* spp. oocysts.

Figure 4.6 *Giardia* spp. Effect of water source types and time of year on number of fields positive from 50 examined.

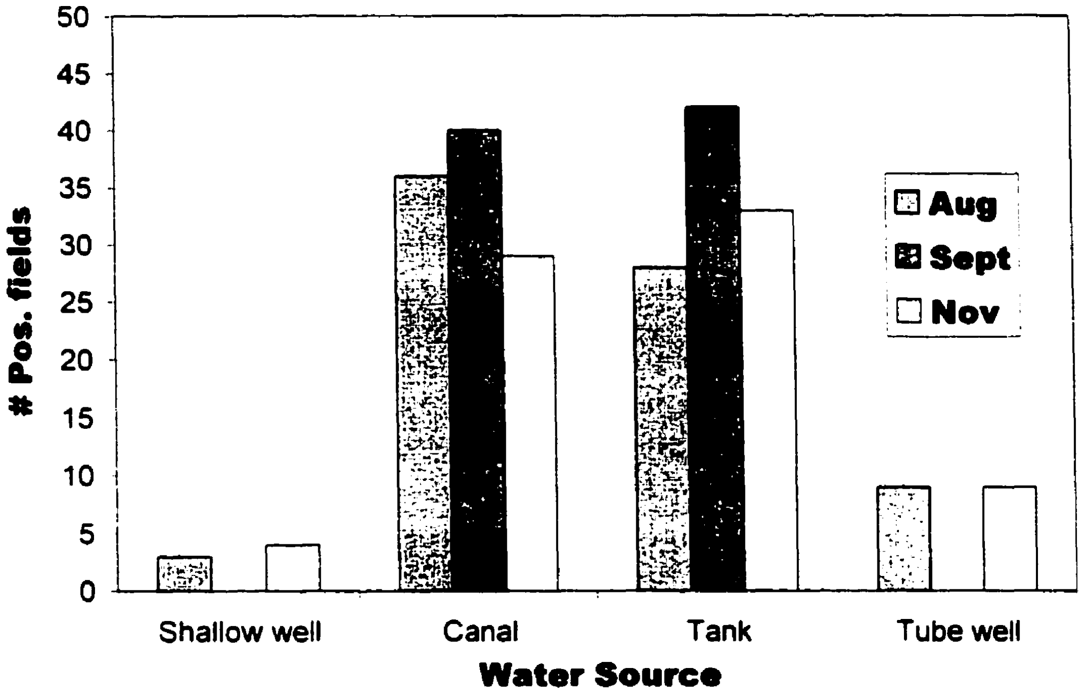


Figure 4.7 *Cryptosporidium* spp. Effect of water source types and time of year on number of fields positive from 100 examined.

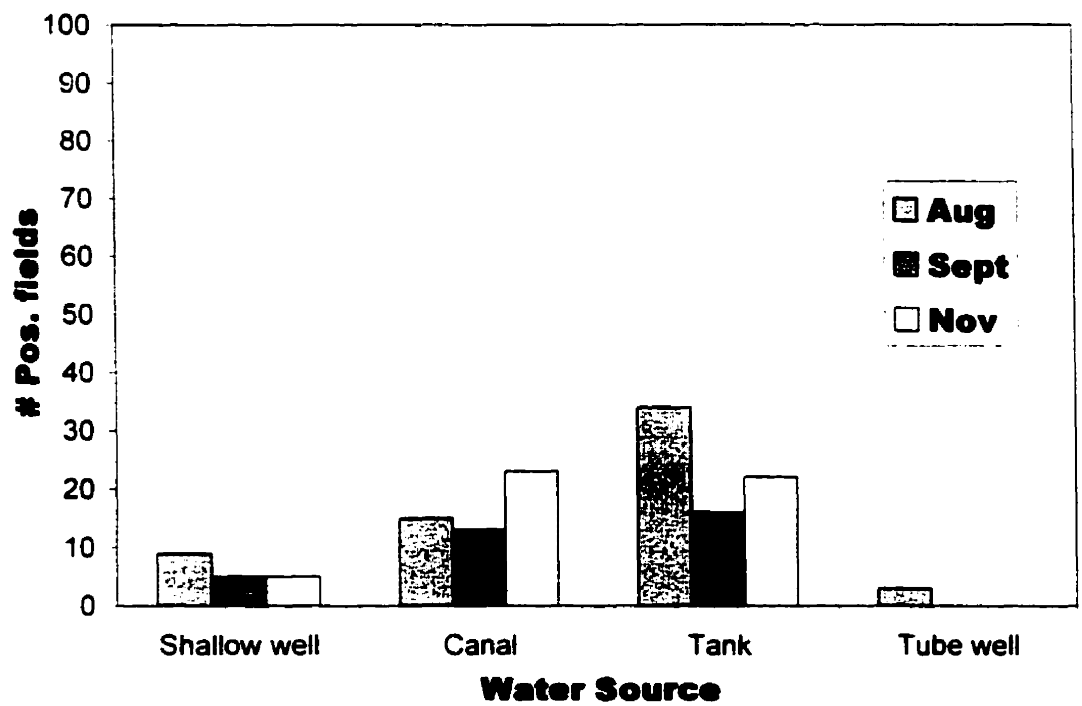


Figure 4.8 *Giardia* spp. Effect of water source types and time of year on number of cysts counted in 50 fields.

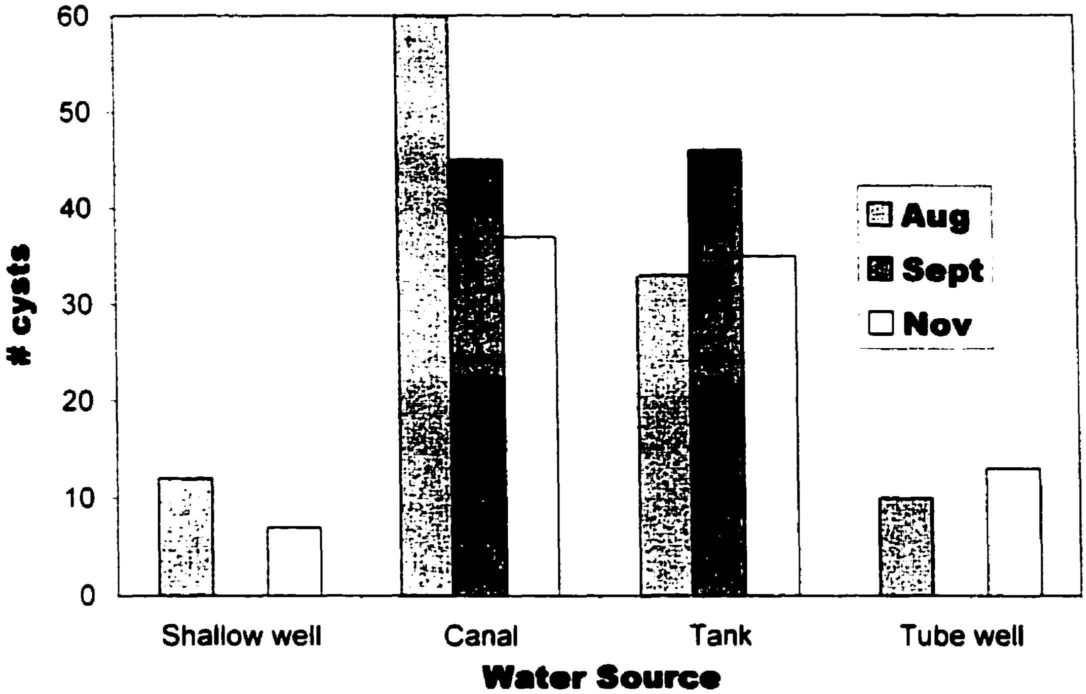


Figure 4.9 *Cryptosporidium* spp. Effect of water source types and time of year on number of oocysts counted in 100 fields.

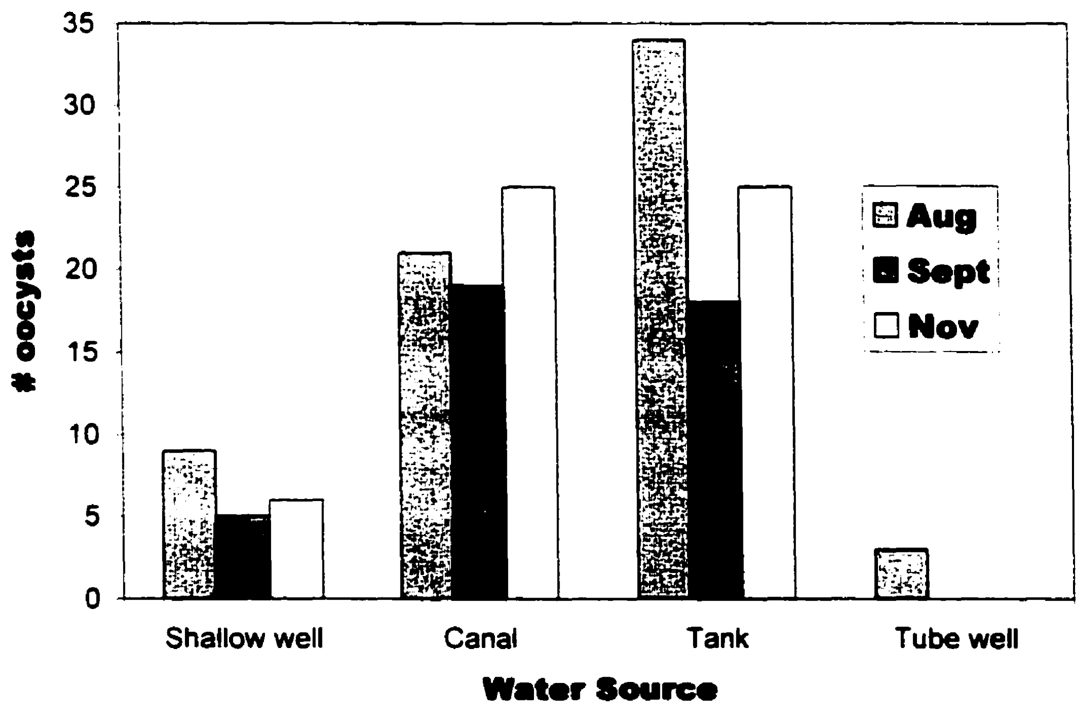


Table 4.16 Logistic regression for number of positive fields in 50 fields examined (*Giardia* spp. oocysts).

Source	Df	P>Chi-Square
Intercept	1	**0.0001**
Month	1	0.1311
Water source	1	**0.0001**
Ln(ThCU+1)	1	**0.0001**
Model Fitting	Df	P>Chi-Square
Model (-2 Log L)	3	**0.0001**
R^2	0.3223	
R^2 max-rescaled	0.4373	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank, tube well.

Table 4.17 Logistic regression for number of positive fields in 100 fields examined (*Cryptosporidium* spp. oocysts).

Source	Df	P>Chi-Square
Intercept	1	**0.0001**
Month	1	**0.0002**
Water source	1	**0.0001**
Ln(ThCU+1)	1	**0.0003**
Model Fitting	Df	P>Chi-Square
Model (-2 Log L)	3	**0.0001**
R^2	0.0694	
R^2 max-rescaled	0.1331	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

Table 4.18 Regression for total number of cycsts (*Giardia* spp.) in 50 fields.

Source	df	P>T
Intercept	1	0.0796
Month	1	0.3478
Water source	1	**0.0050**
Ln(ThCU+1)	1	0.2842
Model Fitting	**df**	**P>F**
Model (-2 Log L)	3	**0.0031**
R^2	0.8069	
R^2 adj.	0.7345	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

Table 4.19 Regression for total number of oocycsts (*Cryptosporidium* spp.) in 100 fields.

Source	df	P>T
Intercept	1	**0.0230**
Month	1	0.0789
Water source	1	**0.0013**
Ln(ThCU+1)	1	0.0636
Model Fitting	**df**	**P>F**
Model (-2 Log L)	3	**0.0014**
R^2	0.8423	
R^2 adj.	0.7832	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

4.4 Electrical-conductivity

4.4.1 Time series analysis

The study was conducted over a 5 month period to examine if there were seasonal variations in EC levels. From Figure B.2 in Appendix B, we can observe little variation in EC over the five sampling months. To determine the importance of time of year on the EC levels, a repeated measures analysis of variance was performed (general linear models procedure) (Table 4.20). Effects due to the time of year were significant. The EC levels varied significantly over the 5 sampling months. As well, there was a significant month x treatment interaction indicating that the month effect was different within different source types.

4.4.2 Comparison of water sources

The study compared the EC levels between the water source types, shallow well, canal, tank and tube well (Figure 4.10). The dotted line at 0.750 mS/cm is the Sri Lanka desirable limit for drinking water. The main water source types were compared within the repeated measures analysis, to identify trends and any significant differences. Significant effects due to the water source type were observed for the EC results as shown in Table 4.20. Tube wells tended to have higher levels of EC than all other sources as shown in Table 4.21 and Figure 4.10. Tube wells had significantly higher ($P=0.05$) EC levels than all other sources in 4 of the 5 months. The exception was for canal samples taken in October. The implication was that tube wells contained salty water, as people had said, and that this made the water unpalatable.

Table 4.20 Repeated measures analysis of variance, for electrical-conductivity (mS/cm).

Source	df	P>F	P>F Adj. [G-G]
Water source	3	**0.0157**	
Month	4	**0.0013**	**0.0131**
Month x Water source	12	**0.0002**	**0.0056**
Contrasts (compared with Month: December)	P>F Mean	P>F Treatment	
Month: August	**0.0186**	**0.0083**	
Month: September	0.1246	0.1127	
Month: October	0.0509	0.1301	
Month: November	0.4987	0.4487	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

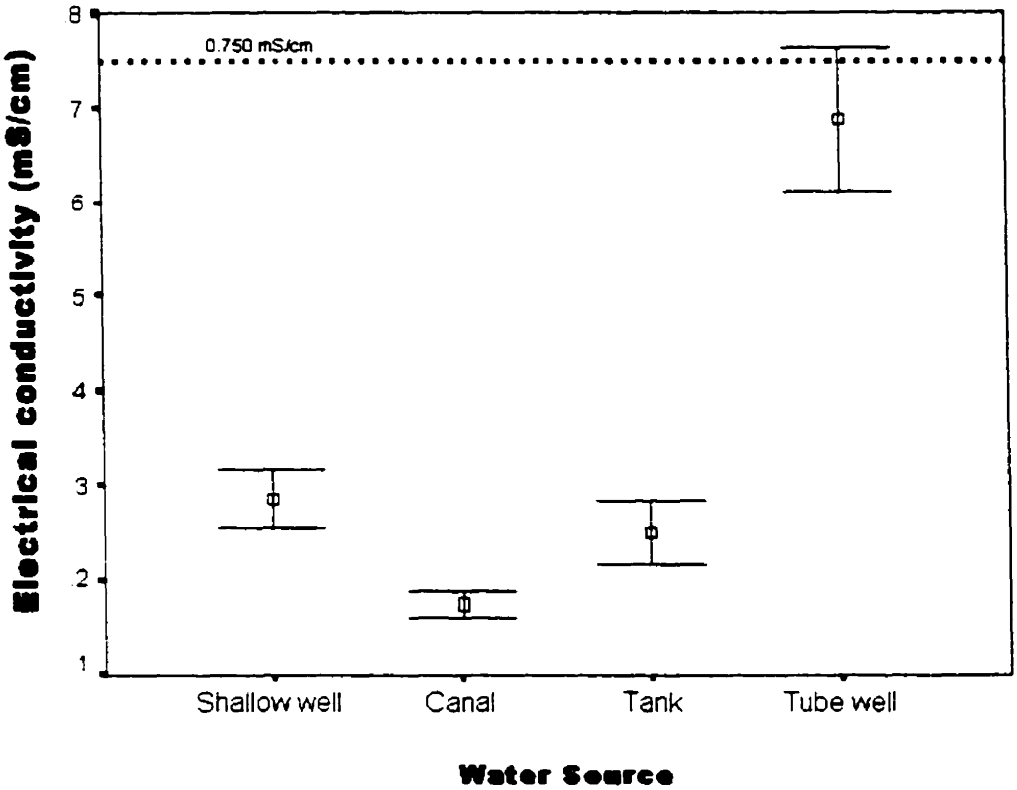
Table 4.21 Electrical-conductivity (mS/cm) and significant treatment effects

Treatment	August	September	October	November	December
		Means EC (mS/cm)			
Canal	0.1873 a	0.1013	0.3067 ac	0.1533 a	0.1280 a
Tank	0.4009 a	0.2089	0.2176 ab	0.2112 a	0.2137 a
Shallow well	0.2514 a	0.2847	0.3050 ab	0.2889 a	0.2960 a
Tube well	0.9143 b	0.5081	0.6999 c	0.5986 b	0.7058 b
		P>F			
Treatment	**0.0002**	0.2863	0.0545	**0.0305**	**0.0157**
CV%	43.87	73.06	61.08	50.95	56.09
Mean	0.3763	0.2983	0.3536	0.3184	0.3389

Significant at P<0.05

Means with the same letter, or no letter, are not significantly different (P<0.05, LSD test)

Figure 4.10 Effect of water source types on electrical-conductivity.



Error bars with mean indicated by square.

4.4.3 Shallow well data: comparison of canal type, head/tail position and protective wall

The data set pertaining only to shallow wells was selected and analyzed in a separate repeated measures model. The study compared ThCU/100ml between shallow wells situated along earthen canals versus concrete lined canals, shallow wells located at the head end versus the tail end of the canal and shallow wells with a protective wall versus those without. This model used three factors: canal type (earthen or concrete), head/tail position (head or tail of canal) and protective wall (well with protective wall or flat to the ground). There were no significant effects due to the individual treatments (Table 4.22). The effect due to time of year was not significant. However, there were two significant month x treatment interactions: with canal type and with protective wall. The month effect was attributed to a possible difference in rainfall incidence between the months causing different effects between wells with and without a protective wall and between wells along earthen or concrete canals.

Table 4.22 Shallow well samples.
Repeated measures analysis of variance, for electrical-conductivity (mS/cm).

Source	Df	P>F	P>F Adj. [G-G]
Canal Type	1	0.7360	
Head/Tail	1	0.6146	
Protective Wall	1	0.7824	
Month	4	0.5471	0.4668
Month x Canal Type	4	**0.0201**	0.0645
Month x Head/Tail	4	0.0808	0.1385
Month x Protective Wall	4	**0.0459**	0.1009
Contrasts (compared with Month: December)	P>F Mean		
Month: August	0.1968		
Month: September	0.0944		
Month: October	0.8737		
Month: November	0.6828		

Significant at P<0.05

Table 4.23 Shallow well samples.
Electrical-conductivity (mS/cm) and significant treatment effects.

Treatment	August	September	October	November	December
		Means EC mS/cm			
Canal, Earthen	0.2511	0.3524	0.3381	0.2876	0.3069
Canal Concrete	0.2517	0.2169	0.2719	0.2903	0.2851
Head	0.2468	0.3424	0.3571	0.2904	0.3545
Tail	0.2561	0.2269	0.2529	0.2875	0.2375
No Protective Wall	0.2356	0.3343	0.3288	0.2955	0.2955
Protective Wall	0.2830	0.1855	0.2574	0.2758	0.2970
		P>F			
Canal Type	0.9945	0.3933	0.6782	0.9827	0.8687
Head/Tail	0.9170	0.4639	0.5176	0.9820	0.3861
Protective Wall	0.6185	0.3779	0.6733	0.8844	0.9914
CV%	59.41	91.42	87.34	74.53	74.68
Mean	0.2514	0.2847	0.3050	0.2889	0.2960

Significant at P<0.05
Means with the same letter, or no letter, are not significantly different (P<0.05, LSD test)

4.4.4 Electrical-conductivity correlation with rainfall and other factors

The possibility of a correlation between the time elapsed since the last rainfall and the EC was investigated. Initially, the hypothesis was that more recent rainfall events would have caused runoff thereby diluting the concentration of salts the sampled sites. No link was found between rainfall (number of days since last rain) and EC in any of the individual water source analyses (Tables 4.25 to 4.28). The absence of a rainfall effect and the presence of a month interaction term in the repeated measures analysis may indicate that the month effect is not based on rainfall differences as was first proposed.

A stepwise regression was performed on the EC data to determine if other factors were affecting it. The factors that were significant in the EC model were water source and temperature. Rainfall was not a main effect in the model (Table 4.24).

Table 4.24 All samples. Model building EC (mS/cm): Stepwise regression.

Included Variables	df	P>T
Intercept		**0.005**
Water Source		**0.000**
Temperature		**0.010**
Excluded Variables		
pH		0.081
# days since last rainfall		0.152
Canal: full/dry		0.275
Month		0.401
Model Fitting	df	P>F
Model	1	**0.000**
R^2	0.233	
R^2 adj.	0.219	

Significant at P<0.05

Table 4.25 Shallow well samples. Model building EC (mS/cm): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.555
Model Fitting	**df**	**P>F**
Model	1	0.555
R^2	0.006	
R^2 adj.	-0.011	

Significant at P<0.05

Table 4.26 Canal samples. Model building EC (mS/cm): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.127
Model Fitting	**df**	**P>F**
Model	1	0.127
R^2	0.103	
R^2 adj.	0.062	

Significant at P<0.05

Table 4.27 Tank samples. Model building EC (mS/cm): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.521
Model Fitting	**df**	**P>F**
Model	1	0.521
R^2	0.035	
R^2 adj.	-0.045	

Significant at P<0.05

Table 4.28 Tube well samples. Model building EC (mS/cm): Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.051
Model Fitting	**df**	**P>F**
Model	1	0.051
R^2	0.261	
R^2 adj.	0.205	

Significant at P<0.05

Table 4.29 Canal samples. Model building EC (mS/cm): Regression (canal: full/dry).

Included Variables	df	P>T
Intercept		**0.000**
Canal: full/dry		0.538
Model Fitting	**df**	**P>F**
Model	1	0.538
R^2	0.017	
R^2 adj.	-0.027	

Significant at P<0.05

For the canal samples it was particularly interesting to see if there were differences between the times when the canal was flowing full (growing season), and when the canal was dry (inter season). Canals were full in August and September, and essentially dry in October, November and December. The effect of canal flow (full/dry) on the EC levels of only the canal samples was analyzed in a separate model. No link was established between the EC levels of canal samples and the water level in the canal (Table 4.29).

4.5 pH

4.5.1 Time series analysis

The study was conducted over a 5 month period to examine if there were seasonal variations in pH levels. From Appendix B Figure B.3 we can observe little variation in pH over the five sampling months. To determine the importance of time of year on the pH, a repeated measures analysis of variance was performed (general linear models procedure) (Table 4.30). Effects due to the time of year were not significant (Table 4.30). However, there was a significant month x treatment interaction indicating that treatment effects may have been different within some months.

4.5.2 Comparison of water sources

The study compared the pH levels between the water source types, shallow well, canal, tank and tube well (Figure 4.11). The main water source types were compared within the repeated measures analysis to identify trends and any significant differences. Significant effects due to the water source type were observed for the pH results (Tables 4.30 and 4.31). Canal and tank samples tended to have higher values of pH than shallow wells and tube wells (Figure 4.11). Canal samples had significantly higher (P=0.05) pH levels than shallow wells in 3 of the 5 months, and higher pH levels than tube wells also in 3 of the 5 months. Tank samples had significantly higher pH levels than shallow wells in 3 of the 5 months and higher pH levels than tube wells in 4 of the 5 months. These high values of pH in the surface waters may be attributable to soap residues from extensive bathing and clothes washing that occurred in these bodies of water.

Table 4.30 Repeated measures analysis of variance, for pH.

Source	df	P>F	P>F Adj. [G-G]
Water source	3	**0.0001**	
Month	4	0.0529	0.0668
Month x Water source	12	**0.0166**	**0.0261**
Contrasts (compared with Month: December)	P>F Mean	P>F Treatment	
Month: August	0.5730	0.5135	
Month: September	**0.0057**	**0.0051**	
Month: October	0.2286	0.8500	
Month: November	**0.0227**	0.0784	

Significant at P<0.05

Water source represents 4 categories: shallow well, canal, tank and tube well.

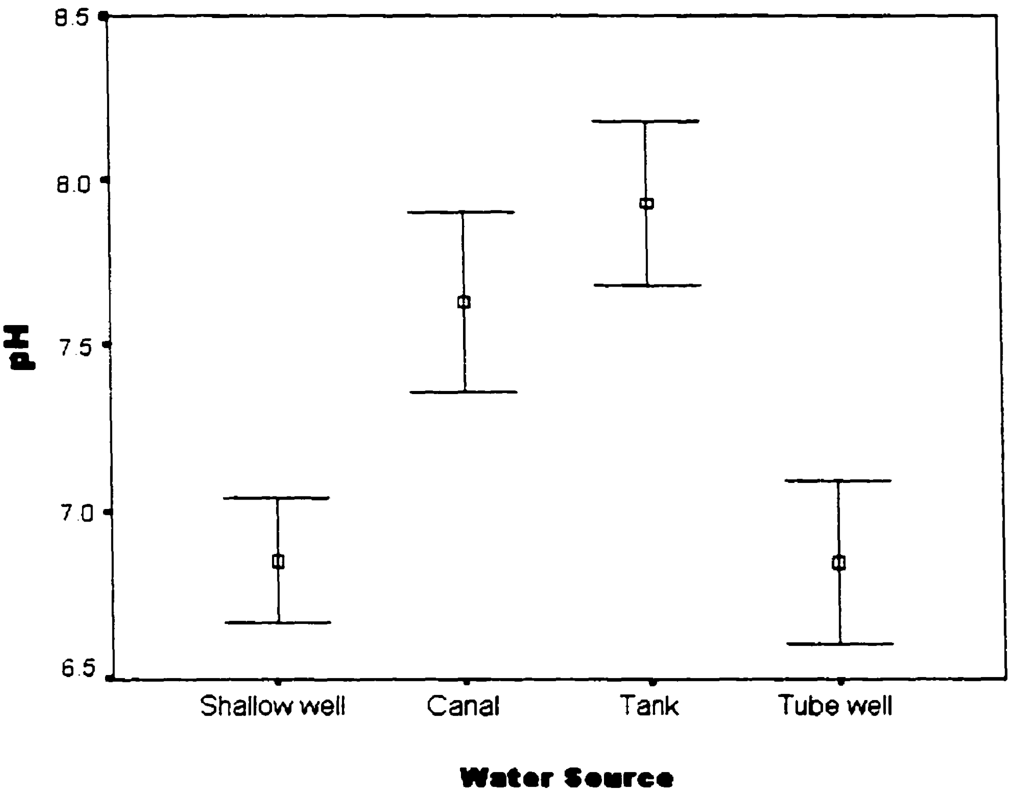
Table 4.31 pH and significant treatment effects.

Treatment	August	September	October	November	December
			Means pH		
Canal	8.573 a	8.020 a	8.257 a	7.467 ab	8.233 a
Tank	7.522 ab	8.152 a	7.627 a	8.294 a	8.062 a
Shallow well	7.038 b	6.035 b	7.056 b	6.642 b	7.518 ab
Tube well	7.278 ab	6.246 b	6.970 b	6.579 b	7.179 b
			P>F		
Treatment	0.1413	**0.0002**	**0.0129**	**0.0001**	0.0546
CV%	8.695	9.100	5.137	5.374	5.483
Mean	7.233	6.507	7.195	6.937	7.588

Significant at P<0.05

Means with the same letter, or no letter, are not significantly different (P<0.05, LSD test)

Figure 4.11 Effect of water source types on pH.



Error bars with mean indicated by square.

4.5.3 pH correlation with rainfall and other factors

The possibility of a correlation between the time elapsed since the last rainfall and the pH was investigated. There was no link between rainfall (number of days since last rain) and pH in any of the individual water source analyses (Tables 4.33 to 4.36).

A stepwise regression was performed on the pH data to determine if other factors were affecting it. The main effect in the pH model was the temperature (Table 4.32). Rainfall was not a main effect in the model.

For the canal samples it was particularly interesting to see if there were differences between the times when the canal was flowing full (growing season) and when the canal was dry (inter season). Canals were full in August and September, and essentially dry in October, November and December. The effect of canal flow (full/dry) on the pH levels of the canal samples only was analyzed in a separate model and no link was established (Table 4.37).

Table 4.32 All samples. Model building pH: Stepwise regression.

Included Variables	Df	P>T
Intercept		**0.040**
Temperature		**0.016**
Excluded Variables		
EC (mS/cm)		0.320
Water Source		0.273
# days since last rainfall		0.564
Canal: full/dry		0.339
Month		0.713
Model Fitting	Df	P>F
Model	1	**0.016**
R^2	0.051	
R^2 adj.	0.043	

Significant at P<0.05

Table 4.33 Shallow well samples. Model building pH: Regression (# of days since last rainfall).

Included Variables	Df	P>T
Intercept		**0.000**
# days since last rainfall		0.809
Model Fitting	Df	P>F
Model	1	0.809
R^2	0.002	
R^2 adj.	-0.025	

Significant at P<0.05

Table 4.34 Canal samples. Model building pH: Regression (# of days since last rainfall).

Included Variables	Df	P>T
Intercept		**0.000**
# days since last rainfall		0.083
Model Fitting	Df	P>F
Model	1	0.083
R^2	0.130	
R^2 adj.	0.091	

Significant at P<0.05

Table 4.35 Tank samples. Model building pH: Regression (# of days since last rainfall).

Included Variables	Df	P>T
Intercept		**0.000**
# days since last rainfall		0.256
Model Fitting	**Df**	**P>F**
Model	1	0.256
R^2	0.106	
R^2 adj.	0.032	

Significant at P<0.05

Table 4.36 Tube well samples. Model building pH: Regression (# of days since last rainfall).

Included Variables	Df	P>T
Intercept		**0.000**
# days since last rainfall		0.239
Model Fitting	**Df**	**P>F**
Model	1	0.239
R^2	0.105	
R^2 adj.	0.036	

Significant at P<0.05

Table 4.37 Canal samples. Model building pH: Regression (canal: full/dry).

Included Variables	Df	P>T
Intercept		**0.000**
Canal: full/dry		0.393
Model Fitting	**Df**	**P>F**
Model	1	0.393
R^2	0.033	
R^2 adj.	-0.011	

Significant at P<0.05

4.6 Temperature

4.6.1 Time series analysis

From Appendix B Figure B.4 we can observe little variation in temperature over the 5 sampling months. To determine the importance of time of year on the temperature of the water samples, a repeated measures analysis of variance was performed (general linear models procedure). Effects due to the time of year were significant (Table 4.38). As well, there was a significant month x treatment interaction indicating that treatment effects on temperature may have been different within some months.

4.6.2 Comparison of water sources

The effect of water source type on temperature levels was explored (Figure 4.12). The main water source types were compared within the repeated measures analysis to identify trends and any significant differences. Significant effects due to the water source type were observed for the temperature results (Tables 4.38 and 4.39). Shallow well samples tended to have lower temperature than all other sources (Figure 4.12). Shallow well samples had significantly lower (P=0.05) temperatures than canal and tank samples in 4 of the 5 months, and lower temperatures than tube well samples in 3 of the 5 months. These low water temperatures may increase people's preference to withdraw water from this source for drinking.

Table 4.38 Repeated measures analysis of variance, for temperature (°C).

Source	Df	P>F	P>F Adj. [G-G]
Water source	3	**0.0006**	
Month	4	**0.0001**	**0.0001**
Month x Water source	12	**0.0008**	**0.0068**
Contrasts (compared with Month: December)	P>F Mean	P>F Treatment	
Month: August	**0.0061**	**0.0483**	
Month: September	0.0642	0.1342	
Month: October	**0.0340**	0.3259	
Month: November	**0.0001**	**0.0062**	

Significant at P<0.05

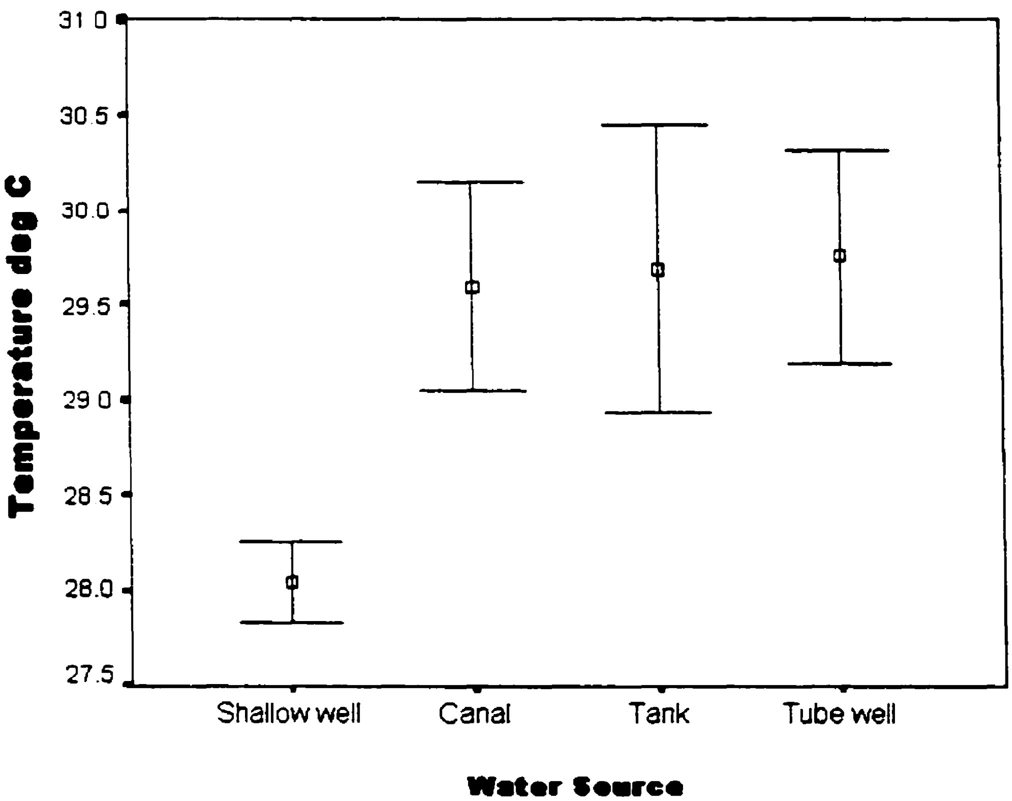
Water source represents 4 categories: shallow well, canal, tank and tube well.

Table 4.39 Temperature (°C) and significant treatment effects.

Treatment	August	September	October	November	December
Means Temp (°C)					
Canal	28.10	29.30 a	31.30 a	31.20 a	29.90 a
Tube well	28.80	30.57 ab	29.70 a	30.50 a	29.23 a
Tank	28.00	30.43 a	30.20 a	30.30 a	29.70 a
Shallow well	27.91	28.37 b	27.95 b	28.09 b	27.93 b
P>F					
Treatment	0.7166	**0.0007**	**0.0010**	**0.0001**	**0.0016**
CV%	4.226	2.663	3.165	2.147	2.397
Mean	28.07	29.09	28.76	28.98	28.51

Significant at $P<0.05$
Means with the same letter, or no letter, are not significantly different ($P<0.05$, LSD test)

Figure 4.12 Effect of water source types on temperature.



Error bars with mean indicated by square.

4.6.3 Temperature correlation with rainfall and other factors

The dependence of temperature on the time elapsed since the last rain was investigated. A regression analysis was performed however, there was no link between rainfall (number of days since last rain) and temperature in any of the individual water source analyses (Tables 4.41 to 4.44).

Effects due to other factors on the temperature data were explored by the use of a stepwise regression to determine significant effects. The significant factors in the temperature model were the water source and the EC (mS/cm) (Table 4.40). Rainfall was not a main effect in the model.

The effect of water level in the canal on temperature of water samples was investigated. Canals were flowing full in August and September (the growing season) and were essentially dry in October, November and December (the intercropping season). The effect of canal flow (full/dry) on the temperature of only the canal samples was analyzed in a separate model and it was not found to be significant (Table 4.45).

Table 4.40 All samples. Model building temperature: Stepwise regression.

Included Variables	df	P>T
Intercept		**0.000**
EC (mS/cm)		**0.000**
Water Source		**0.010**
Excluded Variables		
# days since last rainfall		0.863
PH		0.322
Canal: full/dry		0.429
Month		0.248
Model Fitting	**df**	**P>F**
Model	2	**0.000**
R^2	0.341	
R^2 adj.	0.329	

Significant at P<0.05

Table 4.41 Shallow well samples. Model building temperature: Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.530
Model Fitting	**df**	**P>F**
Model	1	0.530
R^2	0.010	
R^2 adj.	-0.016	

Significant at P<0.05

Table 4.42 Canal samples. Model building temperature: Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.632
Model Fitting	**df**	**P>F**
Model	1	0.632
R^2	0.011	
R^2 adj.	-0.034	

Significant at P<0.05

Table 4.43 Tank samples. Model building temperature: Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.256
Model Fitting	**df**	**P>F**
Model	1	0.256
R^2	0.106	
R^2 adj.	0.032	

Significant at P<0.05

Table 4.44 Tube well samples. Model building temperature: Regression (# of days since last rainfall).

Included Variables	df	P>T
Intercept		**0.000**
# days since last rainfall		0.239
Model Fitting	**df**	**P>F**
Model	1	0.239
R^2	0.105	
R^2 adj.	0.036	

Significant at P<0.05

Table 4.45 Canal samples. Model building temperature: Regression (canal: full/dry).

Included Variables	df	P>T
Intercept		**0.000**
Canal: full/dry		**0.027**
Model Fitting	**df**	**P>F**
Model	1	**0.027**
R^2	0.204	
R^2 adj.	0.168	

Significant at P<0.05

4.7 Summary

The four potential water sources in the regions of the MD17 and BBD5 canals were shallow wells, canals, tank (irrigation reservoir) and tube wells. Of these sources, shallow wells were preferred for most domestic water needs, except that water from the canals and the tank were preferred for washing clothes and bathing. The population of the two canal regions preferred the shallow wells for consumptive uses such as drinking and cooking since the water was perceived as being of better quality than surface waters and tasted better than tube well water. Shallow wells were easily accessible as almost every household in the canal region had a shallow well beside their house.

Over the 5 month sampling period, there was little variation observed in water quality from month to month. The ThCU, parasite levels and pH remained constant over the sampling period. Some variation occurred in the EC levels and temperature. The maximum difference in EC levels was 0.08 mS/cm between the months of August and September. This rise in EC caused more tube well samples to fall above the Sri Lanka desired drinking water standard of 0.75 mS/cm. The other water sources also were affected by the rise in EC. However, the increase did not cause these sources to exceed the Sri Lanka desired drinking water standard. The maximum difference in temperature was 1°C between the months of August and September. A difference of 1°C does not cause water to become unpalatable or a threat to human health. For this reason, the observed difference in temperature over the time period is not interesting to the water quality study especially since temperature was not found to be a significant factor in the determination of ThCU levels. Overall, there was little significant seasonal variation in the measured parameters, despite very seasonal weather patterns in the region. In this respect, during the period from August to December there was no crucial time of year when interventions to improve water quality were more necessary.

Differences between the water sources were seen for all measured parameters, ThCUs, parasites, EC, pH and temperature. For the ThCUs and parasites, the canals had high levels of contamination, and the tube wells had low levels of contamination (Figure 4.30). This would indicate that the tube wells would be the best option as a drinking water source. However, the EC levels of the tube wells were significantly higher than the other water sources and in most cases, above the Sri Lanka drinking water desirable limit of 0.750mS/cm (Figure 4.10). With canals and tube wells sitting at the extremes, for either faecal contamination or salt levels, the best options for drinking water were the shallow wells or the tank. The median for ThCUs in shallow wells and the tank were similar (Figure 4.3). However, the tank tended to have more samples lying above the 1000 ThCU/100ml level, which represents the Sri Lanka limit for bathing and the WHO limit for water to be used as a source for a conventional water supply system. The tank also tended to have higher parasite incidence (Figures 4.6 to 4.9). Therefore, on the basis of microbiological water quality, shallow wells may be recommended before the tank as a source for drinking water.

The pH was higher in the surface waters (canal and tank) than in the shallow wells or tube wells, reflecting the use of these sources for washing and bathing (Figure 4.11). All sources had levels that fell within the Sri Lankan and WHO standards for drinking water (6.5-9.5 and 6.5-9.5). Water from shallow wells was cooler than other sources (Figure 4.12) and this may have further encouraged people to use shallow wells for drinking purposes.

Shallow wells with protective walls tended to have lower levels of ThCUs than wells without a protective wall. Canal type also had some effect on the ThCU levels in shallow wells. Shallow wells along earthen canals had higher levels of contamination (Figure 4.4). Further study with more samples is needed to confirm these findings. Position along the canal (head or tail end) had no effect on ThCU level in shallow wells. Other factors such as amount of sunlight (sun/shade), topography (well in depression or on a hill), bathing activity, distance to canal, distance to latrine and distance to household refuse pile also had no effect on shallow well ThCU levels. However, a study concentrating on these parameters may provide more results. During this research, these parameters had been examined only briefly to confirm that they were not interfering with the main effects. The implication of these findings is that the construction of protective walls around shallow wells could significantly improve the quality of water available for drinking in the MD17 and BBD5 regions.

Position along the canal (head or tail end) had no effect on ThCU levels of canal samples. Canal type (earthen or concrete lined) was a main effect in the model for ThCU within the canal samples. An examination of the box plots of the data (Figure 4.5), revealed that samples from concrete lined canals had a higher median and therefore tended to be more contaminated than the earthen canal samples. This result may be explained by the fact that the concrete (BBD5) canal was downstream from the village of Suriawewa therby permitting contamination to enter from the high concentration of people in the village. The shallow wells, however, had lower ThCUs in the concrete canal area (Figure 4.4), the opposite of the trend in the canal water. This raised the question of the source of water in the shallow aquifer that feeds the shallow wells. Certainly the shallow aquifer is different from the deep aquifer feeding the tube wells. This is demonstrated because of the remarkable difference seen in EC levels. The shallow wells seem to be dependent on the canal to recharge since the time when the shallow wells fell dry was during the period of canal closure. However, the finding of opposite effect of canal type (earthen or concrete) on ThCUs in shallow wells and canals puts into question the link between canal water and the recharging of shallow wells. Runoff or other inputs to the well from above may be the source of contamination found in the wells. Although the main source of water recharge for the wells may be the canals, the water quality may be more dependent on inflow into the well opening.

Rainfall had no effect on any of the parameters. This contradicted the original hypothesis of the study. It had been hypothesized that recent rainfall would have caused runoff, potentially carrying contaminants, into the wells, canals, or tank. However, from the ThCU results there was no evidence of a link between rainfall (runoff) and increased ThCUs. The canal water level (full or dry) also had no effect on any of the parameters. Although it did not directly affect water quality, the closure of canals did impose difficulties for the local people. Water was not available for washing or bathing in the canals, which meant walking to the tank for these activities or drawing water from their wells. However, the closing of the canals also affected the shallow wells, with numerous wells going dry during this time period (see section 4.1). This forced people to walk to other wells, to dig temporary wells (holes) in the canal bed or to transport water from the tank or drainage ditches. This greatly increased the time of water collection. and may have decreased the quality of water used for domestic purposes.

4.8 Discussion

Perspective may be gained by making general comparisons between the gathered data and other studies. Analysis of raw water sources for faecal contamination is rare since most raw water sources are automatically assumed to be contaminated. There has been one published study in Sri Lanka examining water quality in raw water sources (Mertens et al. 1990a,b). This research, in Kurunegala, saw similar trends in water quality as were observed in the present study. Faecal contamination (in terms of the number of samples registering positive) was greatest for unprotected sources (shallow wells without protective walls) followed by protected wells and was lowest in tube wells. Significant reductions in the geometric mean number of thermotolerant coliforms was observed in shallow wells having a protective wall versus those without. These findings support results from this present study and indicate that the construction of protective walls around shallow wells could significantly reduce the risk of diarrhoeal disease in the community. Correlations linking times of high rainfall and increased faecal contamination were shown in the Mertens et al. 1990ab study, but were not found in the present analysis. This disagreement between the two studies provides an opportunity for further research into the rainfall faecal contamination interactions. The work by Mertens et al. 1990b demonstrated that the contamination of tube well water was occurring at the mouth of the hand pump and that deep ground water was essentially free of faecal contamination. This may be also true in the Uda Walawe region however, due to the high salt content of the tube well water, these are not recommended by the present study as a source of drinking water regardless of their adequate bacteriological quality. The Mertens et al. (1990a,b) studies have shown the link between water source and childhood diarrhoeal morbidity indicating the importance of water borne transmission of diarrhoea in one region of Sri Lanka.

Studies in Pakistan by IWMI have also looked at raw water sources, faecal contamination and diarrhoea (Ensink et al. 2001; van der Hoek et al. 2001). Similar to this present study, water sources with lowest levels of faecal contamination were the seepage water sources; higher levels of contamination were found in direct canal water. This emphasizes the importance of the soil acting as a natural filter for canal water, purifying the water as it slowly moves from the canal thought the soil profile and into shallow wells located along the canals. As the filter path increases the soil should trap more organisms, improving the water quality with distance from canal, however, there was no relationship found between faecal contamination levels and a shallow well's distance from canal (Table 4.15). The filtration ability of the soil should be investigated to determine the importance on it's purifying effect on the water.

Ultimately, determining the source of the faecal contamination could lead to a reduction, or even elimination of this pollution. One of the faecal sources is very likely to be water buffalo, as they are the most numerous domestic animals in the area, and are often observed bathing in the canals. Further study to differentiate between human and animal faecal contamination would indicate the extent to which water buffalo are contributing to the contamination. Methods to reduce water buffalo faeces from entering the system could then be developed. Most human sewage, in the region, is disposed in single family pit latrines. A brief survey indicated that these latrines are shallow. Latrine users were questioned on the depth of their latrine and the average was found to be 3.5 m deep. The water table is high during the growing season when the canals and paddy fields are full of water, this high water table may rise into the latrines, contaminating the shallow ground water. Most latrines are located over 30 m away from the canals however, the question remains, is this distance far enough to see a reduction of the water table below 3.5 m. People in the region are aware of the risks of latrines contaminating water and consequently have not built latrines between the canal and their well. However, the flow path is not necessarily direct between canal and well and therefore a better map of flow paths could enable people to make better informed choices for relative latrine/well locations.

5. CONCLUSIONS

5.1 Summary

Water scarcity that limits the availability of domestic water supply is a major problem in the Uda Walawe region of Southern Sri Lanka. This study was conducted to determine to what extent the management of the irrigation system could affect the quality of water available for domestic purposes. Four sources were identified as potentials for the domestic water supply. These sources were: canals, shallow wells, tanks (irrigation reservoirs) and tube wells. Their water quality and availability were monitored and compared across two canal types (earthen and concrete) and two water-issuing periods (full – growing season and dry – intercropping season). An analysis for effect of climatic variation was also performed.

5.2 General conclusions

The following conclusions can be drawn from this study:

1. Water from canals had higher thermotolerant coliform units/100ml than from other sources. Water from tube wells had lower ThCU/100ml than from other sources.

2. Tube wells had higher values of EC than all other sources. Many of the tube well samples had levels of EC above the Sri Lankan desirable standard for drinking water (0.75 mS/cm).

3. Shallow wells had the best water quality of all sources in terms of the parameters studied: ThCU/100ml, *Giardia* spp., *Cryptosporidium* spp., EC, pH, and temperature. Although shallow wells had higher levels of ThCU/100ml than tube wells, the shallow wells did not suffer from excessive EC levels.

4. Shallow wells were the preferred water source of the community. They were easily accessible to all people in the canal areas.

5. Shallow wells with a protective wall had lower levels of ThCU/100ml. Water samples from wells with protective walls had ThCU/100ml below the Sri Lankan bathing water standard and the WHO standard for raw water to supply a conventional water treatment plant (1000ThCU/100ml).

6. Water management, in terms of closing of canals for the intercropping season, eliminated the canals as an ample and accessible water source. This caused greater hardship in performing washing of clothes and bathing. Canal closure also led to a decrease in water levels in shallow wells, causing many to go dry. This caused greater hardship in water collection for drinking by reducing the accessibility of water resources. As an alternative to shallow wells some people drew drinking water from other sources having poorer quality of water.

7. The concrete lining of canals caused more shallow wells to go dry during the intercropping season when the canals were closed.

8. Rainfall did not affect the ThCU/100ml, electrical conductivity, pH or temperature levels of any of the sources studied.

9. Variations with time, over the course of the study was not observed for ThCU/100ml or pH.

6. DIRECTIONS FOR FURTHER RESEARCH

i. To confirm the importance of the bacterial contamination found in this research, a study should be undertaken to differentiate between the non-faecal portion of the thermotolerant coliforms and those originating from faeces (*Escherichia* coli). The non-faecal thermotolerant coliforms are the *Klebsiella*, *Enterobacter* and *Citrobacter* and they originate from industrial effluents, decaying plant materials or soil.

ii. To confirm the importance of the bacterial contamination found in this research, a study should be undertaken to differentiate between contaminations due to animal faeces as opposed to that of human faeces. This investigation would be important since pathogens originating in human faces are more likely to be infectious to humans, than pathogens originating in animal faeces. This study could be done by the identification of faecal streptococci, which is generally indicative of human faecal contamination.

iii. An investigation of zoonosis should be undertaken. This study would identify the role of animals in disease transmission (transmission of pathogens infectious to humans). The domestic water buffalo was the most commonly observed animal in the region and would therefore be of particular interest to the researcher.

iv. In an attempt to reduce the faecal contamination of the Uda Walawe surface waters, a study identifying the pathways of faecal contamination could be very useful. For example, the contributions of municipal point sources, rural latrines, direct defecation in canals, runoff etc.

v. Research will soon be needed for low cost appropriate technology for sewage treatment in small towns. The populations are increasing in the small municipalities of the Uda Walawe region and the space required for concrete septic tanks is quickly running out.

vi. Rainwater harvesting is a possibility in this region and this potential water source must be explored. Rain provides water without the faecal contamination found in surface waters and without the salinity, fluoride, or iron problems found in the deep ground water of the Uda Walawe region. Some trials have already begun by a local NGO and a rainwater harvesting movement is active in other parts of the country. At present some local people practice various low technology forms of rainwater harvesting.

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Appendix A

Scatter plots relating ln(ThCU/100ml +1)
to number of days since last rainfall

Figure A.1 Scatter plot of all data ln(ThCU/100ml + 1) VS. number of days since last rainfall

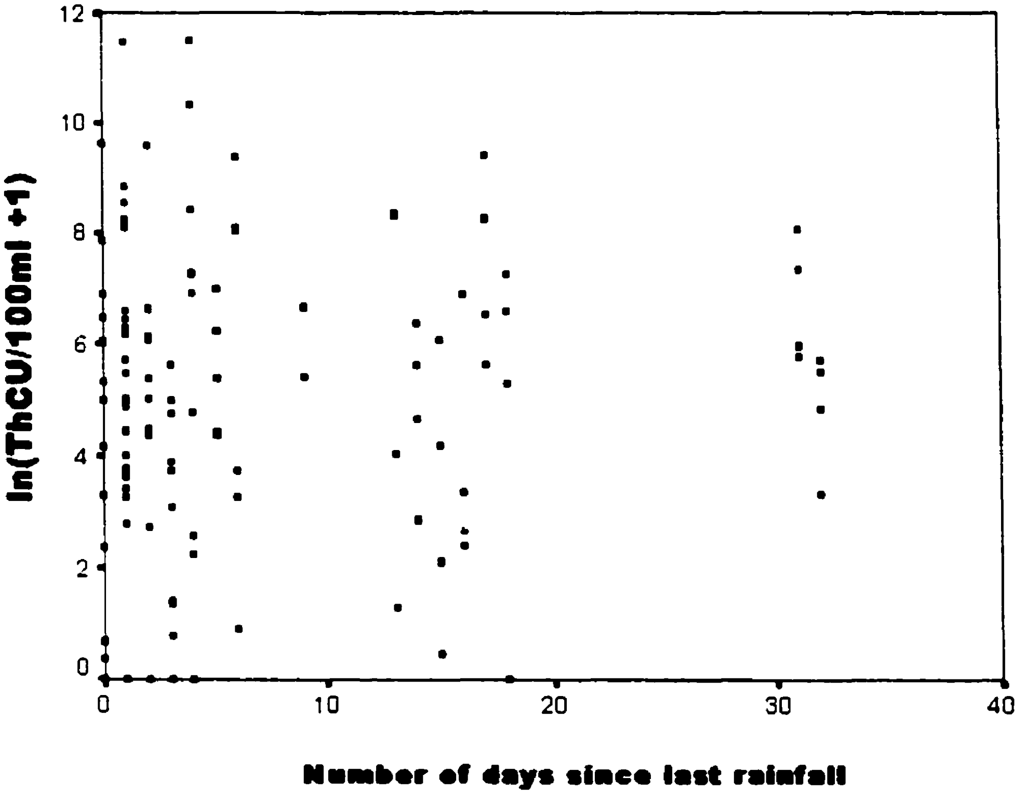


Figure A.2 Scatter plot of canal data ln(ThCU/100ml + 1) VS. number of days since last rainfall

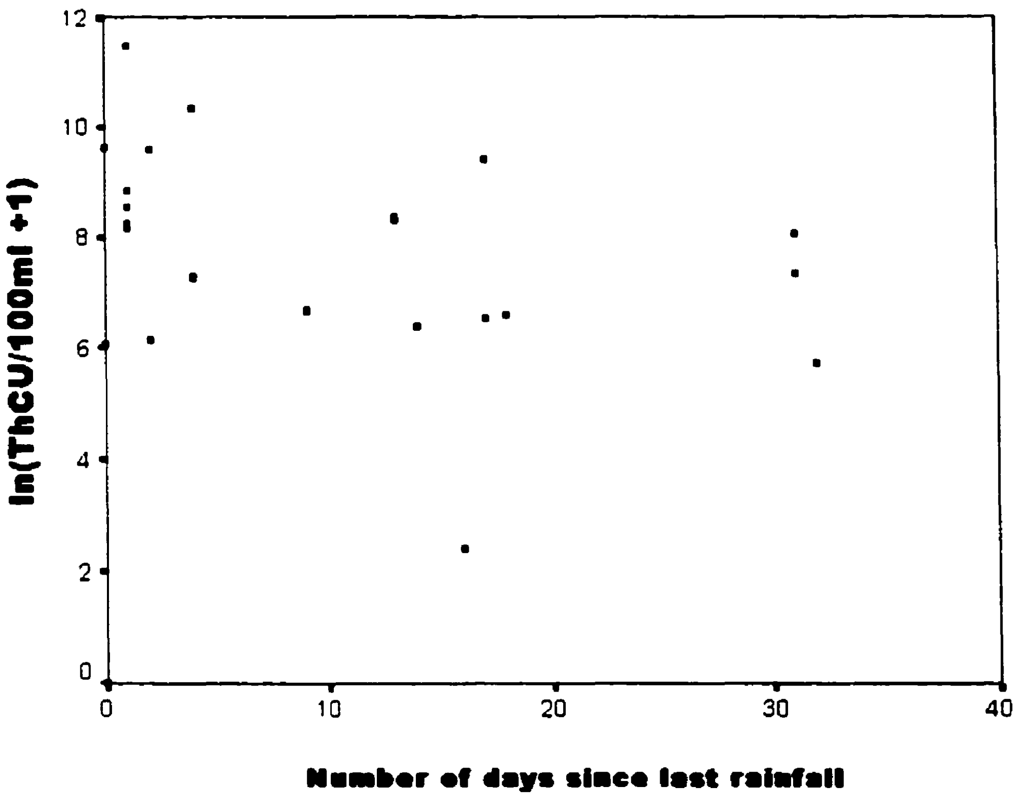


Figure A.3 Scatter plot of shallow well data ln(ThCU/100ml + 1) VS. number of days since last rainfall

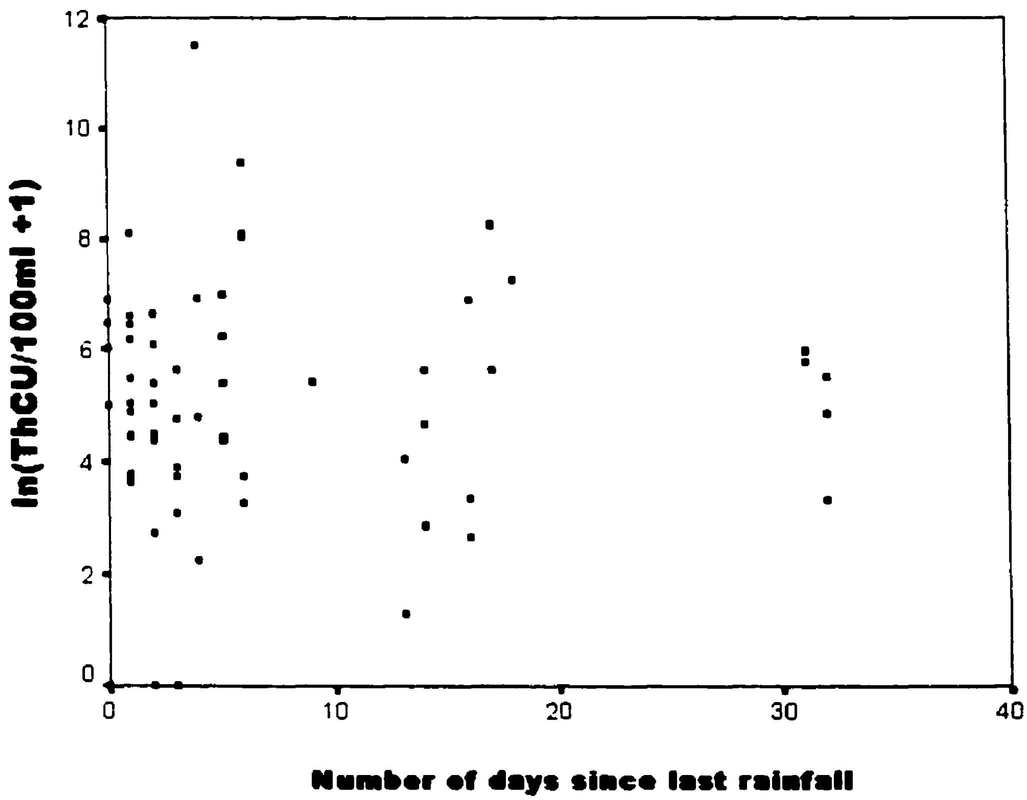


Figure A.4 Scatter plot of tank data ln(ThCU/100ml + 1) VS. number of days since last rainfall

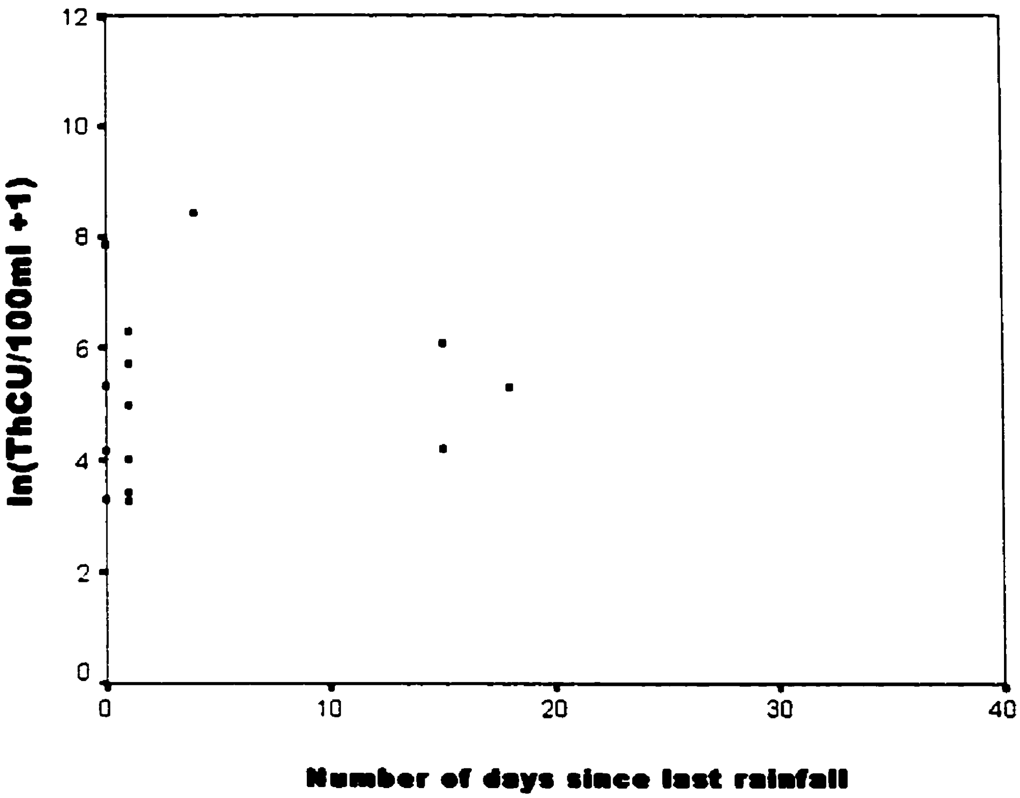
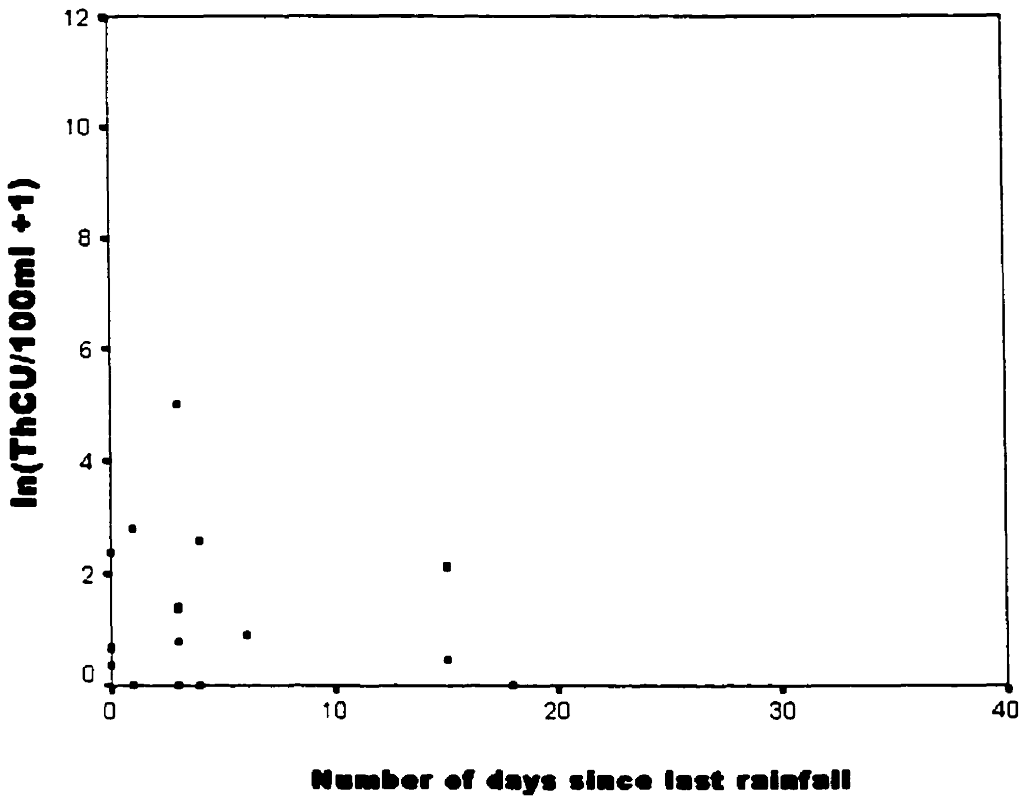


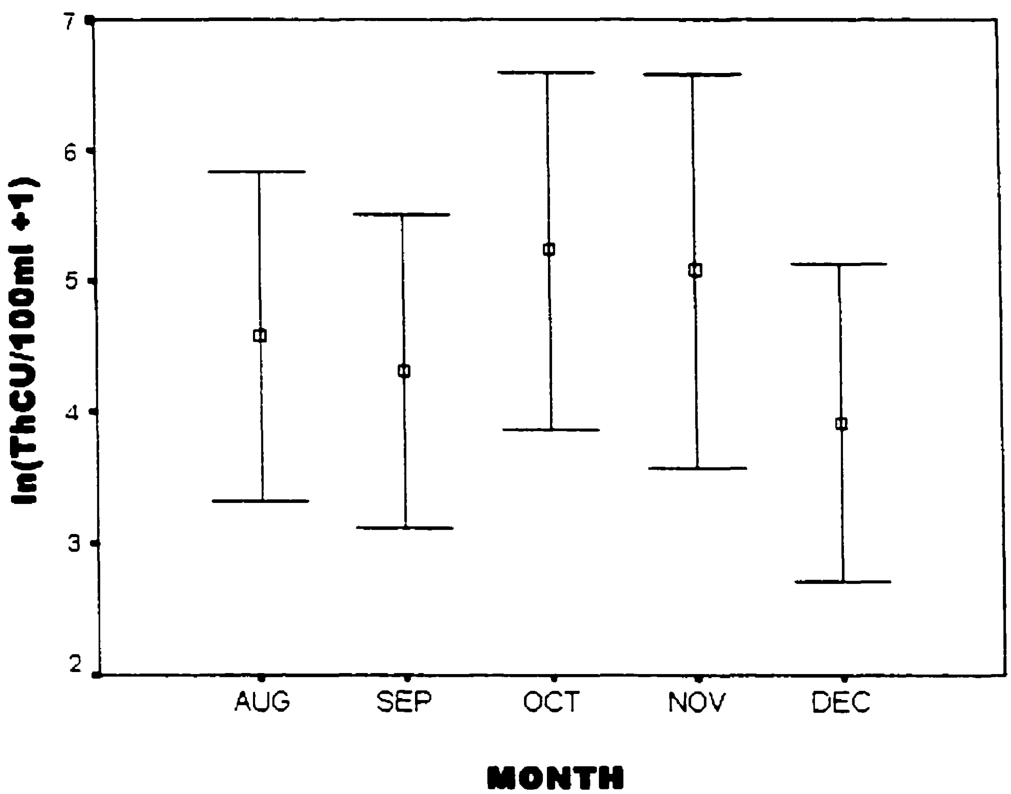
Figure A.5 Scatter plot of tube well data ln(ThCU/100ml + 1) VS. number of days since last rainfall



Appendix B

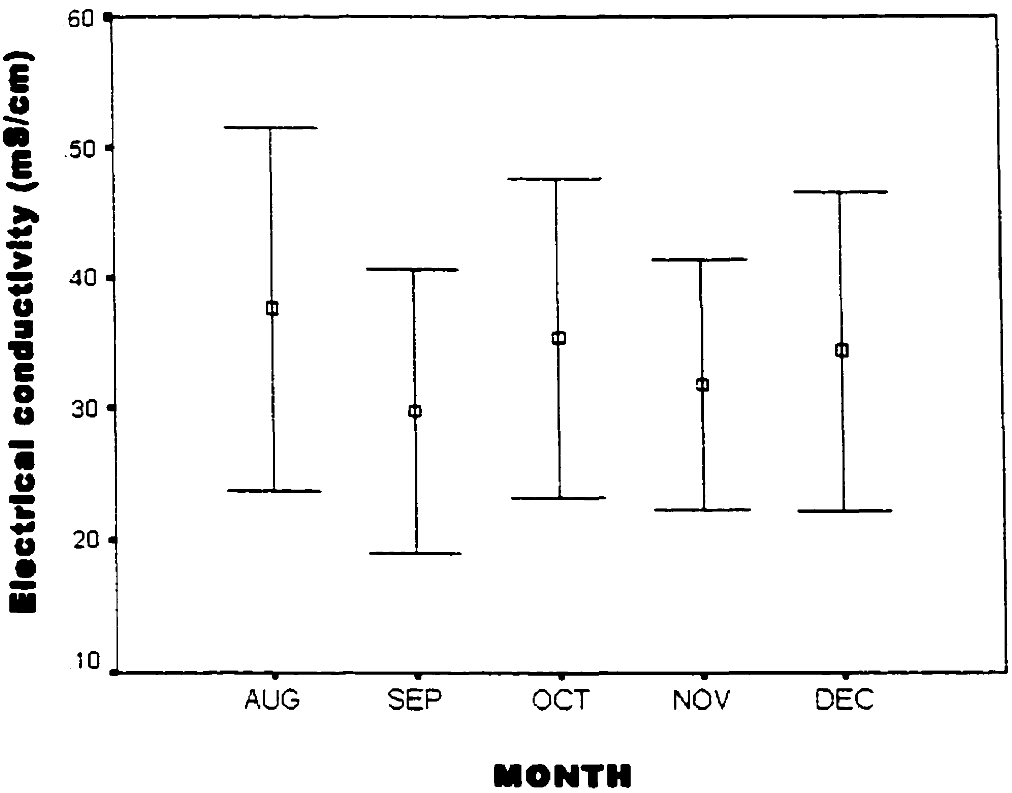
Graphs of monthly comparisons for ln(ThCU/100ml +1), EC, pH, and temperature data.

Figure B.1 Comparison of ln(ThCU/100ml + 1) by month



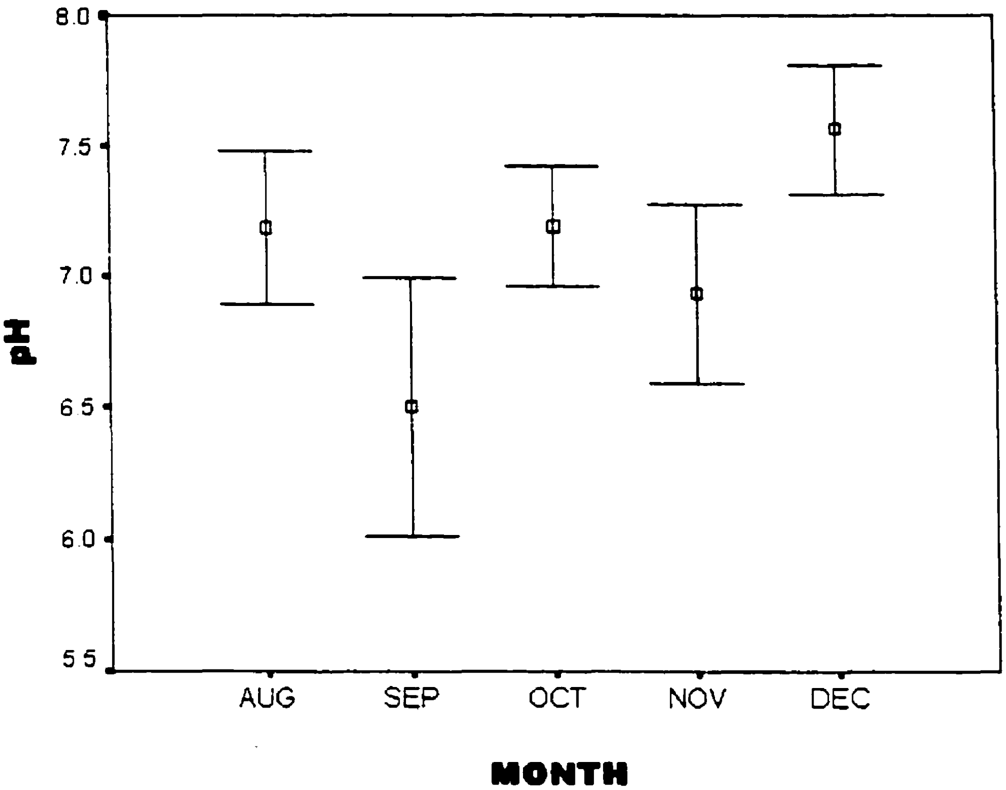
Error bars with mean indicated by square.

Figure B.2 Comparison of EC (mS/cm) by month.



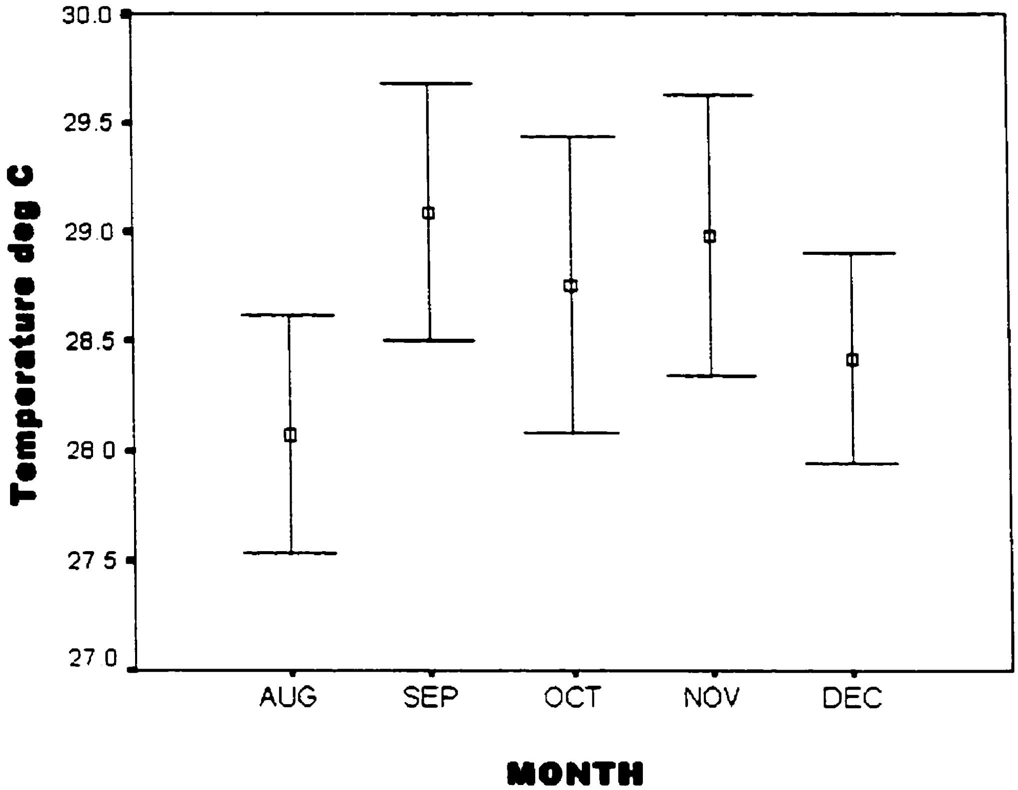
Error bars with mean indicated by square.

Figure B.3 Comparison of pH by month.



Error bars with mean indicated by square.

Figure B.4 Comparison of temperature (°C) by month.



Error bars with mean indicated by square.