Quality assessment and interrelations of water supply and sanitation: a case study of Yogyakarta City, Indonesia

Belinda Salendu

February, 2010

Quality assessment and interrelations of water supply and sanitation: a case study of Yogyakarta City, Indonesia

by

Belinda Salendu

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation, Specialisation: Urban Planning and Management

Thesis Assessment Board

Chairman	: Prof. Dr. Ir. M. F. A. M. van Maarseveen
External Examiner	: Dr. Ir. D.C.M. Augustijn
First Supervisor	: Ir. M.J.G. Brussel
Second Supervisor	: Dr. Ir. M.H.P. Zuidgeest

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

Abstract

Provision of quality urban infrastructure system has become a major concern in many developed countries. In the contrary to this, the quality aspect of providing water has been downplayed by the much focus put on access provision to these infrastructures. This is mostly the case of water supply provision and other basic infrastructures. The low quality of urban infrastructure such as water supply and sanitation may be detrimental to the environment leading unhealthy living conditions. The performance of one infrastructure may affect the other. Thus to say some of these infrastructures such as water supply and sanitation are interrelated. Understanding this integration and interrelation may therefore provide a better understanding on the importance of providing quality infrastructures.

This research is aimed at understanding interrelation between water supply and sanitation by assessing the performance of sanitation infrastructures on the quality of water supply. The research was carried out in City of Yogyakarta, Indonesia particularly in the area near the river. The assessment of water quality was based on the people's perceptions about their drinking water with regards to the odor, taste and colour qualities both before and after flooding. The continuity of water supply was also assessed. A water supply index was then made from these indicators. Water quality tests (total coliforms and total dissolved solids) were also performed to assess the quality of the water quantitatively. The effect of the sanitation infrastructure on the water quality was then investigated by looking at the distance of water source to septic tank, river and the well depth in cases of groundwater use.

Three main water sources (tap water from providers (PDAM), private well and communal well) were identified even though a section of the people bought sachet water for drinking purposes. Based on the water supply index from the users' perception, private wells were seen to be the best (index of 0.999) followed by communal wells (index of 0.878) then tap water from providers (index of 0.732). It was therefore no surprising most of the people used groundwater sources. A water quality test however showed higher pollutions in the groundwater as compared to tap water from providers. The perception of the user where they were reporting good taste, odor and colour qualities may therefore be misleading. Higher concentrations of total coliforms were observed in high dense areas and along the river as compared to lower dense areas. It was found that the distance to the river does not necessarily affect the occurrence of total coliforms in wells. These occurrences where about 44.1% explained by the distance of well to septic tank and the depth of the well.

The distance of well to septic tank and its depth can therefore be regulated to reduce contamination of well water by total coliforms. The people could also be educated about the water quality of the different water sources. Purification method could also be explained to the people for much quality water. Keywords: interrelation water supply and sanitation, water quality assessment, water pollution.

Keywords: interrelation water supply and sanitation, water quality assessment, water pollution

Acknowledgements

Above all, I would like to thank God for giving me strength until I can finish writing this document.

First of all, I would like to give my gratitude to my two supervisors who provided guidance and encouragement to do this research. Ir. M. J. G. Brussel and Dr. Ir. M. H. P. Zuidgeest thank for supervised me during the hardest moments from the beginning until completing my final research. I am deeply grateful for your support, encouragement, collaboration, guidance and productive remarks during this research. I would also like to give my special thanks to the UPM staff for the academic guidance and assistance during the programme and particularly for the course director Mrs. Monica Kuffer, MSc.

I also owe my gratitude to Ir. Agus Wismadi, MSc and Dr. Ir. Heru Sutomo, MSc and PUSTRAL staff in University of Gadjah Mada, for their hospitality and providing the valuable support to undertake the fieldwork in Yogyakarta. My cordial thanks to the staff from Public Works Agency, Health Agency and Planning and Development Board (Bappeda) City of Yogya, to help me in gaining knowledge for a better understanding of the infrastructure related to water supply and sanitation conditions in Yogya.

I would like also to give my warm thanks to all UPM colleagues for the discussions, the exchange of knowledge and friendship during the course. My special thanks to Eric for keeping me in track as well as the technical assistance and encouragement during the hardest time.

Last but not least, I would like to give my very special thanks to my parents and my sister for their wonderfully warm support and encouragement during my study, their understanding has been invaluable to me in reaching my future goals in urban planning.

Table of contents

List of figures

List of tables

List of acronyms

BPS	Badan Pusat Statistik
EPA	Environmental Protection Agency
E.coli	*Eschericia coli*
GIS	Geographical Information System
GPS	Global Positioning System
ILWIS	Integrated Land and Water Information System
IUIDP	Integrated Urban Infrastructure Development Programme
MPN	Minimum Probable Number
PDAM	Perusahaan Daerah Air Minum
SPSS	Statistical Package for the Social Sciences
TDS	Total Dissolved Solids
UNESCO	United Nations Educational, Scientific and Cultural Organization
WHO	World Health Organization

1. Introduction

This chapter sets the framework of the research explaining the background in general, scoping to the condition in more specific and leading to the research problem and justification that motivate this research. The conceptual framework highlights the theoretical and introduction to the concept of interrelation and integration of urban water. The research design is elaborated to give an overview of this research. The research matrix contains the type of data that will be needed and possible analysis.

1.1. General Introduction

The effect of urban infrastructures on individuals in a community should be a major concern in its provision since they are geared towards the improvement of their living standards, been economic, social and environmental effects. Infrastructures may include facilities and processes , some aspects being: public utilities such as power, piped water supply, sanitation and sewerage, etc..; public works such as roads and canal works; other transportation sectors such as urban transport, railways, ports, etc…(Parkin and Sharma 1999; 2001). In developed countries, infrastructure management has been controlled by public service ethos to provide adequate and secure services, available and affordable to communities (Guy, Marvin et al. 2000). The infrastructure provision in developing countries on the contrary is sorely lacking because of the ineffective relationship between all sectors involved as well as with the populations themselves. It is therefore a matter of urgency to identify the important features of urban infrastructure provision and the management aspects that are related to these problems (Kyessi 2002).

Many cities over the world have experienced unprecedented growth during the past few decades. According to Choguill (1996), the growth is self perpetuating in that it will continue to attract people, jobs, services, interest and opportunities. The increase in population is in alignment with the increase in demand for more public infrastructures. Urban infrastructure, especially water supply, sanitation, drainage and solid waste management, is considered as essential elements if improvement is to be made to the urban environment. Unfortunately, the majority of residents in many cities in developing countries do not have access to basic urban services (Choguill 1996). The lack of urban infrastructure particularly water related and sanitation could lead to serious deterioration of the urban environment such as unhealthy living environment, unaffordable services leading an unsustainable development.

For public infrastructures to be deemed sustainable, they should perform effectively to enhance the lives of present individuals without hampering the lives of future generations. The provision of an integrated system may be the solution. It is no wonder researches have been focusing on how asset management, which includes electric, gas and oil, water, transportation, banking and finance, control of communication infrastructure systems, can be integrated (Hirst, Goldman et al. 1991; Erbe, Risholt et al. 2002). Studies are also being undertaken to investigate the interrelationships between different infrastructures and its effects if they are not adequately planned and maintained.

Frameworks geared at improving the physical integration of basic infrastructures are however, rare to find. Most of these frameworks involve the integration of assets in managing these infrastructures instead of the physical integration of the infrastructure. Physical integration of public utilities is important because they are closely related to fulfilling a community's needs regarding basic services. In many developing countries, mismanagement of public utilities (water supply, sanitation, electricity, etc...) are evident. This may lead to inequitable access to services. These problems need urgent attention to provide effective and equitable services. Integration of public utilities is thus needed.

1.2. Integrated Urban Infrastructure in Asia and Indonesia

Since the 1990s, governments in Asian countries have been faced with tremendous challenges in coping with rapid urbanization and land scarcity (Rondinelli 1991). Indonesia is the fourth most populous nation in the world, with a current population of 225 million in 2008. From the beginning of 1990s, urban growth has been accompanied by a noticeable expansion in economic activities. This was as a result of successful national economic diversification from petroleum and other commodities (Dimitriou 1991). Dimitriou (1991) raises two issues with the population and economic growths of cities, thus: the ability and capacity of cities to manage and plan their infrastructures to meet the projected demands and whether local governments can tailor the taxes, expenditures and budgets to suit the growth situations.

After the economic boom during the 1980s until the mid 1990s, about 41% of the total urban population in the country was concentrated in the four largest metropolitan areas (Jakarta, Surabaya, Bandung and Medan). The urban growth in these cities led to the provision of corridors connecting them. These corridors opened up rural areas increasing economic activities at the fringes of the city. These have resulted in an uncontrollable expansion of the urban areas. (Firman 2002). However, the economic crisis in the late 1990s and in the beginning of 2000s brought many problems including disparity in urban growth and economic development between big cities with medium and small cities. Firman (2002) described how the government had put too much emphasis on the development of major cities by providing physical infrastructures (including sanitation, drainage, water supply, urban roads, etc...) through the Integrated Urban Infrastructure Development Programme (IUIDP), whilst little attention was given to medium sized cities like Yogyakarta. Also the role of the public as stakeholders is extremely limited leaving development to be more top-down in character reflecting the power of the ruling elites.

The increase of population and physical growth puts heavy pressures on urban infrastructure. Existing supply for water, solid waste management, drainage, housing, etc... may not be sufficient in fulfilling the increasing demand (Steinberg 1991). The problem that remains with the provision of infrastructure in Indonesia is that different governmental agencies, even shareholders with private organizations, provide different (sometimes overlapping) components of infrastructure services. Meanwhile the challenges of infrastructure provision that have to be addressed such as rapid urbanization, lack of appropriate services, separation of services, sectoral provisions, limitation of resources, weak local government administration and the centralised system of bureaucracy are left unattended (Steinberg 1991). Thus, the need for a more integrated approach in the provision of planning, management and technical aspects have gradually grown and became a concern on the national and local levels in Indonesia.

In relationship to an urban services delivery program in Indonesia, the government initiated an approach called Integrated Urban Infrastructure Development Programme (IUIDP) dating back to April 1985. This approach has addressed some issues such as the responsibility of local government to plan, develop and implement developmental programs; with the support from provincial and central governments (providing technical and financial assistance). Provincial and central governments see to the integration of various components of infrastructures both in the physical sense as well as financial resources. This stimulates the mobilization of increased local government resources through availability, period and capacity (Wegelin 1990). However, the program of integration has to meet the required technical, financial and economic appraisal criteria.

The need to understand different systems of infrastructure and to integrate their performance will be a priority study. This in order to prevent the undesired development of events that cause damage to the infrastructures, also to identify the serviceability such as reducing inequality to the poorer groups. The importance of this pending research has two different aspects: helping the authorities to maintain and improve the performance of existing utilities as well as the ability to cooperate with different services; and by addressing the problems of the inadequacy of the services including the distribution and quality.

The term integration remains vague if there is no specific statement that can define it. Integration in this research means the interaction of different infrastructures that may create a complex relationship, dependencies, and interdependencies from one to another. The modelling and analysis of dependencies and interdependencies between infrastructure elements is a relatively new and very important field of study (Pederson, Dudenhoeffer et al. 2007). Moreover Pederson et.al (2007) state that much effort is currently being spent to develop models that accurately simulate infrastructure behavior and identify interdependencies and also vulnerabilities. The results of these simulations are used by private companies, government agencies, communities to plan for expansion, reduce costs, and to prepare for and respond to emergencies.

An example of integration infrastructure for basic services is the dependency between water supply and sewage system. Basically, the behaviour of these two systems can be measured independently as most cases in developing countries. However, even though they are mostly separate from one another, the disturbance of one infrastructure will affect the other; collapse of a sewer, pollution incidents in sewers, flooding, will influence the quality and quantity of clean water distribution. This case is related to performance both on the system performance and the statutory function. Apart from that, various stakeholders are involved in public services provision; each of them has a different point of view, however it may contribute to the inefficiencies of the system performance (Lemer 1998). The effort of integration infrastructure would be able to bridge a gap between the inefficiency of public utilities and the demand of provision.

1.3. Scientific Justification

Access to adequate and safe drinking water still remains a challenge in developing countries. Untreated surface and groundwater have still being used for some people in the rural and even in urban areas (Mkandawire 2008). About 80% of all illness or deaths in developing countries were caused by water-related diseases and kill more than 5 million people every year (UNESCO 2007). Thousands of microorganisms which are causing disease, will survive in the water because water as a medium (Pritchard, Mkandawire et al. 2008). Some of the pathogens cause diseases such as diarrhoea related illness: cholera that derived from human faecal material. Therefore, the research on water quality assessment has been growing specifically in developing countries because of the many cases of health problems related to the insufficient water quality.

The provision of drinking water in sufficient amounts of acceptable quality is a basic needs and ensuring the sustainability, long-term supply of drinking water is a concern of national and international organizations (Reid, Edwards et al. 2003). However, the quality of drinking water is currently threatened by many factors such as chemical and microbiological contaminations.

The benefit of water quality interventions significantly reduce the water-borne disease such as diarrhoea stemming from pathogens in household water supply (Hoque, Hallman et al. 2006). The contamination of water supply could become worst if coupled with poor sanitary conditions. This may pose serious health risks to communities, affecting social life and economical progress if these contaminated water sources are not treated (Pritchard, Mkandawire et al. 2008; Rietveld, Haarhoff et al. 2009).

The contamination of water supply might be caused of several factors. One of the microbiological contamination may be due to effluent of water discharged from sewer or septic tank (Pang, Close et al. 2004). The management of urban water supply also relates to the management of wastewater and solid waste. Usually, they are often conflicting therefore an integrated approach is needed where all these systems are considered simultaneously (Pokrajac 1999).

According to Rinaldi, Peerenboom et.al.(2001), interdependencies or integrated / interrelation between multiple infrastructures which are considered as a system of systems can increase the complexity if there is a change in the system(s). Therefore, interrelation between infrastructures with the consideration of factor dependency between multiple systems is important to be explored in order to simulate the vulnerability and the system performance itself.

1.4. Research Problem

The provision of quality water supply and sanitation are basic needs of people of a community. In most developing countries, the provisions of these infrastructures are done by different authorities. There are mostly not integrated. Efforts to integrate the provision of these infrastructures have been focused much more at the institutional level and less importance given to the spatial integration. These infrastructures may however have effect on each other depending on their spatial locations. For example, a broken septic tank in close proximity to a water supply source may influence the water quality from that source. The study area, Yogyakarta, Indonesia has many problems related to infrastructure quality, building density and also problem with flooding. These may increase the influence of sanitation infrastructures on water quality. This research is therefore going to be concern with the spatial locations of these infrastructures and how they influence each other. Special concern would be given to how sanitation infrastructure influences the quality of water supply in the city of Yogyakarta.

1.5. Research Objectives

1.5.1. Main Objective

The main objective of this research is to assess the water quality and its relationship between sanitation's conditions in the city of Yogyakarta, Indonesia.

1.5.2. Sub Objectives

In order to achieve the main objective, several sub-objectives have been drawn:

- To assess the water quality
- To analyze the spatial performances of water contamination spreading
- To identify the factors of water contaminations

1.6. Research Question

In order to achieve the research objectives, several research questions have been constructed in which specific answer must be sought. The research questions are written in table below together with the research objectives.

Table 1-1 Research Objectives and Research Questions

No.	Research objectives	Research questions
1.	To assess the water quality	- What are the approaches of water quality assessment? - What are the indicators to measure water quality? - Is there any relation between the approaches applied in this research? - What is the condition of water supply in the study area?
2.	To analyze the spatial performances of water contamination spreading	- Are the values of water contamination related from one place to another? - Is there any cluster of high level contamination? - What is the estimation of water contamination?
3.	To identify the factors of water contaminations	- What are the factors of increasing water contaminations? - What is the relation between the factors and values of contamination? - Is sanitation considered as a source of contamination?

1.7. Conceptual Framework

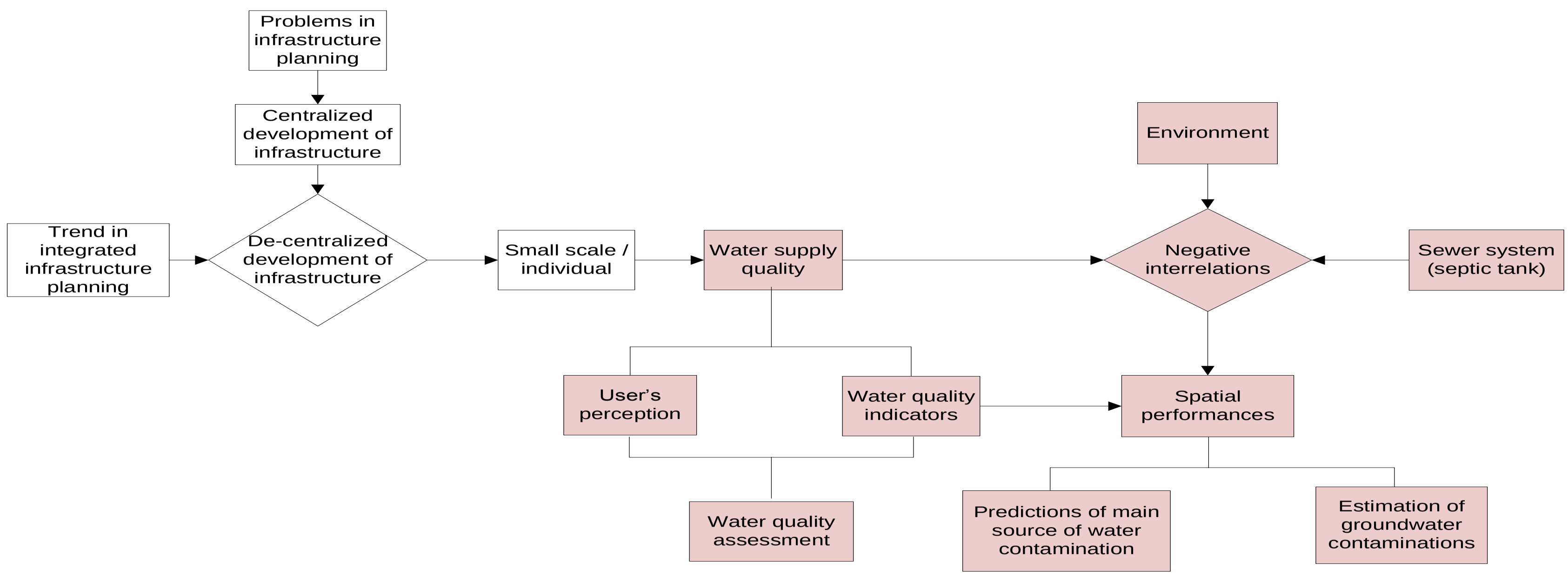
Integrated infrastructure is a broad concept and can be seen from many perspectives and understandings. Integration in the urban infrastructure field can be categorized as a tangible objective while integration of all urban development activities is too ambitious (Singh and Steinberg 1996). For that reason, this research will only focus on the interrelation of infrastructures between water supply and sanitation infrastructures.

In the year 1985, the emerging issue of integrated infrastructures program in Indonesia was quite substantial. The main objective of the program was to create a more decentralised government for the improvement of local infrastructures (Davidson 1996), According to (Steinberg 1991), the realistic planning has to consider the appropriate design standards and affordability to implement such programs. A conceptual framework was developed in this research to identify the application of infrastructure provision in the small scale (neighbourhood or individual).

Apart from emphasizing on the provision of infrastructure on small scale area, the performance of water quality based on users' perception and water quality indicators was assessed. The interrelationship between quality water supply other infrastructures (sanitation) was investigated. A combination of these indicators gave the performance of different water supply sources in the users' perception and from the water quality testing.

In relation to other infrastructures, the dependency water supply quality on other sanitation systems were investigated The concept behind the dependency factors is that one type of infrastructures can directly and indirectly affect other infrastructures and it may impact to the surrounding areas (Rinaldi, Peerenboom et al. 2001). There is a higher degree of dependency between water supply and sanitation compare to other type of infrastructures, and it will influence the public health and safety (Pederson, Dudenhoeffer et al. 2007).

Figure 1-1 Quality Assessment and Interrelation of Water Supply and Sanitation (conceptual model)



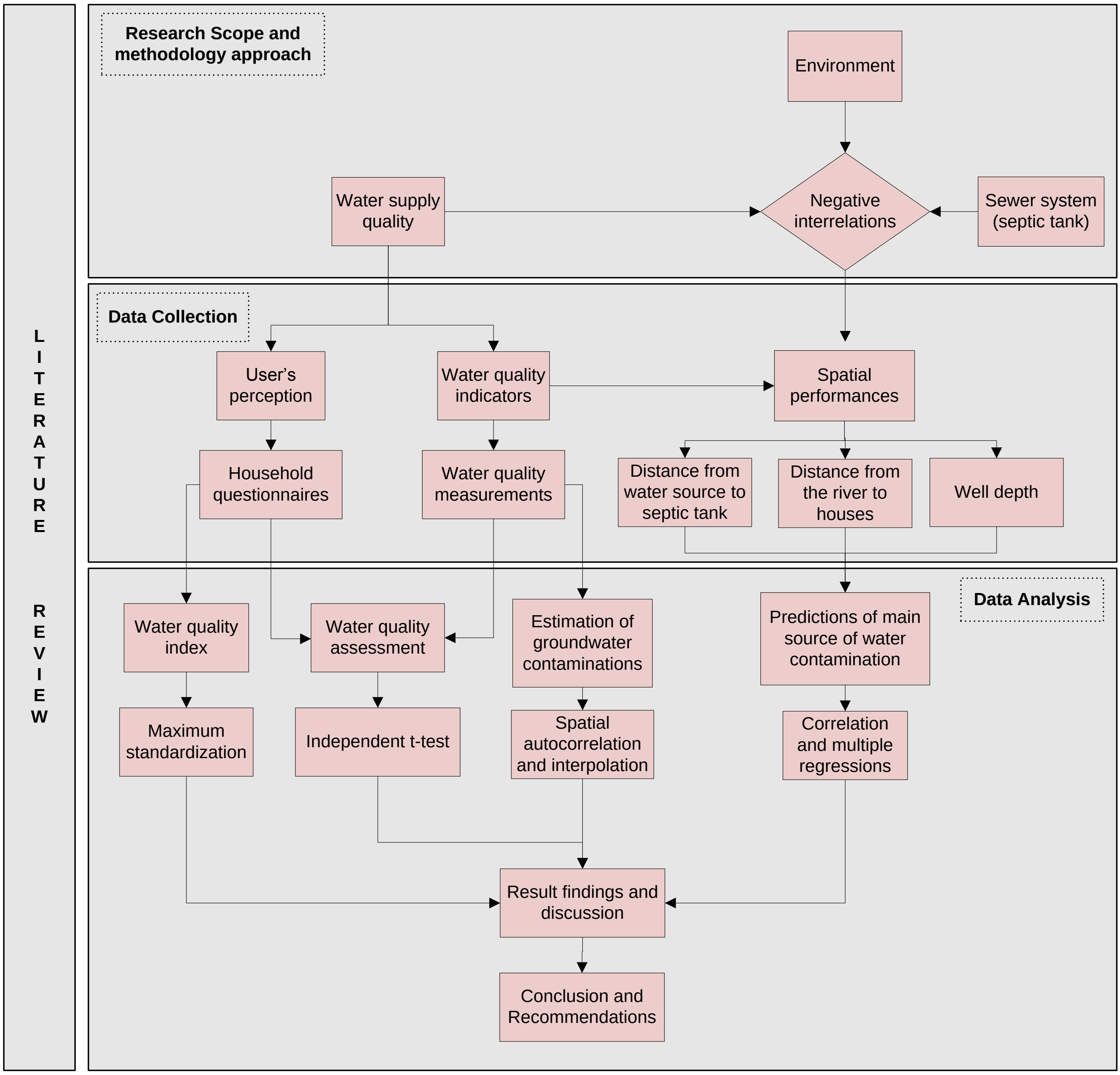
1.8. Research Design

Figure 1-2 provides an overview of how the research work was operationalised. There was an extensive use of literatures as it governed almost every phase of the research. Initially, the research was aimed to understand the concept of integrated infrastructure. The concept of integrated infrastructure is categorized as a broad concept which includes the whole process of infrastructure provision. This research is focusing on the interrelation between two infrastructures: water supply and sanitation but emphasized on the water quality assessment. There are two points of observation in identifying the theory related to this research: (1) identifying the indicators of water quality and (2) identifying and evaluating the factors of dependency / interrelation between water supply and sewage system.

The second phase includes the research elements of data collection in relationship to the user's perception, water quality indicators and spatial performances. This research is conducted using the primary data collections based on household survey, water quality testing.

The last phase involves data analysis. The analysis includes the development of a water quality index (which of the water supply scores best according to the user). This index was based on water quality assessment (this comes from the user's perception about water quality and compares with water quality indicators). An estimation of spatial water contamination and prediction of main source of water contamination was also done. The tools to support the analysis are ArcGIS (spatial analysis and estimation of water pollution) and SPSS (analysis for household survey, correlation and multiple regressions).

Figure 1-2 Research Design



1.9. Research Matrix

The research matrix explains the data requirements, data source and methodology that will be used in order to answer the research sub-objectives. The detail is explained on the table below.

Table 1-2 Research Matrix

No	Specific Research Objective	Data Required	Data Source	Methodology
1	To assess the water quality	Relevant literature on water quality and indicators	Secondary	Literature review
		Water quality measurements	Primary	Water sampling and laboratory tests
		Water quality according to the user	Primary	Household questionnaire and statistical analysis, water quality index
		Water quality assessment between user and water quality indicator	Primary	Independent t-test
2	To analyze the spatial performances of water contamination spreading	Water sampling points	Primary	GPS measurement
		Water sampling points and water quality measurements	Primary	Spatial autocorrelation
		Evaluation of water pollution spreading	Primary	Spatial interpolation
3	To identify the factors of water contaminations	Relevant literature on interrelation of water supply and sanitation	Secondary	Literature review
		Prediction of water contamination	Primary	Correlation and regression

.

1.10. Organization of the Thesis

This thesis is organized into seven chapters. The following provides a brief description of each of the chapters:

Chapter One

The Introductory chapter provides the background and research problem, and narrowing down the main objective to sub-objectives, conceptual framework, research design and research matrix.

Chapter Two

This chapter highlights the theoretical overview about quality assessment in general term, generating the index of water quality, interrelation between water supply and sanitation. This provides the state of the art of elements in quality assessment and interrelation of water supply and sanitation.

Chapter Three

This chapter gives an introduction about study area and more focused on how household survey carried out including the measurement of distance, well depth and water quality measurements. On the second part, it describes about the methods that are going to be used to analyze the data.

Chapter Four

This chapter describes the insight of study area, Yogyakarta City, with the emphasis description about urban infrastructures related to water supply, sewage system and drainage.

Chapter Five:

This chapter explores and measures the user's perception about their water quality and generating to the index, the water quality result and how it is spreading spatially, the assessment between user's perception and water quality measurement, evaluation of water pollution spreading and the prediction of water pollution.

Chapter Six

This chapter discusses about the findings from the analysis and the policy responses to the problems that are found.

Chapter Seven:

This chapter concludes the work and provides some recommendations.

2. Interrelation of Water Supply and Sanitation

This chapter looks on the interrelation and integrated system performance in general term but still related to infrastructure problems. Even though it is explaining about urban water system, the water supply performance is describing thoroughly specifically about the quality and user's perceptions. In this chapter, the integration is closely related to the interrelation of different systems and failure of the systems. Moreover, in this chapter, it is elaborated the urban water systems, the performance and failure. Hence, the negative interrelation is elaborating more within some cases example.

2.1. Integrated System Performance

In some literature, it has been a trend to relate integrated system performance with the critical infrastructure interdependencies. Moreover, critical infrastructures are highly connected and mutually dependent through physical dependencies (Rinaldi, Peerenboom et al. 2001). Understanding different types of interdependencies can be a challenge in any country since the majority of the infrastructures are related to daily life such as electrical power, telecommunications, transportation, water supply and other fundamental services (Rinaldi, Peerenboom et al. 2001). However, this research will only focus on the basic infrastructures that are related to water supply and its environment.

Most of the security, economic prosperity and social well-being depend on the functionality of complex and interdependent infrastructures (Gillette, Fisher et al. 2002). However, failure to recognize disruptions of one infrastructure could influence others or result in common cause failures, decision makers would therefore be unprepared to deal with those impacts (Gillette, Fisher et al. 2002). In addition to understanding the complex infrastructures that are being operated, a broad range of interrelated factors and systems have to be identified first. Rinaldi, et.al (2001) describes the interrelation of infrastructural interdependencies that can be divided into six dimensions (Figure 2-1): types of interdependencies, state of operation, infrastructural characteristics, types of failure, coupling and response behaviour and environment.

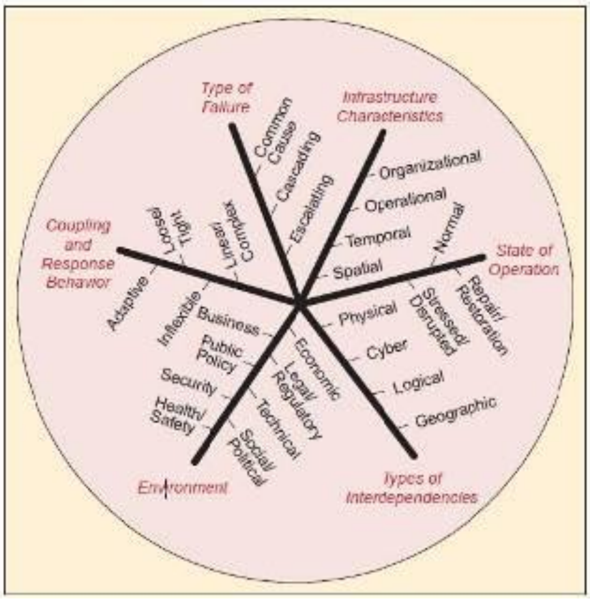


Figure 2-1 Dimensions for Describing Infrastructure Interdependencies (Gillette, Fisher et al. 2002)

2.1.1. Definition and Perspective of Integration

In order to acquire a deeper understanding of the integration of system performance, specifically for integrated infrastructure, the definition and concept of each system has to be clarified before further discussion. Infrastructures can be defined as man-made systems and processes, mostly privately or public owned and a network of independent that function collaboratively and synergistically to produce and distribute a continuous flow of goods and services (Gillette, Fisher et al. 2002). Meanwhile, physical infrastructure is an aggregation of all facilities that involve a functional society, it has to be responsive to social objectives and serves social purposes of health, safety, economics, employment, etc… (Rainer 1990). Thus, infrastructure here means physical infrastructures that operate to fulfil the public's needs and works as mutual related systems.

Some literatures mention that integration is related to a broad perspective of planning, operation and maintenance aspects in an infrastructural field. An example of an integrated project related to infrastructure was a project from IUIDP (Integrated Urban Infrastructure Development) that focused on developing the capacity of local government, financial organisation and implementation of the programme. Apart from that, integration and adaptation of the transport can be seen as a different approach of vertical and horizontal aspects such as an interaction between institutional and implementation of the physical planning. Furthermore, integration can be seen also as an interrelationship between two or more different systems. An integrated approach is a methodology to define the relationships between systems for further analysis (Pokrajac 1999). Hence, there are so many concepts of integration which are important and need to be explored. Meanwhile this research will focus on the integration that concerns the interrelation between systems.

Essentially, in urban planning and management, there are two different systems that can be seen: performance-oriented and statutory form (Davidson 1996). Statutory form is basically based on law, less flexible and possibility of rapid action. Whilst performance-oriented is determined by performance requirements and orientated to meet the needs. The statutory form may lead to bureaucratic routines and may suffer when attitudes to the law are weak. The performance-oriented form can be categorized as a form that puts an emphasis on participative process, especially if it is meant to engage key actors from problem identification until operationalization of the infrastructures (Davidson 1996). The integration system performance of infrastructure to some extent needs to involve various departments in order to avoid overlapping tasks and decisions related to the planning and operation of urban water systems. Thus, the performance-oriented form would be suitable for the infrastructure planning in comparison to the statutory form.

2.1.2. Elements of System Performance

In order to develop the framework of integration system performance between urban water (including tap water, groundwater, and sanitation), a measurement of system performance of each infrastructure and their relation to each other needs to be identified. Firstly, measuring the performance can be done by setting up performance indicators to recognize their relationships (Ashley and Hopkinson 2002). Overall performance of integrated infrastructures can be assessed using several categories such as: performance of each system, interdependency types (geographical and physical) in normal condition or during disaster such as flooding or earthquake and environmental impact (degree of contamination). However, there are limited performance indicators that are being used especially related to urban water in the overall situation (Ashley and Hopkinson 2002). Moreover Ashley and Hopkinson (2002) describe that integrated system management – across sectors that can be an essential feature in the provision of an adequate level of service. Therefore, assessing performance in relation to an integrated system is needed in order to fulfil and satisfy the needs of a community.

As mentioned above the performance of an integrated infrastructure can be measured from the performance of each system, type of interdependency, environmental impact and disaster condition. Each of assessing factor will be discussed below:

1. Performance of each system. For each system, the assessment criteria can be divided into reliability and durability (Rietveld, Haarhoff et al. 2009). According to Rietveld, Haarhoff, et.al (2009) assessment criteria are aimed to obtain a rapid indication of the technical state and yet easy to measure. Reliability can be split into three sub-criteria: availability, capacity and continuity. Firstly, availability refers to the adequacy of the source, both quantity and quality of the system. Secondly, capacity is mostly related to the adequacy of the storage, and dealing with the size of the system. Thirdly, continuity pertains to the consistency of the system and whether there is a failure in the distribution such as pipe damaged, etc… Durability can be categorized as the condition of a system and the lifetime it can perform.

2. Type of interdependency. This considers the more specific and individual connection between two infrastructure systems (Rinaldi, Peerenboom et al. 2001), for instance, the electricity used to generate groundwater, in this case the relationship is unidirectional because infrastructure *i* depends on *j*, but *j* does not depend on *i* through the same link. In other words, dependency is "*a linkage or connection between two infrastructures, through which the state of an infrastructure influences or is correlated to the state of the other*" and interdependency is "*a bidirectional relationship between two infrastructures through which the state of each infrastructure influences or is correlated to the state of the other*" (Rinaldi, Peerenboom et al. 2001). Type of interdependency: (1) Physical is where two infrastructures are interdependent in terms of physical elements, for instance the output from a used water supply would be the input of a sewer line, meanwhile if the sewer line is not managed properly it would influence the water supply because

of spillage. (2) Geographic interdependency is when elements of multiple infrastructures are in close spatial proximity. Given this proximity, two elements that are close to each other may correlate if one of them is broken.

3. Environmental impact. The assessment of environmental quality can identify whether there is a potential hazard from one system to the others (WHO 2006). Environmental impact in this case could be the impacts that are being produced by the system. Degradation of water source quality may result from predictable incidents, emergencies or unplanned events. These are considered to increase the potential for a breakthrough in contamination (WHO 2006). For example, the performance of a sewer line might fail and affect water contamination for drinking water. Therefore in order to identify water contamination it should be measured from several parameters. The presence or absence of *faecal indicator bacteria* is a commonly used operational monitoring parameter (WHO 2006). The critical parameter for microbial quality is *E.coli*. However, there are pathogens that are more resistant to chlorine disinfection than the most commonly used indicator – *E.coli* or thermotolerant coliforms.

   Apart from that, other chemical parameters can be used as quality assessment such as total dissolved solids and total suspended solids. Total dissolved solids include inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and some small amounts of organic matter that are dissolved in water (Wilkes University Environmental Engineering and Earth Sciences). The total solid content should be less than 500 mg/ l, based on industrial uses of water supply (Chinn 2003). Chinn (2003) states that higher concentrations may cause physiological effects and make drinking water less palatable, if the TDS containment has reach 1000 mg/litre then it is categorized as saline. Meanwhile suspended solids contain inorganic fraction (silt, clays, etc) and organic fractions (algae, zooplankton, bacteria, and detritus).

2.2. Urban Water

2.2.1. Water Supply Provision

One of the problems that is related to urban water supply provision is the lack of a portable water supply, it can be stated that quite often, household connections to a piped water are only available for the higher income group of the population (Akbar, Minnery et al. 2007). The reasons behind this are because the physical availability of water for many cities in developing countries are in areas of heavy rainfall or are close to major rivers. In other words, because of the limited access to a portable water supply then people may decide to consume water of a doubtful quality from a nearby unprotected river, well or spring (Chinn 2003; Akbar, Minnery et al. 2007). Thus, in developing countries, people that live in poor areas are not concerned with a safe water supply as an adequate source but more on the availability of water.

Based on the paper from Choguill (1996) where he elaborates problems related to water supply provision and sanitation, those who are unable to afford the service of drinking water-well or pit latrines or septic tanks, mostly provide their own system or can be called “on-site systems” (Choguill 1996). Residents in urban areas especially in the developing world with a limited access to water supply and sanitation, usually solve their problems by using river or ponds to obtain water supplies which have a negative impact on the environment and health. Furthermore, on-site systems may not meet the environmental standards which in many cases show the pollution of ground-water resources and unhealthy aspects. These could be the beginning of contamination cases because of the inappropriate integration between physical infrastructures specifically water supply and sanitation.

2.2.2. Performance of Water Supply

Modern urban water distribution networks consist of piping grids located in the underground of streets, for example in United States usually branch mains are fed from two main feeders to provide service in a situation where one feeder main is not functional (Rainer 1990). Furthermore, another component in urban water distribution are valves, which are considered as devices to manage the flow of water by opening and closing the passageway to sectionalize branch mains to simplify repairs or new connections (Wikipedia ; Rainer 1990). The advantage of using pipes as a method to distribute water may be considered as safe water, however the selection of pipes, the strength of the pipes, ductility and corrosion resistance need to be deemed (Ntengwe 2005).

There are two important aspects that have to be considered in water supply provision: quantities consumed and water quality (Rainer 1990; Chinn 2003). According to Rainer (1990), water consumption is influenced by several factors such as: (1) climate, people who live in a warm climate take more showers, build pools and consume more water; (2) availability, the shortage of water supply would lead to the conservation of resources; (3) development process, developed countries have more requirements to fulfil their standards; (4) cultural preferences, some social preferences would consider the hygiene aspects so more water is consumed, etc.. During 1980s – 1990s, the average water consumption for cooking, sanitation, irrigation and industrial uses ranged from 100 to 200 gallons per person per day (Rainer 1990). However, population increases, water pollution, urban development, climate change and drought have led to significant disparities between the availability of quality water sources and demand for consumption (Jorgensen, Graymore et al. 2009). Thus, quantities of water supply became major issues for the water authorities to manage future water demand.

Apart from quantities consumed, water quality is compromised by various factors that require measurement. Some factors such as physical, chemical and biological processes cause the quality of surface water to vary during the years (Rainer 1990). The available sources for a portable water supply are groundwater and surface water; therefore it should be protected, used and maintained in an appropriate way. There are several parameters used to determine the suitability of water and the health contaminants such as microbiological, physical, chemical and microscopic examinations, that may be found both in untreated and treated water (Chinn 2003). Problems with drinking water in developing and transitional countries often concern microbial pollutants, although organic and inorganic chemical pollutants can also play a role (Ashbolt 2004 as cited in; Peter-Varbanets, Zurbrügg et al. 2009). In order to insure water quality, some routines and procedures like maintaining water clarity, chlorine residual in the distribution system, confirmatory absence of indicator organisms, and low bacterial population in the distributed water are needed (Chinn 2003). Thus, there are a range of methods to obtain a better quality of water that have to be applied right to the point where the consumer gets the water.

2.2.3. Water Quality

There are two types of water: (1) surface water is untreated water or usually called raw water from lakes, streams and rivers that is used for utilities or even individual use; (2) finished water is used by the consumers after treatment such as disinfection (Davies and Mazumder 2003). Overall, the quality of water has to meet the standard and has to be safe for drinking and cooking. Globally, there are several drinking water standards but they are basically similar, such as World Health Organization (WHO), national standards, local authorities standards, etc… (Roccaro, Mancini et al. 2005).

According to WHO guidelines, a water supply provider requires operational monitoring. The water quality has to be monitored in terms of microbiological quality which includes the test for E-coli as an indicator of faecal pollution (it should not be present in drinking water) and chemical water quality especially those which are affecting public health risk such as nitrates (WHO 2006).

The water quality criteria according to Health Agency in Canada and EPA (Environmental Protection Agency) includes (Davies and Mazumder 2003): (1) the water should not contained diseases that are caused by organisms; (2) harmful chemicals should be below the threshold and physical parameters should be in ranges that are acceptable; (3) radioactive compounds should be below the threshold.

Meanwhile, the water quality criteria according to Ministry of Health Indonesia (Ministry of Health 2002) are: (1) drinking water that is distributed through pipes, water tanks, portable water as well as water that is being used to produce foods and drinks for society has to fulfill the health standard; (2) the health standards for drinking water include microbial, chemical, radioactive and physical monitoring.

The main outline for water quality criteria therefore includes factors of microbial, chemical, radioactive, and physical aspects. All of the criteria have to be below certain thresholds. This research is focused on the interrelation between water supply and sanitation. Water quality indicators that are used to measure the influence are mainly total coliforms (from bacterial contamination) and also total dissolved solids. Later on we will discuss about each of the indicators.

2.2.4. Perception of Water Supply

The perception of water supply based on the literature is discussed and in particular the use of water as drinking water. In terms of water quality, the user's perception is of utmost importance more so than reality especially when it pertains to the quality of drinking water (Sheat 1992; Doria 2010). There are some factors that influence public perception regarding drinking water (Doria, Pidgeon et al. 2009):

- Some factors that are related to sensory human perception are taste, odor and colour. This sensorial information (taste, odor and colour) is related to psychological factors and which consistency is to be expected. However, to some extent the taste of water is more important because it may detect water contamination (e.g. chemical) than other senses.

- Risk perception. People who use tap water believe that it has minimal risks to their health. High risks of water supply may be associated with water pollution. Risk perception usually relates to controversial hazards because the user may have little experience with it.

- Previous experience (familiarity with a specific drinking water). In relation to the assessment based on taste, odor and the colour of water, experience shows that people prefer their drinking water what they have been used to (Strang 2001 as cited in; Doria 2010). For example, people from a certain location where the drinking water is typically yellowish may feel that bluish water is strange or unusual for them (Doria 2010). However, experiences of people are not always positive but sometimes a negative experience may influence their perception of drinking water.

- Interpersonal information. There are two types of information that may influence the perception of people: impersonal and interpersonal. Impersonal information is usually originating from the media and it may affect a whole society, examples being mass media and brochures. Interpersonal information is from one person to another that may only have an influence on a personal level.

2.2.5. Groundwater

2.2.5.1. Type of Groundwater

Groundwater can be categorized as the source of drinking water for many people around the world especially in rural areas (Nas and Berktay 2006). The provision of urban groundwater in developing countries can be mainly categorized into two types of source: (1) private groundwater - a well is located inside the domain or property or in other words the user owns the well; (2) communal groundwater is public property, a water point to provide water for the local community. It must be recognized that in cities in developing countries there are always informal and formal sectors (Choguill 1996). Most informal dwellers are not able to pay the capital cost of a connection fee or establishment by a one-off payment, but they are able to pay the instalments as a service charge, with the user charge, and to pay some upfront development fees for the construction of water points (Akbar, Minnery et al. 2007).

According to Chinn (2003), there are different types of water wells such as:

1. Dug out well. A dug out well is one that is usually excavated by hand until water is reached, but most of the time it would be dug using machine equipment. The diameter is around 1 to 2 meters and the depth around 5 to 11 meters, this depending on where the water-bearing formation or groundwater table is encountered. A dug well has a large storage capacity because of the

diameter. However, the potential hazard of contamination from soil if improperly constructed may occur, also applies to shallow bored, driven, and jetted wells.

2. Bored well. This is constructed with a hand- or machine-driven auger. The diameter varies from 0.05 to 0.7 meters and the depth from 8 to 18 meters. A casing of concrete pipe, vitrified clay pipe, metal pipe, or plastic pipe is necessary to prevent soft formation penetrated from caving into the well. The characteristics of this well are easily polluted, and easily affected by droughts.

3. Driven and jetted well. Consists of a well point with a screen attached, or a screen with the bottom open, which is driven or jetted into a water-bearing formation found at a comparatively shallow depth. Driven wells are commonly between 0.03 and 0.05 meters in diameter and less than 15 meters in depth; jetted wells are around 0.05 to 0.3 meters in diameter and up to 30 meters deep, although larger and deeper wells can be constructed.

4. Drilled well. This is more superior to dug, bored or driven wells and springs. Drilled wells are less likely to become contaminated and are usually more dependable sources of water. Drilled wells are usually 0.1 to 0.3 meters in diameter or larger and may reach 228 to 300 meters in depth or more.

2.2.5.2. Performance of Groundwater

There are two types of groundwater distribution: intake and pumping. When water has to be pumped from the source, electrically operated pumps should have gasoline or diesel standby units having at least 50 percent of the required capacity or using electricity power from the provider (Chinn 2003). A pump usually has a function to raise and distribute water. There are several types of pump e.g. jet pump, air lift, hydraulic pump, also in developing countries it is common to use chain and bucket pumps and hand pumps (Chinn 2003). The most commonly used is the jet pump, a combination of a centrifugal pump and a water ejector in a well below or near the water level. Furthermore, the intake procedure is to collect the water on the water points where it is usually being saved on large storage. The water distribution of groundwater is varied based on the ability of the consumer to afford it.

Apart from the water distribution system, it is also crucial to identify and understand the distance or other aspects between a well and the sources of pollutants. It is apparent that the safe distance between a well and a sewage or industrial waste disposal system is dependent on many variables, including chemical, physical, and biological processes (Chinn 2003). Factors to be considered in arriving at a satisfactory answer include the following (Chinn 2003):

1. Amount of sand, clay, organic matter, loam in soil, groundwater level, soil depth to determine the ability of the soil to remove microbiological pollution deposited in the soil.

2. Volume, strength, type and dispersion of the polluting material, rainfall intensity, infiltration, distance, elevation. Volume of water pumped and well drawdown.

3. Well construction, tightness of the pump line casing connection, depth of well and well casing and sealing.

2.2.5.3. Failure Performance of Groundwater

Groundwater may become contaminated either naturally or because of human activity (Nas and Berktay 2006). Oils, minerals, gases, organic matter, and other compounds and elements in the water cause tastes and odors in water supplies (Chinn 2003). The well recharge (wellhead) area, geology, and land use possibly permit groundwater pollution. The main causes of groundwater pollution are organic chemicals (trichloroethylene, trichloroethane, benzene, perchlorate, gasoline, pesticides and soil fumigants, disease-causing organisms, and nitrates), other sources (ponds, pits, leaking underground storage tanks and pipelines, accidental spills, illegal dumping and abandoned oil and gas wells) (Chinn 2003). Moreover, Chinn (2003) classifies the sources and causes groundwater pollution:

- Wastes: drainage wells and sumps; leaky sanitary sewer line
- Non wastes: accidental spills

The characteristics of water systems, water use and demand, contaminant flows, treatment technologies, public acceptance and the costing of urban water system impacts on environments will enable identification of water systems that have environmental impact as well as the costs (Gray and Becker 2002). Spillage from sewage and industrial waste could be one of the contaminant sources in groundwater. Sewage would have to be present in extremely large concentrations to be noticeable in a water supply. Micro-organisms which could cause illness or death if not removed or destroyed before consumption are the greatest danger in sewage pollution. Apart from that, industrial waste introduced in water, or colloidal matter, dissolved minerals and organic chemicals are toxic and produce tastes and odors (Chinn 2003).

2.2.6. Waste Water

The components of wastewater can be varied; they depend on the community and water use, industries, infiltration, and whether the sewers are combined sewers or sanitary sewers (Kiefer 2003). Usually, the wastewater from a residential community is the same for every household. There are two classifications of waste water: *black water* is wastewater from water closets and latrines or aqua privy flushing, *grey water* is all other domestic wastewater (Kiefer 2003). Grey wastewater is also known as wastewater without any input from toilets, purely produced from bathtubs, showers, hand basins, laundry machines and kitchen sinks and mostly from households or office buildings, schools, etc… (Eriksson, Auffarth et al. 2002; Kiefer 2003; Stasinopoulos, Smith et al. 2009). It has to be considered as sewage or wastewater and has to be treated because of practical purposes and from a public health point of view (Kiefer 2003). Furthermore, grey wastewater in many developed countries mainly concerns the use of grey waste water for urinal and toilet flushing because the water that is used for toilet flushing is of drinking water quality (Eriksson, Auffarth et al. 2002).

All sewage (wastewater) should be considered contaminated because of many pathogenic microorganisms and toxic chemicals are found there, with disease producing organisms and toxic chemicals (Kiefer 2003). Additionally, it is known that some pathogenic organisms will survive for less than one day in peat and up to more than two years in freezing moist soil, moist soil is favourable and dry soil is unfavourable for the survival of many pathogens (Kiefer 2003). Moreover, a survey from Albrechtsen shows that *E.coli* did not grow in the grey wastewater system but it can survive and be detected after 14 days (Eriksson, Auffarth et al. 2002). Thus, there is still the possibility of clean water contamination from wastewater concerning the type of contaminants.

2.2.6.1. Characteristics of Grey Wastewater

Suspended solids are relevant components that are measurements of physical parameters. Measurement of suspended solids would give some information about the content of particles and colloids that could induce clogging of installations such as piping for transportation or sand filters used for treatment. The containment of solids should usually be lower in grey wastewater than from combined sewer because of the combination between colloids and surfactants from detergents that may stabilize the solid phase.

- Micro-organism components: *Eschericia coli* have been used as an indicator of faecal contamination and by investigating its content in wastewater or drinking water as important information to rectify a health hazards. Bacterial and viral contaminations would be a serious problem if it affects the groundwater.

Based on some research about grey wastewater, the measurement of suspended solids indicates that the highest values from the range of content are basically from laundry and kitchen. Moreover, laundry wastewater may contain sand and clay from clothes and zeolites from detergents. Apart from that, some researchers conclude that a high range of zinc concentrations come from the bathroom wastewater which including chlorine tablets for disinfection. Chlorine tablets have a high acidic content and would cause leaching of zinc from the plumbing.

2.2.6.2. Type of Sewer System

Generally, there are three distinct types of sewers: sanitary, storm and combined (Rainer 1990). He defines that sanitary sewers drain wastewater from residential and industrial uses; storm sewers are carry the runoff from rain that is collected from roofs, road and other surfaces; combined sewers have both functions of sanitary sewage and storm water. Initially sanitary and storm drainage are not separated but during the rainy season the flow from combined sewers might swell 50 times more than the normal flow and cause untreated sewage to spill into waterways (Rainer 1990). Discharge, or overflow from combined sewers occuring immediately after a heavy rain would have a BOD of several hundred milligrams per litre of thousands of coliform organisms (Chinn 2003). Chinn (2003) elaborates that in older cities, combined sewers can be found where the dry-weather flow is treated. Therefore, in countries that have a heavy rainfall it is necessary to consider separate systems rather than combined sewer systems.

In some countries, the general map for infrastructure of a sewerage system indicates the locations of the sewers including surface elevations at street intersections and the grades, the size of sewers, outfalls, slope, length between manholes, and invert elevations of sewers (Kiefer 2003). Meanwhile, detailed plans to a suitable scale are required of all apertures, manholes, flushing manholes, inspection chambers, inverted siphons, regulators, pumping stations, and any other devices, to permit thorough examination of the plans and their proper construction. Sewers are usually designed for a future population for 30 to 50 years.

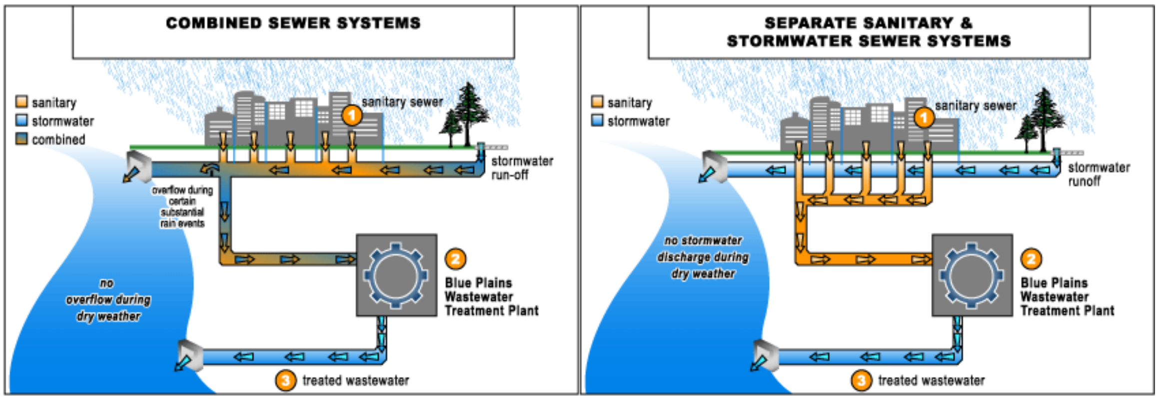


Figure 2-2 Combined and Separate Sewer Systems (DC Water and Sewer Authority)

2.2.6.3. Performance of Sewer System

Sewer systems consist of a network of pipes that are located under the street level. The connection from household sites called laterals terminate in sub-mains and this may lead to a treatment plant. After being treated the water is discharged into a nearby waterway (Rainer 1990). Usually, sewage flows by gravity and always steeply to maintain the velocity which is mentioned in the literature about 0.5 meters per second (Rainer 1990). Sewage departs from the building through a cast-iron house drain with a vented-trap which has 2 types: P and S, to keep odors out of the buildings' interior. These are the main the sewer configurations in a system that has to be considered in infrastructure planning.

Before planning the capacity of a sewage system, the quantity of sewage generated is closely linked to the clean water that is being consumed. The quantity of sewage can be predicted from the total population to be expected, land use and density permits (Rainer 1990). However, the quantity of sewage water mostly exceeds the water supply because of the infiltration into the sewer system from groundwater. Meanwhile, urban storm water runoff would depend on the local rainfall pattern and type of surface (Rainer 1990). The quality of storm water is far from clean because of the chloride containment coming from highway de-icing.

2.2.6.4. Failure Performance of Sewer System

During a number of years the local problem of soil pollution which stemmed from the practice of land application of sewage in an early stage, has been changed into a regional problem of water pollution (Beck 2005). Recently, the need to view urban water waste system as a whole including the sewer system, wastewater treatment plant and receiving water body, became an awareness in developed countries (Fu, Butler et al. 2008). The system however has to be able to accommodate the discharge from households in a region. As described in the sub-chapter before, a combined sewer system is no longer suitable for the areas that have high level of precipitation and is not recommended unless the authorities treat it correctly. Pollutants may come from domestic dry flow and rainfall runoff, and the type of pollutants are mainly suspended solids, total COD, ammonium and nitrate (Fu, Butler et al. 2008).

Apart from the sewage line failure, performance of the urban water storm can be seen from the capability to catch and store the rain water. Thus, if there is flooding the depth and length of duration may indicate that urban water storms do not work properly (Kolsky and Butler 2002). Furthermore, the effects of flooding may also influence the quality of the water supply in an area because of the failure of the urban water storm system or the increase of the water table in the nearby waterway.

2.2.7. Septic Tank

A septic tank can be defined as a watertight tank designed to slow down the movement of raw sewage and wastes passing through so that solids can separate or settle and be broken down by anaerobic bacterial action (Kiefer 2003). However, a septic tank does not purify sewage, eliminate odours, or destroy all solid matter. A plastic sludge and gas deflector on the outlet as shown in Figure 2-3 is highly recommended. Moreover, in order to protect drinking-water wells and surface water bodies from microbial contamination, the government authorities have determined arbitrary setback distances from septic tank systems (Pang, Close et al. 2004). For instance, these arbitrary setback distances in a case study in New Zealand range from 20 to 30 m for surface water and 30 to 50 m for groundwater (Pang, Close et al. 2004).

In relationship to contamination, an effluence of viral, bacterial and protozoan pathogens are contained in the septic tank (Pang, Close et al. 2004). There are some viruses and bacteria that can be used as an indicator of attenuation and transport pathogens in groundwater and soils. For instance, *E-coli* (faecal bacteria indicators), faecal coliforms are usually present in human wastes (Pang, Close et al. 2004). Moreover, they (Pang, Close et al. 2004) studied that the effluence of the septic tank could spill out into the groundwater with bacterial concentrations, and specifically in the condition where the water table rises to flood the disposal trench / bed of septic tank system. The figure bellow shows the typical location of well and sewage disposal.

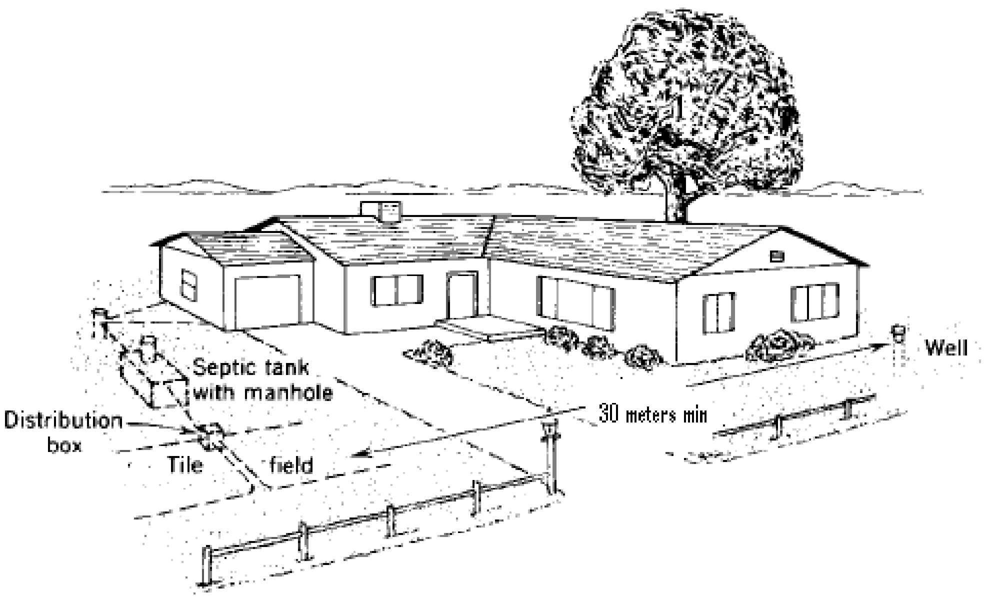


Figure 2-3 Typical Well and Sewage Disposal Layout

2.3. Interdependency and Interrelation between System Performances

2.3.1. How do the Systems Depend upon One Another?

The causal relationships of water supply and sewerage systems can be seen under normal conditions of business as usual, and in the event of a natural hazard. In general, (Gillette, Fisher et al. 2002) state that water and waste water systems have unique interdependencies with other infrastructures that are necessary when constructing vulnerability assessments also in developing response and recovery plans in order to address the problems of security and protection. For example, water and waste water infrastructures have some factors of dependencies with the transportation, natural gas, petroleum liquids, telecommunications, and electricity power infrastructures. The interdependencies may vary from the type, scale, spatial, temporal, and complexities. There are types of failures that can affect interdependent infrastructures. (Gillette, Fisher et al. 2002) divide the failures of infrastructure interdependencies into three categories: (1) cascading failure is a disruption in which one infrastructure causes a disruption in a second, (2) escalating failure is a disruption in one infrastructure that exacerbates an independent disruption of a second infrastructure, (3) common cause failure is a disruption of two or more infrastructures at the same time as the result of common cause for example natural hazards.

2.3.2. Groundwater Contamination Cases

Waterborne disease transmission occurs by drinking water contamination and the lack of a distribution system (Lindley 2002; WHO 2006). The problem has occurred in many dramatic outbreaks of faecal-oral diseases such as typhoid and cholera (WHO 2006). In WHO report of water supply and sanitation 2000 states that diarrhoea is affected by water and sanitation both from waterborne and water-washing. Some problems that are related to distribution system deficiencies are backflow at connections, contamination during infrastructure repair, pathogen contamination along buried infrastructure during low pressure periods, dissolution of pipe material such as copper or lead, as well as contamination of storage tanks (Lindley 2002).

Some problems such as poor drinking water quality, loss of water supply, high clean-up costs, high costs for alternative water supplies and potential health problems are derived from the possibility of groundwater contamination (Nas and Berktay 2006). Estimation on the likely presence of problems related to storm water, mobility through soil, the type of treatment received before infiltration and infiltration method used would potentially effects the groundwater quality (Pitt, Clark et al. 1999). Urbanization may cause the permeable soil surface area through which infiltration could occur was reduced. There are a numerous number of groundwater contaminants associated with storm water pollutants (Pitt, Clark et al. 1999):

- *Nutrients*:

  Roadway runoff has been recorded as the source of a groundwater nitrogen contaminant in urban areas, this happened because of vehicular exhaust onto road surfaces and adjacent soils. Leakage from sewers and septic tanks in urban areas also indicate the contamination of nitrate-nitrogen of the soil and groundwater.

- *Pathogens*:

  Virusal and bacterial contamination of groundwater is likely to happen if the water table is near the land surface. The spread of viruses happen in the liquid phase and involves water movement which is associated with suspended particles; moreover the movement occurs from soil to groundwater. Pathogens may leak from the burial of sewage and sludge and contaminate groundwater. The acid soil and large amounts of organic matter would make the bacteria survive longer, between two or three months, even though the survival time is up until five years.

- *Dissolved minerals*:

  Some dissolved minerals contaminate the groundwater. A case in the UK showed that increasing chloride concentrations in groundwater have been used as an indicator of the groundwater contamination.

3. Methodology

This chapter presents an overview of methodological approaches for the design and analysis of the integration factors. This research carries out into three different sections. The first section is elaborating the conceptual framework and methodology approaches of integrated system performance of urban water in which will be used to measure the condition in the field. The second section is data acquisition both primary and secondary data in Municipality of Yogyakarta. The primary data is mainly focused on perception of different urban water infrastructures applied in that area in order to identify how different systems are related one to each other. The third section is the description about analysis of water quality assessment and interrelation between water supply and sanitation.

3.1. Data Acquisition in Yogyakarta

The primary data collection related to household survey was aimed to gather people's opinion about how the urban water systems (water supply, waste water system, and septic tank) work and how did the system interact and dependent in local scale. Field observations such as water quality testing with two parameters were carried out in order to identify whether water supply quality. Efforts were also made in identifying some of the influences of waste water system on water supply. Two parameters (total coliforms and total dissolve solids) have been measured to determine whether water supply is affected by contaminants from sewage or septic tank. Apart from that, secondary data were collected from institutions such as; Public Work Department, Planning and Development Bureau and Health Agency Yogyakarta. Secondary data acquired include detailed planning documents of urban infrastructures, some standards related to location of urban water systems, water quality and also discussion about existing systems. From the data acquired and discussion carried out, it was realised that there was no detailed infrastructure planning documents available nor specific standards related to distance from which water sources should be spaced from waste water systems. Even though the distance may have effect on the contamination levels, less is been done about that. Rather focus is placed on the construction materials of each component to avoid contamination to the groundwater. Also evident is the lack of coordination between different sub-agencies specifically about data arrangements, overlapping tasks and functions especially between provincial and local agencies. Steps taking in carrying out the household survey include questionnaires design, village selection and a transect random selection of household. Questions asked include water quality parameters such as colour, scent and taste. Other parameters measured include location of well, well depth, and distance between infrastructures such as septic tank and well.

3.1.1. The Questionnaire Design

The questionnaire was undertaken to gather information about existing conditions of water supply, sewage system, septic tank, drainage and also the situation during disaster, in this case flooding. The variables that being used in the questionnaire were selected during the preliminary survey and literature review. A discussion with Gadjah Mada University was carried out in order to get an idea about areas that were affected by flooding as well as the low quality of sanitations before the survey.

The first part of the questionnaire looked at the socio-economic characteristics of households which considered household income, education levels, house type, the ownership of assets such as land, house, toilet, telephone, electricity connection as well as the supply condition. This part was aimed at identifying the different social classes.

The second part of questionnaire identified the water sources such as private and communal groundwater, water from provider, rainwater, surface water (river), and buying from vendors. The respondent also indicated the quality of water sources, water purification methods if source is not clean, water supply expenditure, and diseases occurred related to water quality. The purposes for which water is used, quantity of water consumed and difficulties in getting water were asked to get user's perception about water supply performance.

The third part of questionnaire included characteristic of sewer system, type of septic tank, drainage type and also about the performance of each system and other supporting elements. These questions were intended to examine the existing urban wastewater system whether it works properly or not. In relation to that, then classification of poor system can be drawn.

The last part of questionnaire focused on performance of the system both urban wastewater and water supply, during disaster condition in this case flooding. The area of research was chosen to be around the Code River which was seen to be much vulnerable to flooding. The perceptions about flooding were established through questions relating to flooding frequency, duration of flooding, height of flooding and especially the water supply quality after disaster.

3.1.2. GPS Points and Other Measurements

Other measurements were carried out together with the questionnaire survey. GPS points of houses, septic tanks, wells, and kitchens were taken with the purpose to knowing the distances between them in reality. Apart from GPS points taken, the measurement of distance was done with the step measurement, starting from one point to the others as a check. With households using well water, the GPS points and step measurements were taken from the well to the septic tank. Distance from septic tank to the kitchen where taps are usually located was measured in the cases of households using water from providers. Beside the GPS points and step measurement, the well depth was also measured by using meter tape in case of households with wells. The points and step of measurements are described in the figure 3-1 below. The measure of well depth was taken from the top soil until the surface of the groundwater.

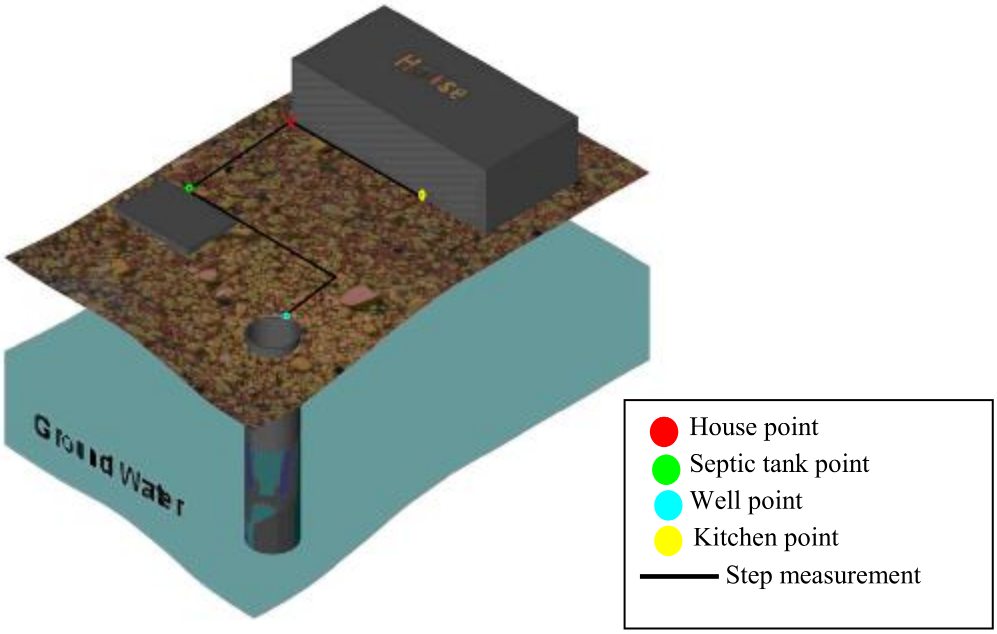


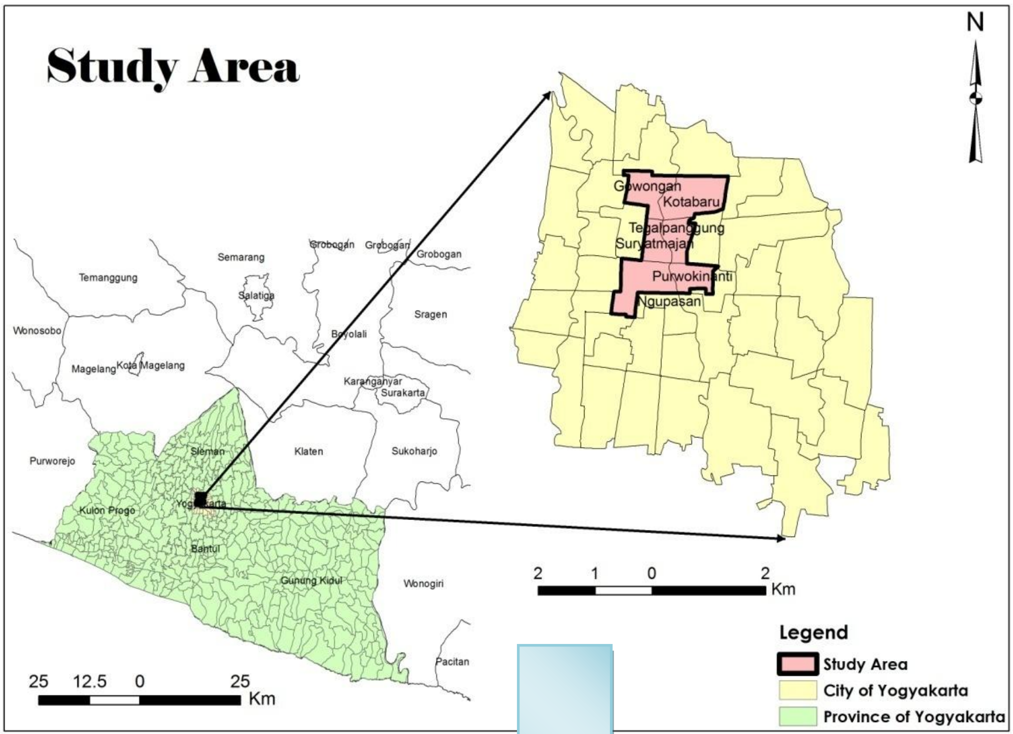
Figure 3-1: GPS Points and Step Measurements

3.1.3. Selection of Urban Villages

The intention of household data collection was to explore and identify how the existing water supply and urban wastewater worked in the local scale. The integration of water supply and urban wastewater would be derived from the interrelation between different systems applied in the field. The selection of urban villages for this research was based on the density of houses and also nearness to the river. It was assumed the high density of houses can translate in the physical proximity of these types of water supply and waste disposal systems. This could cause detrimental effect of not addressed.

Finally six urban villages were selected to for this research about integrated system performance of water supply and urban wastewater system; they are located along the river Code, Municipality of Yogyakarta, Province of Yogyakarta Indonesia. The location of these villages is depicted in figure 3-2. These are the six villages:

- One urban village (Gowongan) in Ward Jetis
- One urban village (Kotabaru) in Ward Gondokusuma
- Two urban villages (Tegalpanggung and Suryatmajan) in Ward Danurejan
- One urban village (Ngupasan) in Ward Gondomanan
- One urban village (Purwokinanti) in Ward Pakualaman



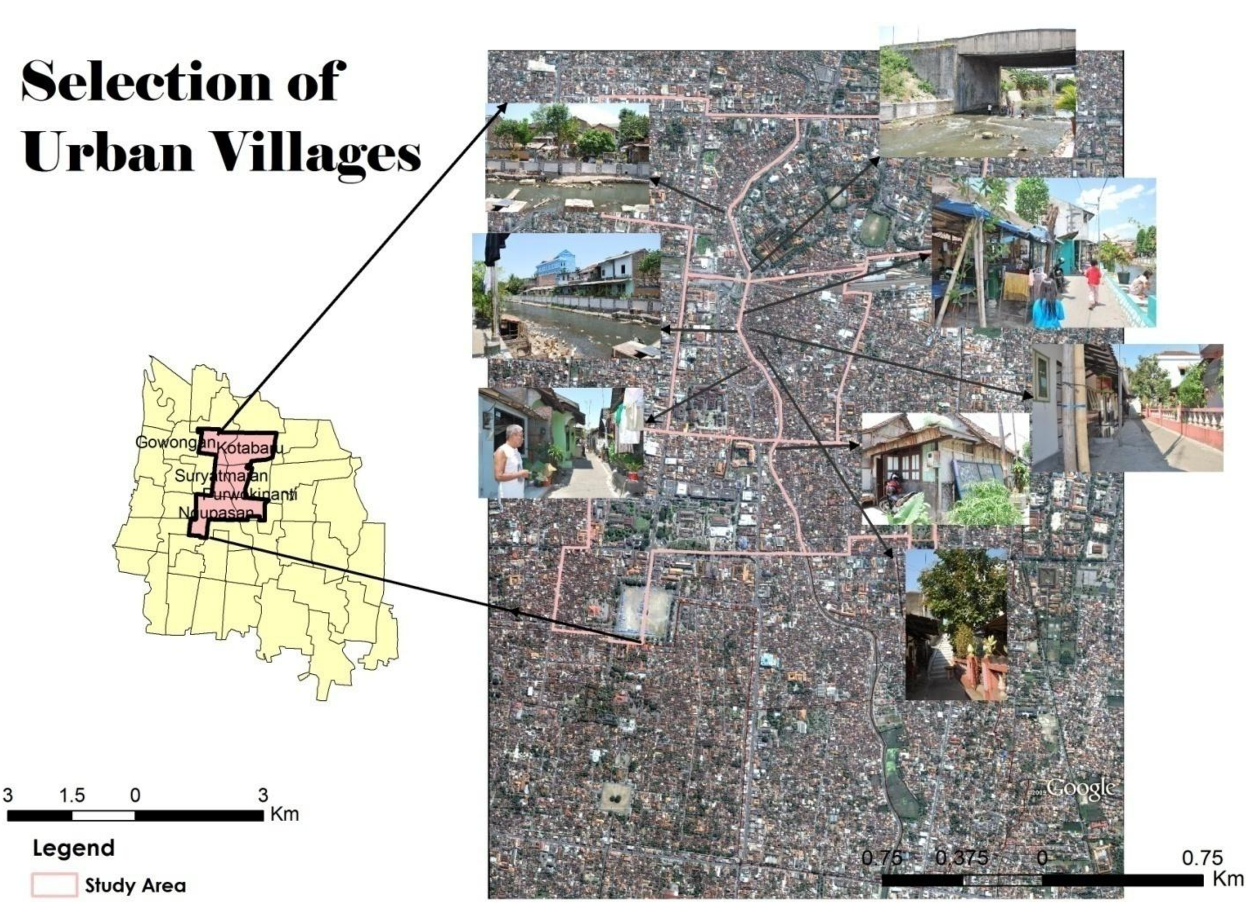


Figure 3-2 Study Area of Yogyakarta City

Among the six urban villages have selected, not all households were surveyed. With the assumption that the proximity to the river could also determine the level of contaminant, only the houses within 100 meters distance from the Code River were selected to be surveyed. Another reason was that in developing countries, most of informal settlement are formed on river banks for easy source of water and to discharge waste into them (Choguill 1996). The sampling procedures are explained much better in the section below.

3.1.4. Sampling Design

Transect sampling

Transect sampling that was used in this research is adapted from line transect sampling (Ringvall, Stahl et al. 1998). A line transect sampling is taken within a fixed distance between two objects. For example in this research the distance from the river to houses. It was made in ArcGIS 9.3 using buffer within several distances from the river. Thus, it determined the sample size as it explains following.

- Sampling frame:
  From a Google earth image, all the buildings in the villages were included as part of the sampling frame. Each of the buildings had the same chance of been selected for the household survey.

- Sampling unit
  The sampling unit of this research was at the household level. This was chosen to get a much disaggregated data as possible. Personal survey was not chosen because of the likelihood of getting similar response from the same household since people in the same household use the same source of water and discharge wastewater into the same sewer, septic tank and drainage.

- Sample size:
  A sampling size of around 334 households was chosen because of time and financial restraints. A 30 x 30m grid was constructed in order to cover the whole villages. The centroid of each grid was generated and 334 households (105 HH within 30 m, 122 HH within 70 m, and 110 HH within 100 m) were selected to be questioned.

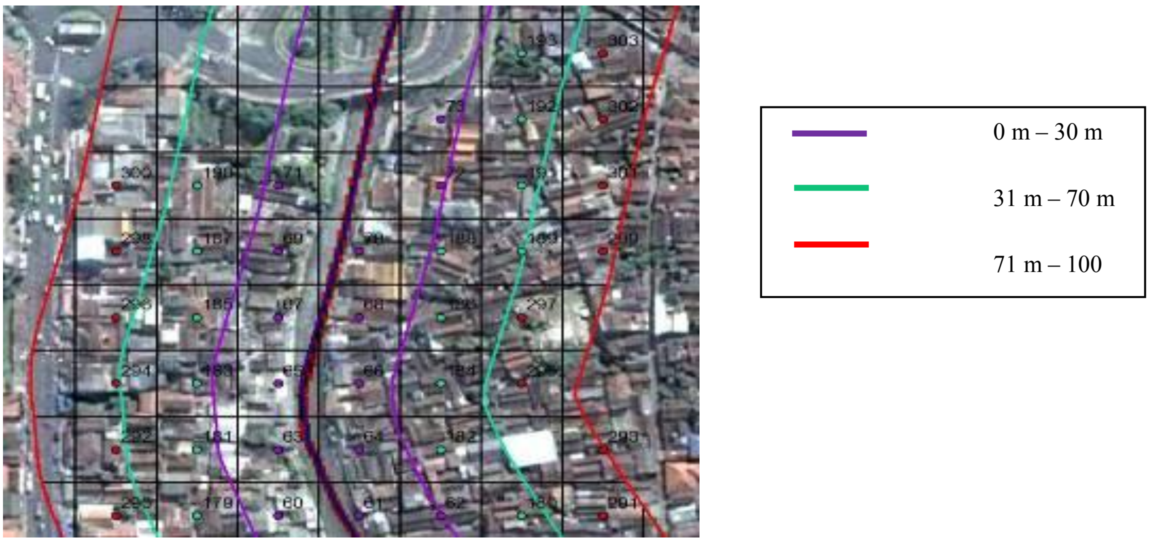


Figure 3-3 Sampling Design

Water quality sampling

The second stage of sampling is to define sample size for water quality testing. A stratified random sampling was applied in choosing household for the test.

- Sampling frame
  The sampling frame for this sampling consisted of the 334 households that had been selected in the previous sampling stage. Each of these 334 households had the same chance of been picked.

- Sample unit
  The sampling unit of this stage was still household survey.

- Sample size
  93 households were chosen to be tested for their water quality. This is based on financial constraints due to the high cost of laboratory testing for E-coli and dissolved solids.

- Strata:
  It was assumed that people living closer to the river are affected more as compared to that afar. Because of this, stratification according to distance of 30m, 70m and 100m were made. 50 households were chosen from all households within 30m from the river, 30 households from those within 31m to 70m and 20 to those within 71m to 100m.

3.1.5. Procedure of Household Surveys

Before the actual survey was done, a pilot survey was conducted on 18th September 2009 in Tegalpanggung Village. About 10 questionnaires had been distributed in order to evaluate the content of questionnaire and also the time consumed whether they were appropriate or not. After the pilot survey had been conducted, it was found that some questions related to urban wastewater system had to be changed. In the literature, there are only three systems of urban wastewater available: separate sewer, combined sewer and urban water storm system. However, in the field, it was found that most of the houses on the river bank do not have appropriate sewer and they discharge the waste water directly to the river from the pipe of their houses. Besides that, there were some cases that people rented land but they owned the house, therefore the question about the ownership assets related to house and land were separated. The actual household survey was conducted from 21st September to 8th October 2009 from 9 a.m. until 5 p.m. with a team of three surveyors. The duration of one house been surveyed was around 20 minutes.

Figure 3-4 Household Survey in Tegalpanggung Village

3.1.6. Water Quality Sampling Procedure

In order to follow the standards of taking and testing the quality of water samples, the Health Agency was employed to carry out the water quality test. Bacteriological contaminant such as total coli forms and chemical contaminants such as total dissolved solids were to be examined. Because of the difficulties in taking samples for bacterial determination, steriled containers and tubes were used in collecting and handling samples. The water were collected in the Pyrex glass as a container and had to be washed with a brush and phosphate free-detergent, rinsed with cold tap water and distilled. The samplings were carried out by a trained surveyor in order to avoid mistake and unsterile samples. This survey was conducted by Health Agency of the city of Yogyakarta for the bacteriology test and dissolved solids test. Moreover, the water quality sampling had to be taken according to the households' points that had been generated from the stratified random sampling. Each of the household had its own label / number in order to match with the household survey before.

3.1.7. Secondary Data Collection

There were some difficulties in gathering secondary data from the government agencies. The causes mostly were because some of the data were confidential and not available if it was in digital format. Some digital data were gathered from the Gadjah Mada University, like water pipe networks, sewer lines, and drainage lines. However, most of them were in different projection system and had to be corrected before work.

Some data related to standard of infrastructures were collected from Public Work Agency (Dinas PU) and Bureau of Planning and Development (Bappeda) with parameters of monitoring water quality and standard of drinking water from the Health Agency (Dinas Kesehatan) City of Yogyakarta.

3.2. Data Entry and Analysis

Data collected from the household survey were inputted into a spread sheet using Microsoft Excel. This was done by the surveyors under supervision from the author. These were cross checked with questionnaire sheets before there were converted into SPSS spread sheet for analysis. Data entered to

SPSS spreadsheet had to be given appropriate codings and data types for statistical analysis. Furthermore, the analysis was including water quality assessment where the index were generated from user's perception, mapping the result of water quality testing, relationship between user's perception and the result of water quality testing, spatial spread of water pollution and factors influencing water pollution.

- **Water quality assessment**

Water quality assessment will be measured from the performance of water supply particularly from the quality of the water. The performance of water supply includes reliability and durability of the system. However, this research is focused only on the reliability that includes availability and continuity.

Availability refers to the physical or financial access to water supply whiles the capacity refers to the adequacy of the source, both quantity and quality of the system. The performances of the systems are quantified and compared to each other. The availability of water supply system can be measured from the type of system that the household use. For the water supply, people may get water from the tap in their house, private well, communal well, etc… Table bellow will explain the system applied in Yogyakarta.

Table 3-1 Types of Urban Infrastructure Systems and Functions

No	Infrastructure	Type of System	Function
1.	Water Supply	Water supply from provider (PDAM)	To distribute clean water to the house through pipe line connections
		Private well	Groundwater that is located in the house compound and it can be generated by jet pump or manually
		Communal well	a public ownership and located not in the house compound, has to be reached by some distances
2.	Sewers lines	Combined sewer	Carrying away a sewage water both sanitary and storm water discharged
		Separate sewer	Carrying away a sewage water only from sanitary waste water
		From pipe directly to the river	Carrying away a sewage water with a direct connection to the river because the houses are closed to the river
	Septic tank	Communal septic tank	Tank designed to take sewage but not connected to a central sewer. Usually one septic tank can accommodate many houses' sewage

		Private septic tank	It has the same function like communal septic tank. However, private septic tank accommodate one or two houses' sewage
	Drainage system	Underground carriage system	Carrying away storm water from the house and usually it is buried underground
		Open drains	Carrying away storm water from house. Usually found on the surface and uncovered.

The availability of clean water source can be shown from the descriptive analysis of the sampled population using water from different sources and from the water consumption of the people. The quality of water can also be analyzed from respondents' perception about physical condition of their water such as odor, taste and colour qualities in daily life and after flooding. Continuity relates to the consistency of the system whether there is a failure in the distribution like pipe damaged, etc… The continuity of water supply can be categorized as: continuous supply of the water every day, difficulties in peak hours or difficulties during dry season as well as the continuity during flooding. The water supply index considered odor, taste, colour and continuity of the service during normal condition and after flooding.

There are two parameters to be measured in order to identify the interrelation between water supply and contamination with sewer or septic tank. *E.coli* or total coliform is considered as an important parameter for testing the existing of microbial in the water. Another chemical parameter that is used as water quality assessment is total dissolved solids. Total dissolved solids (TDS) in water supplies originate from natural sources, sewage, urban and agricultural run-off, and industrial wastewater (WHO 2003).

In any standard of water quality always mentioned that water to be consumed for drinking, cooking and other purposes related to human's health has to fulfil some criteria or parameter before being used. The standard of water quality in this research is using standard from Minister of Health Indonesia (Ministry of Health 2002) and WHO. The table below shows drinking water quality standards comparative table between WHO and Indonesian's standard. The user's perceptions about water quality were compared with the result of water quality testing (total coliforms and TDS) in order to identify the relationship.

Table 3-2 Comparative Standard of Water Quality

Parameters	WHO standards	Indonesia standards
Total Coliforms Drinking water Clean water	 0 MPN/100 ml Not mentioned	 0 MPN/ 100 ml 50 MPN/ 100 ml
Total Dissolved Solids	300 – 1200 mg/litre	Maximum 1500 mg/litre

- **Spatial spread of water pollution**

The results from water quality testing related to total coliforms and TDS are used to identify the areas that contain high coliforms or TDS. The water quality results were inserted into SPSS then joined with the point of houses in ArcMap 9.3, therefore it can be identified the houses with the value of total coliforms and TDS.

In order to identify source of pollution, analysis spatial autocorrelation was carried out. The analysis was done in ArcMap 9.3 using spatial statistic tool of moran's I index, the spatial autocorrelation between points were identified.

After analysing the spatial autocorrelation between points, evaluation of water pollution spreading was carried out by operating spatial interpolation in ArcMap 9.3. This is aimed to obtain the values of water pollution in the place that lack of samples.

- **Factors influencing water pollution**

The interrelation between water supply and sanitation (septic tank) would be measured by evaluating the main predictor of water pollution. Other factors that also considered were distance from the river to houses and the well depth. Multiple regression analysis in SPSS 13 was undertaken to identify the main factor that caused water pollution. The correlation was first analysed before multiple regression to identify the significant relationship.

4. Study Area, City of Yogyakarta, Indonesia

This chapter deals with the local context of study area. The study area presents the existing condition of its demographic and geographic conditions in general and also provides an overview of public utilities' characteristics. The public utilities' characteristics in this chapter includes the major research of water supply condition, sewer system, drainage system and another supporting utility like waste collection system.

4.1. An Overview of Study Area

4.1.1. Physical

The city of Yogyakarta is one of the historical cities in Indonesia located in Java Island serving as the provincial capital of D.I. Yogyakarta (Daerah Istimewa Yogyakarta). It is also categorized as a big city and nicknamed as a student city because 20% of the population are students and with about 137 higher education institutes. The city is situated between 110°24"19"- 110°28'53" East Longitude and 07°49"26"- 07°15'24" South Latitude with 32.5 km² of land area about 1.02% of Province D.I. Yogyakarta. Yogyakarta City is bounded with two counties: Sleman on the north-western side, Bantul on south-eastern side. The administrative region of Yogyakarta consists of 14 districts and 48 sub-districts or urban villages (BPS Statistics of Yogyakarta City 2007). Table 4-1 presents the districts and sub-districts of Yogyakarta City.

Table 4-1 Districts and Sub-Districts in Yogyakarta City

No.	Districts	Land area (km²)	Sub-districts (urban villages)	Land area (km²)
1	Mantrijeron	2,61	Gedongkiwo	0,9
			Suryodiningratan	0,85
			Mantrijeron	0,86
2	Kraton	1,4	Patehan	0,4
			Panembahan	0,66
			Kadipaten	0,34
3	Mergangsan	2,31	Brontokusuman	0,93
			Keparakan	0,53
			wirogunan	0,85
4	Umbulharjo	8,12	Giwangan	1,26
			Sorosutan	1,68
			pandean	1,38
			Warungboto	0,83
			Tahunan	0,78
			Muja-muju	1,53
			Semaki	0,66
5	Kotagede	3,07	Prenggan	0,99

			Purbayan	0,83
			Rejowinangun	1,25
6	Gondokusuman	3,99	Baciro	1,06
			Demangan	0,74
			Klitren	0,68
			Kotabaru	0,71
			Terban	0,8
7	Danurejan	1,1	Suryatmajan	0,28
			Tegalpanggung	0,35
			Bausasran	0,47
8	Pakualaman	0,63	Purwokinanti	0,3
			Gunungketur	0,33
9	Gondomanan	1,12	Prawirodirjan	0,67
			Ngupasan	0,45
10	Ngampilan	0,82	Notoprajan	0,37
			Ngampilan	0,45
11	Wirobrajan	1,76	Patangpuluhan	0,44
			Wirobrajan	0,67
			Pakuncen	0,65
12	Gedongtengen	0,96	Pringgokusuman	0,46
			Sosromenduran	0,5
13	Jetis	1,7	Bumijo	0,58
			Gowongan	0,46
			Cokrodiningratan	0,66
14	Tegalrejo	2,91	Tegalrejo	0,82
			Bener	0,57
			Kricak	0,82
			Karangwaru	0,7
	Total area	32,5		32,5

Source: (BPS Statistics of Yogyakarta City 2007)

Topographically, the city of Yogyakarta is located in the southern plain of Merapi mountainside with a slope between 0 – 2 % within the height of 114 meters above sea level. Half of the area (1.657 Ha) have heights less than 100 meters with the rest (1,593 Ha) having heights between 100-199 meters above sea level. Meanwhile, geologically, the city is mostly founded on the fluvio volcanic mountain of Merapi. The soil formation is therefore dominated by the volcanic eruptions from volcanic activities.

The hydrological condition in this city is influenced by the volcanic of Mount. Merapi. High levels of groundwater are observed near this mountain. Ground water levels vary from 0.5 to 20 meters increasing as one move away from the volcanic mountain. However, the condition of groundwater on the southern part of the city is shallow and polluted. Mostly, groundwater pollutions are caused by the bad sanitation in residential areas and even non residential areas. Majority of the groundwater pollutants have been seen to be high containment of nitrate and *E.coli*, especially in a very highly dense areas. An average rainfall depth of 2012 mm / year with 119 days of raining is observed. The city has an average temperature of 27.2° Celsius with about 24.7 % of moisture.

4.1.2. Demographic Characteristics

Demographic characteristics describe the population structure of Yogyakarta City based on age, gender, level of education and economic conditions. This also explains about population growth and population density in Yogyakarta City.

The highest number of population based on gender and age is in the class between 20 – 24 years old with 45,351 male and 48,237 female (BPS Statistics of Yogyakarta City 2007). A detailed composition about this is provided in table 4-2 and figure 4-1 below.

Table 4-2 Population Structure based on Age and Gender in 2006

Age group	Male	Female	Total
0-4	16288	17143	33430
5-9	16257	17243	33500
10-14	15473	16670	32143
15-19	26778	28849	55627
20-24	45351	48237	93588
25-29	25697	26215	51912
30-34	21218	21627	42845
35-39	18779	19252	38031
40-44	16281	16805	33085
45-49	12824	13327	26150
50-54	9143	9606	18749
55-59	8193	8337	16530
60-64	7623	7722	15344
65-69	6173	6405	12578
70-74	4831	5083	9914
75+	4705	5058	9763
Total	255612	267579	523191

(Source: BPS Yogyakarta, 2006)

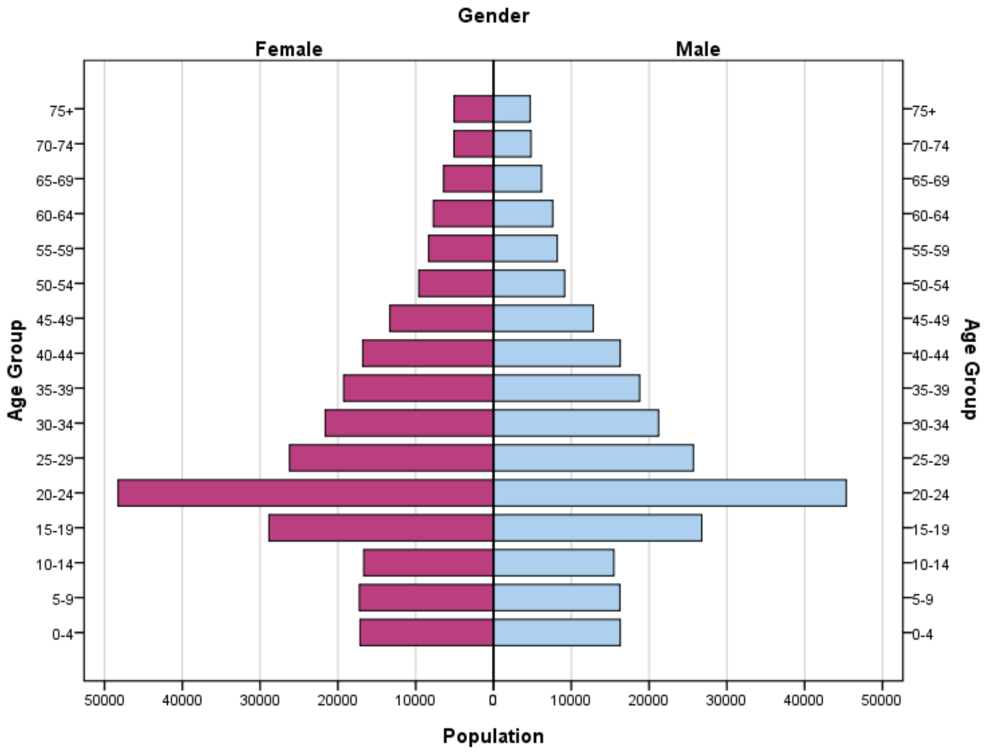


Figure 4-1 Number of Population based on Age

4.1.3. Population Growth and Population Density

The increase in population growth through the past years is relatively high. At the end of 2005, the population of Yogyakarta City was around 518,033 people and at the end of 2006 the population reached 523,191 people. An average growth of 0.9% annually was experienced from 2001 to 2006.The population growth in Yogyakarta City is depicted at the districts level in table 4-3 below.

Table 4-3 Number of Population and its Growth during 2001 until 2006

No.	Districts	Number of Population						Average Population Growth (%)
		2001	2002	2003	2004	2005	2006	
1.	Tegalrejo	38809	39433	40357	40981	41261	41860	1,55
2.	Jetis	36726	37497	38268	37700	37980	38213	0,85
3.	Gondokusuman	73046	73730	74414	74919	75199	75803	0,73
4.	Danurejan	30660	30840	31020	31284	31564	31707	0,73
5.	Gedongtengen	25998	26448	26898	23956	27236	26791	1,17
6.	Ngampilan	23079	23189	23299	23425	23705	23841	0,67
7.	Gondomanan	16837	16693	17084	17215	17495	17958	0,97
8.	Pakualaman	14790	14762	14862	14902	15182	15118	0,66
9.	Kotagede	30382	30662	30942	31222	31502	32269	0,91

10.	Umbulharjo	71064	71344	71624	71904	72184	74347	0,39
11.	Mergangsan	41928	42208	42488	42768	43048	42811	0,66
12.	Kraton	28253	28533	28813	29043	29373	29952	1,98
13.	Wirobrajan	30139	30533	30882	31162	31442	31397	1,06
14.	Mantrijeron	39223	39693	40163	40582	40862	41124	1,03
	Total	500934	505565	511114	514130	518033	523191	0,90

Source: (BPS Statistics of Yogyakarta City 2007)

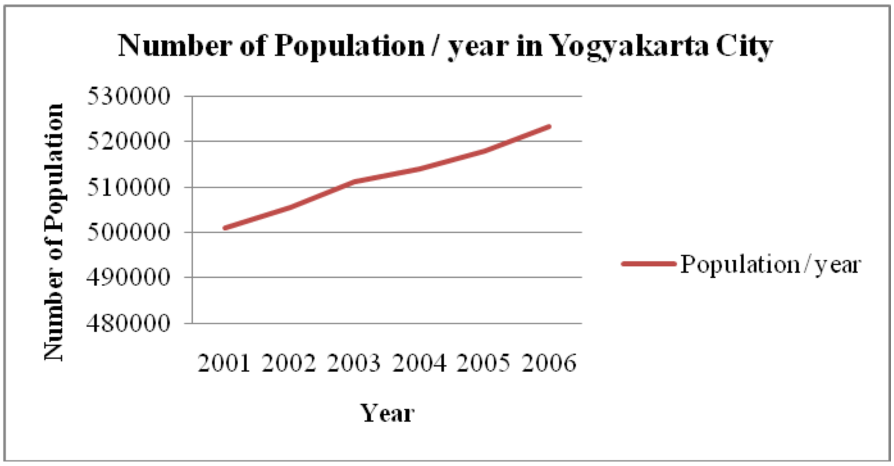


Figure 4-2 Population Growth in Yogyakarta City during 2001 -2006

Generally the city of Yogyakarta has a population density of about 16,262 inhabitants / km². Population density is however not evenly distributed across the districts. Ngampilan has the highest population density of about 29074 inhabitants/km^2 with Umbulharjo having the least population density of about 9156 inhabitants/km^2 (table 4-4).

Table 4-4 Population Density of Yogyakarta City on 2006

No	District	Land area (km²)	Number of population (inhabitants)	Population Density (inh/km²)
1	Tegalrejo	2,91	41860	14385
2	Jetis	1,7	38213	22478
3	Gondokusuman	3,66	75803	20711
4	Danurejan	1,103	31707	28746
5	Gedongtengen	0,96	26791	27907
6	Ngampilan	0,82	23841	29074
7	Gondomanan	1,12	17958	16034
8	Pakualaman	0,63	15118	23997
9	Kotagede	3,07	32269	10511
10	Umbulharjo	8,12	74347	9156

11	Mergangsan	2,31	42811	18533
12	Kraton	1,4	29952	21394
13	Wirobrajan	1,76	31397	17839
14	Mantrijeron	2,61	41124	15756
	Total:	32,173	523191	16262

Source: (BPS Statistics of Yogyakarta City 2007)

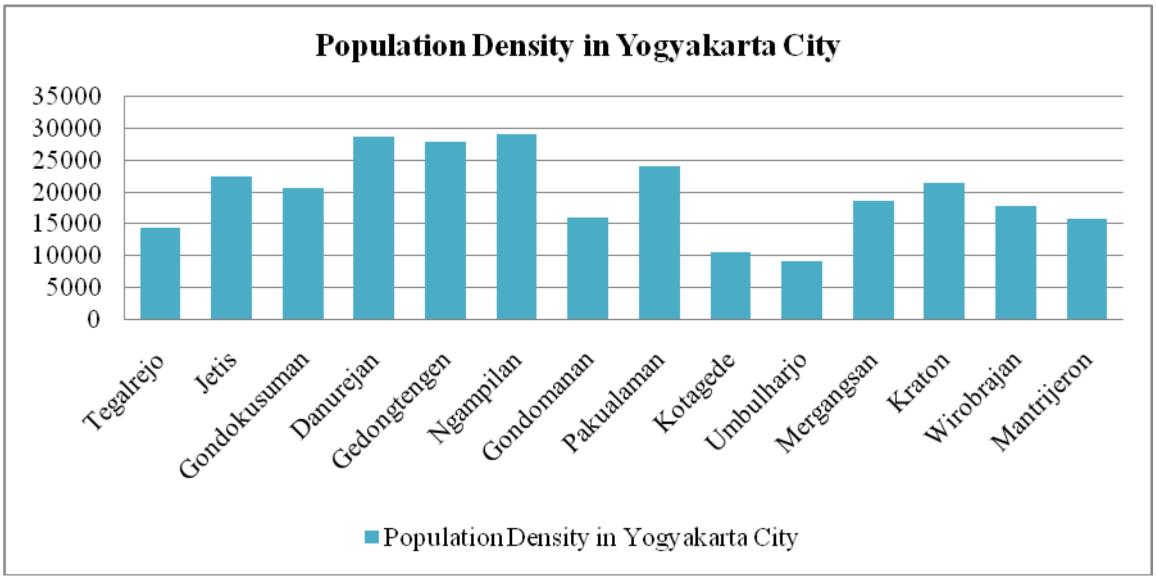


Figure 4-3 Population Density of Yogyakarta City on 2006

4.2. Infrastructure Conditions

Urban infrastructures managed by Public Work Agency includes water supply, waste collection, sewage system, drainage, and building arrangement. This section talks about drinking water, sewage system, and drainage in Yogyakarta City.

4.2.1. Water Supply

Based on the data from PDAM Tirtamarta (provider incharge of water supply), the production of water supplied in 2006 was 17,743,191 m³. This depicts a decrease in water production of about 4.79% from the previous year which was 18,635,137 m³. The volume of water being distributed was 16,232,106 m³ or about 91.48% from the total production. The number of customer that used water supply from PDAM in 2006 was 34,750 customers. If compared with the number of population of Yogyakarta City in 2006, the number of customer only represented 39.85% from the total population. Most of the customers came from households or residential areas and government organizations or offices. The number of customer from non-commercial group was 32,387 customers or 95.53% from the total customer, this consisted 31,299 customers from household and 1,088 from government organizations. During the last 5 years, the condition of water production and water distribution in Yogyakarta were fluctuated. For instance, in 2004, the water production was 17,535,644 m³ with distribution around 10,973,780 m³. Meanwhile, in 2005, the water production increased by about 1.02% representing about 18,635,137 m³ of water production. Despite the increase in production, a decrease in water distribution of about 1.03% was observed.

Water supply infrastructures have a problem with the water quality because of the other infrastructure systems. The sources of water supply from the groundwater and water pipe are been contaminated because of human activities both from industrial and commercial activities. Water quality from the well (or non pipe) were not fulfilling the standard of drinking water having E.coli containments reaching 2400 MPN/ml.

Water supply comes from two main sources, surface water and groundwater. Surface water sources include two water springs from Umbul Wadon and Kali Kuning and the Padasan River which is equipped with a semi-complete water treatment plant. Groundwater are extracted from depth wells and shallow wells. Water is extracted from 8 deep wells located in Kota Gede, Ngaglik, and Bedok; and 8 shallow wells located in Karang Wuni, Besi I, Besi II, Gemawang, Bulusan, Kentungan and Jongkang. The water from Umbul Wadon are purified through chlorination to reach drinking water standards physical and chemical, before they are distributed.. Water from Kali Kuning has to be purified through filterization and sedimentation processt to disinfect the water. The groundwater is usually treated with aeration, this applied for water coming from production wells in Bedog, Ngaglik, and Karanggayam, while the water from Kotagede was treated with aeration, coagulation, flokulation, filtration and chlorinitation as disinfectants. The water coming from shallow wells were treated using filter and chlorinitation.Table 4-5 below shows the number of households using different type of water sources.

Table 4-5 Clean Water Sources based on Districts

No.	Districts	Number of Households	Clean Water Sources			
			Tap water	Pump water	Well / spring	River / Surface Water
1.	Mantrijeron	10488	1340	45	9086	17
2.	Kraton	8574	1452	30	7044	48
3.	Mergangsan	10796	1468	70	9202	56
4.	Umbulharjo	16357	1380	605	14226	146
5.	Kotagedhe	7004	578	588	5816	22
6.	Gondokusuman	19416	2888	88	16296	144
7.	Danurejan	8163	1911	431	5748	73
8.	Pakualaman	3981	706	75	3177	23
9.	Gondomanan	5726	878	27	4769	52
10.	Ngampilan	6186	1566	97	4502	21
11.	Wirobrajan	7862	1352	70	6425	15
12.	Gendongtengen	7175	3172	65	3908	30
13.	Jetis	10196	5104	506	4447	139
14.	Tegalrejo	9916	1767	56	8093	30
Total		131840	25562	2723	102739	816

Source: (Health Agency City of Yogyakarta 2009)

4.2.2. Water quality monitoring

The water supply monitoring has been done from years in order to evaluate the containment of bacterial in the water. The water samplings were taken randomly in each of the district and some of the samplings have been taken from the hospitals or clinics. This has been done by the Health Agency. The water samplings mainly were taken from the tap water. Usually, as a project from the provider where they have to monitor their water quality.

The main tasks of Health Agency in monitoring the water quality are (Ministry of Health 2002):

1. Inspection of the sanitation condition and water sampling taken are including groundwater, production process, tap water and refill of portable water.
2. Water quality testing is done in the laboratory.
3. Providing recommendations to solve the water quality problems.
4. Public health education.

The provider of water supply has to (Ministry of Health 2002):

1. Test the water and ensure the quality of drinking water fulfils the standard. The water quality testing includes:

- Measurement from the installation of water treatement
- Measurement from the distribution pipes
- Measurement from the main to the consumers
- Measurement of the refill or sachet (portable water)

2. The water testing as mention in number (1) has to follow the activites of water quality monitoring such as:

- For the tap water, the sample for microbial testing (table 4-6):
- Chemical testing: minimum 10% from the samples of microbial
- The sample has to represent the whole inhabitants that served by the water pipe

The monitoring of water quality from January until August 2009 in City of Yogyakarta as recorded for 12 districts showed that only 277 samples out of 636 samples were suitable as drinking water the value of 0 MPN / 100 ml total coliforms. The water samplings were taken both for tap water and groundwater (table 4-7).

Table 4-6 Criteria of Sample Size for Tap Water

Number of people	Minimum Sample per Month
< 5000 inhabitants	1 sample
5000 – 10000 inhabitants	1 sample / 5000 inhabitants
> 100000 inhabitants	1 sample / 10000 inhabitants, substraction 10 samples

Source: (Ministry of Health 2002)

Table 4-7 Monitoring of Total Coliforms

Districts	Classes of Total Coliforms					
	1	**2**	**3**	**4**	**5**	**Total**
Kotagede	36	7	13	5	28	89
Mantrijeron	26	3	6	2	20	57
Pakualaman	4	0	1	0	2	7
Danurejan	9	3	5	5	17	39
Gondokusuman	64	7	19	13	30	133
Tegalrejo	15	1	5	3	9	33
Jetis	7	1	1	1	0	10
Gondongtengen	5	1	5	1	2	14
Ngampilan	22	3	10	7	10	52
Kraton	3	1	0	1	0	5
Gondomanan	51	2	1	0	5	59
Wirobrajan	35	8	19	12	64	138
Total	**277**	**37**	**85**	**50**	**187**	**636**

Source: (Health Agency City of Yogyakarta 2009)

1 : 0 MPN / 100 ml

2 : 51 – 100 MPN / 100 ml

3: 101 – 1000 MPN / 100 ml

4 : 1001 – 2400 MPN / 100 ml

5 : > 2400 MPN / 100 ml

4.2.3. Sewage System

In general, almost all the districts in Yogyakarta City have connection to sewage. Only two districts that do not have connection: Kotagede and Wirobrajan Districts. Mergangsan District has the largest sewage system with 30.366.43 meters followed by Kraton District with 26,212.70 meters and after that Jetis District with 20,619 meters. During 1998 until 2001, the construction of sewage system had increased 4.07% from the increasing of new connection (Public Works 2002). Table 4-8 describes the increasing construction of new sewage system based on its components.

Table 4-8 Sewage Construction

Year	Type of system (meters)				
	A system avoid clogging	Main system	Lateral	Total length	Manhole
1998	19433	29436	124093	172962	4639
1999	19433	31443	125891	176767	4751
2000	19714	31443	127547	178704	4840
2001	19714	31443	128027	179184	4860

Source: (Public Works 2002)

Approximately 20% of the total population are been served by the centralized sewage system. This system consists of lateral network and a system to avoid clogging in the pipe, it was established during 1930s, and main network / pipe with the waste water treatment plant was constructed in 1995. Apart from that, more or less 60% of the people needs for sanitation has been served by the local sanitation facilities. The rest of the population still use public toilet or discharged waste directly into the river. Meanwhile, waste water from industries (small and medium type of industries) are still been discharged without treatment. The services to clean-up septic tanks are usually was carried out by private sectors using septic tank truck or manually. The sludge from septic tanks are sucked when clogging (or has not been function in long period of time). Sludge from septic tanks is sometime treated before discharging. However they are sometimes discharge without treatment into the environment (Public Works 2002).

4.2.4. Drainage System

In 2005, the total length of open drains in Yogyakarta City was about 90,790 meters, with closed drains of about 140,725 meters and culverts of about 3,837 meters. In some places, flooding are still experience in the rainy season; for example in Karang Malang. Most of these drainage systems are found in residential areas, commercial and industrial areas along roads. Most of the drainage systems both close and open drains had problem with sedimentation caused by garbages and soil. Furthermore, many of drainage systems were not maintained properly, decreasing their performances. Most of the inlet did not function effectively because it was located higher than the street or because it was blocked by soil, therefore the rain water could not be accomodated by the drainage. Absorbing wells that have been constructed were not performing properly because the inlets have been blocked by garbages or soil (Public Works 2002).

4.2.5. Infrastructure Provision in the Study Area

The residential area along Code River was to be categorized as slum areas. In 1984, the Government of City of Yogyakarta had planned to demolish the houses along the river (Voice of human rights 2007). In early 1980s after the big flooding hit the area along Code River, an initiative of one person (Romo Mangun) and together with the local communities there, the housings had been re-built to be more liveable (converted the houses from non-permanent to be permanent) and provided communal services such as communal well and toilet (Voice of human rights 2007). The pictures below depicted some communal infrastructures along the Code River.

Figure 4-4 Housing and infrastructure conditions in study area

5. Water Supply Assessment and Interrelation

This section looks into the analysis of water supply assessment and interrelation with the sanitation. The first section of this chapter discusses the water supply assessment by observing the availability and the use of water supply, the generation of water supply index and the quantitative analysis of total coliforms and total dissolved solids. The second section of this chapter identifies the spatial spread of water pollution including the methods that are applied as well as the result. The last part of this chapter predicts the main source of total coliforms pollution in the groundwater.

5.1. Water Supply Assessment

This session describes the availability of water sources, the use of water supply. It moves on to generate a water supply index for assessing the different water sources. Quantitative analysis about water quality indicators and the relationship between user's perceptions and quantitative analysis is also examined. User perceptions about water quality are based on the household's questionnaire surveyed. They are then compared with the quantitative test carried out about the quality of water sources used. The first sub-chapter is a brief description about the availability and the type of water sources been used. The second sub-chapter concerns the generation of the water supply index based on the quality and continuity. The quality of water supply consists of odor, taste and colour in normal conditions and after flooding. The continuity of water supply portrays whether consumers have access to water continuously without shortages or not. The quantitative analysis involves the comparison of user's perception of water quality with the water quality test (total coliforms and total dissolved solids) performed.

5.1.1. Descriptive Analysis: Availability and the Use of Water Supply

In order to assess the interrelationships between water supply and waste water systems, the sources of water consumed by the individuals in the city needed to be identified. The availability of these sources of water supply to consumers was identified.

Water supply sources used in the communities could be categorized into pipe water, groundwater and combination of the two. The classification of existing sources of water supply with the percentage of users can be seen in the graph below (figure 5-1). From the household survey, a majority of the people (66.5%) were using groundwater that consisted of 32% using only private groundwater, 22.5% using only communal groundwater, 7.2% using private groundwater and 4.8% using communal groundwater in addition to service from providers. About 45.5% of the people use water from PDAM, consisting of 33% using only tap water from PDAM, 7.2% and 4.8% using it in addition to private and communal groundwater respectively as their water sources.

A classification about the income levels of the people and their water sources was plotted. People with income levels below 700,000 Indonesian rupiah were considered to be of low income (Government of Yogyakarta Province 2009). People with income levels between 700,000 and 2,000,000 Indonesian rupiah were considered to be of middle income with those above this level considered as high income earners. Even though most of the people using tap water were in the middle to high income earners, a substantial percentage (40.4%) of tap water users were classified as of low income. Considering the use of private groundwater, most of users were seen to be in the middle to high income levels with about 29.0% in the low income group. However, communal groundwater was mostly used by low income earners (71.4%) with 24.2% and 4.4% of users classified as middle income and high income earners.

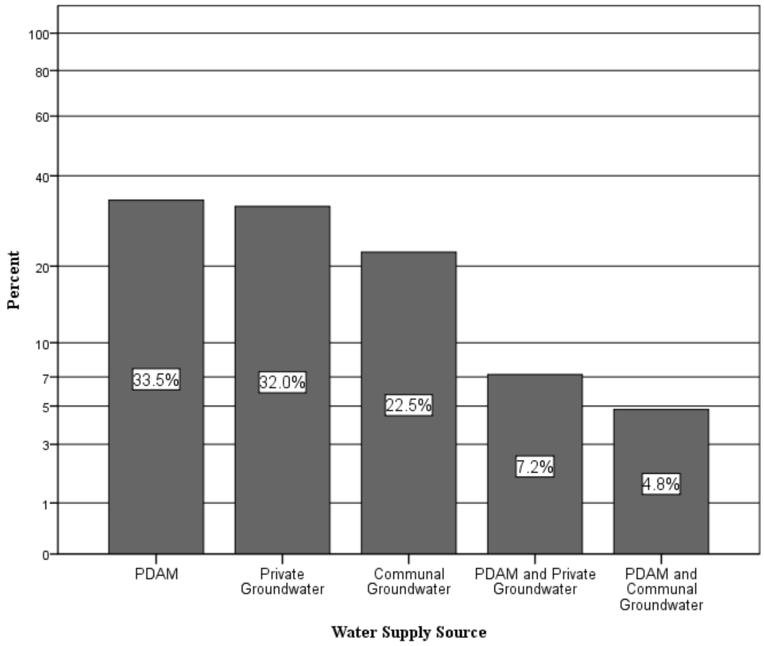


Figure 5-1 Percentage of water supply sources

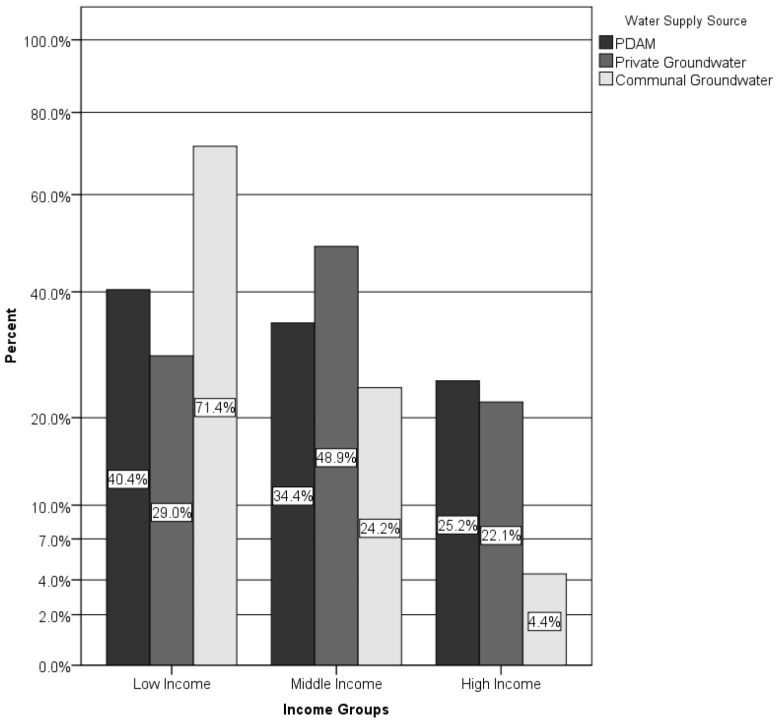


Figure 5-2 Percentage of People Using Water Sources based on Income Level

Different uses for the different water sources were observed. Water sources from PDAM were mostly (85.6%) used as drinking water and for cooking, washing and showering. About 13.4% of the respondents however used PDAM water source for gardening activities. This may be as a result of the few houses having garden. The use of private groundwater and communal groundwater tended to be the same as tap water from PDAM, in which 81.7% of private groundwater and 82% of communal groundwater were used as drinking, cooking, washing and showering. Besides that, only 8.4% of private groundwater and 2.2% of communal groundwater were used for gardening purposes (Appendix).

From the household survey, it was also realised that about 26.7% of the people bus portable water such as sachet water for drinking purpose. This may indicate the perception of water quality by a section of the people. A cross tabulation has been made of the people with the different sources of water that purchase portable water for drinking purposes (table 5 -1). From the table, it could be seen that about 50% of the people using both PDAM and private groundwater also bought portable water. This may however not be representative because of the small sampling size compared to those with only one source of water supply. It could therefore be said that the majority of consumers also buying portable water were those with PDAM water sources with about 36.6%.

Table 5-1: Cross Tabulation of Water Supply Sources and Purchase of Portable Water

		Total number of households in survey	Number purchasing portable water for drinking purpose	Percentage purchasing portable water for drinking purpose
Water supply source	PDAM	112	41	36.6
	Private Groundwater	107	23	21.5
	Communal Groundwater	75	8	10.7
	PDAM and Private Groundwater	24	12	50.0
	PDAM and Communal Groundwater	16	5	31.3
	Total	334	89	26.7

5.1.2. Water Supply Index

After determining the different water sources used, this section aims at analysing the performance of water supply available in the study area of Yogyakarta City. To compare the performances of the different water sources, a water supply index was generated based on user perceptions. Water supply has to deliver sufficient services especially the quality of water supply and the condition of the system whether they performed good or not.

The water supply index consisted of indicator concerning water quality before and after flooding and continuity of water supply. Water quality indicators include; the percentage of water without scent, colour and taste. The continuity of water supply indicator was to look at whether water was available all the time or not. The different water sources were graded based on these indicators.

5.1.2.1. Quality and continuity of water supply

- **Odor quality of water**

The odor quality of water sources from PDAM, private groundwater and communal groundwater were observed from the household survey. About 53.9%, 98.5% and 98.9% of water sources from PDAM, private groundwater and communal groundwater respectively were without any scent (figure 5-3). The rest were reported to be with scents, smelling like chlorine, rust iron and muddy. The smell of chlorine in could be due to the use of chlorine as disinfectant in drinking water purification processes (Drinking Water Inspectorate 2003). Other smells like rust iron and mud could be originating from the use of materials such as copper, iron and galvanised pipes in the construction of water supply systems (Drinking Water Inspectorate 2003).

In looking at the case after flooding, most of the water sources were seen to be with scent. About 52.6%, 47.8% and 61.7% of water sources from PDAM, private groundwater and communal groundwater were seen to be smelly (figure 5-4). Waste and mud smell were the main scents reported by consumers after flooding. These were evident in all three types of water sources.

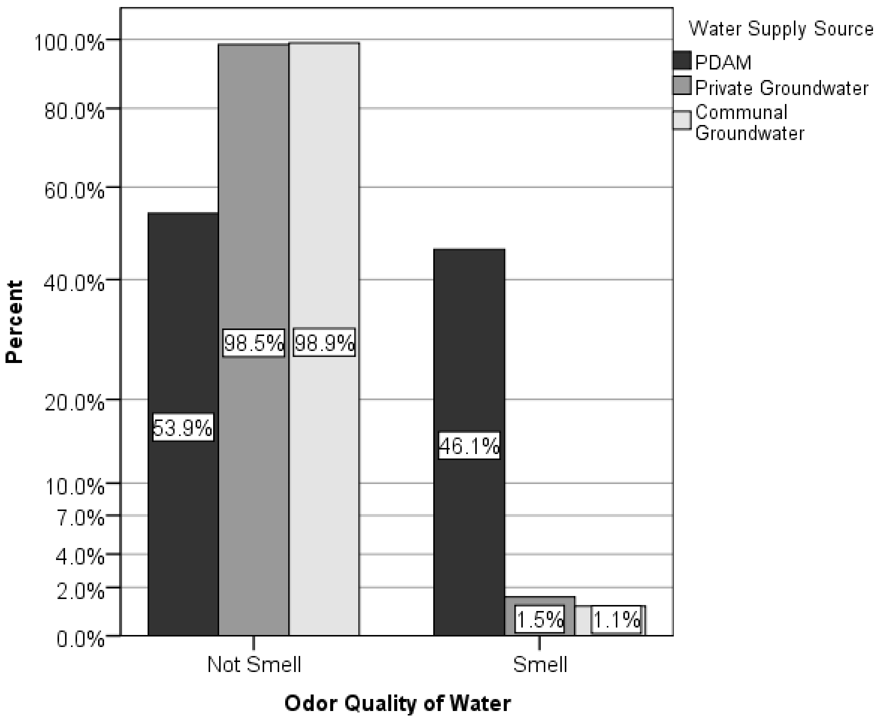


Figure 5-3: Odor Quality of Different Sources of Water before Flooding

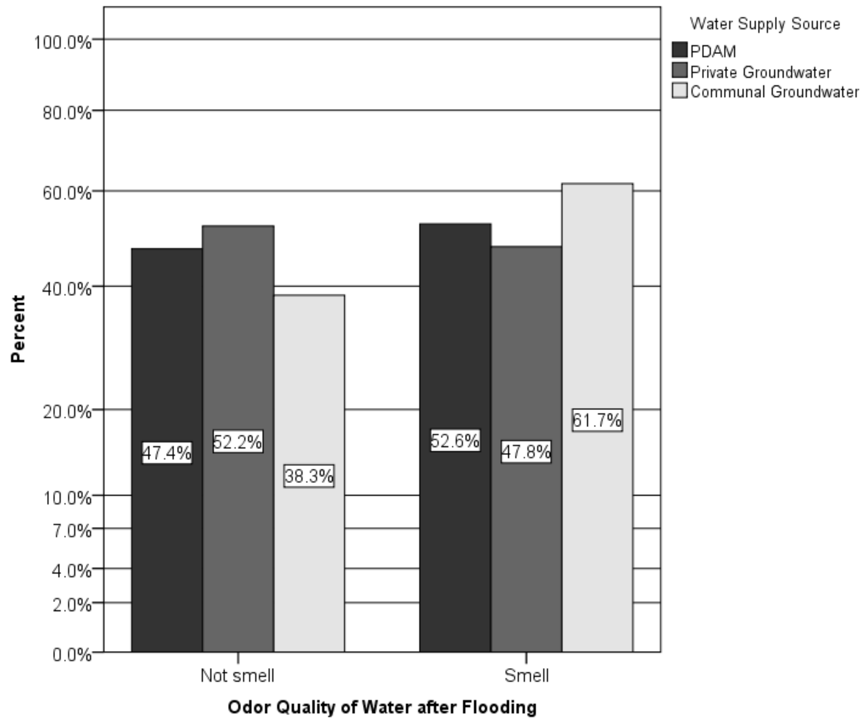


Figure 5-4: Odor Quality of Different Water Sources after Flooding

- **Taste quality of water**

After exploring the users' perception of odor quality of water from different sources, the next step was to observe the taste quality of water from the same sources of water supply. About 50% of respondents indicate good taste quality of PDAM with the rest indicating strong taste like chlorine. Contrary to that experienced with water from PDAM, all respondents reported good taste quality for both types of groundwater sources (figure 5-5).

The taste quality of water source after the flooding was then assessed to identify the conditions after flooding. From the questionnaire, about 47.4%, 52.2% and 38.8 percent of respondent indicated good water taste for PDAM, private groundwater and communal groundwater sources respectively (figure 5-6). This indicated a reduction in the water taste quality in all the water sources especially the communal groundwater source which recorded 100% good taste before flooding.

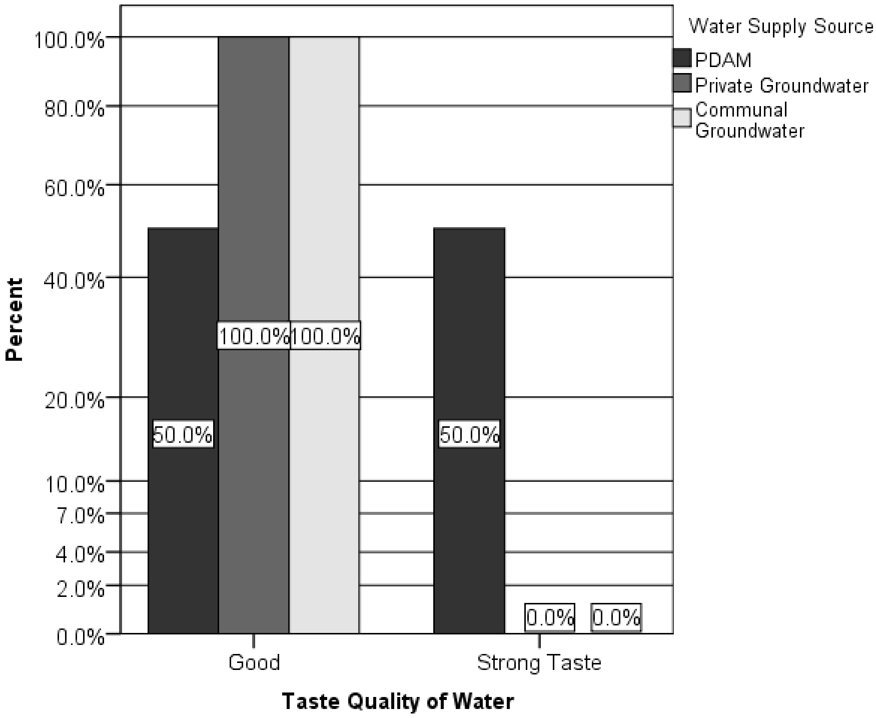


Figure 5-5: Taste Quality of Water before Flooding

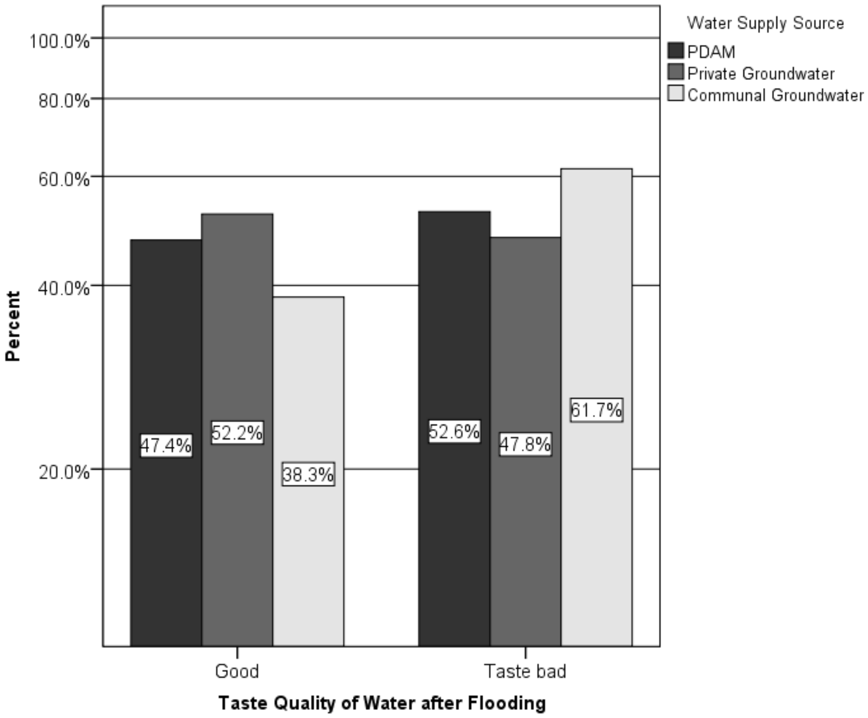


Figure 5-6: Taste Quality of Water after Flooding

- **Colour quality of water**

Another physical quality of water is colour. Water with good quality is usually colourless. Percentage of respondents with colourless and coloured water were made (figure 5-7) From the survey, about 57.9%, 98.5% and 97.8% of respondents with PDAM, private groundwater and public groundwater sources were colourless. The rest reported water with colour from brownish to blackish to muddy.

The after flooding case saw about 47.4%, 50% and 40.4% of respondents reporting colourless water for PDAM, private groundwater and communal water sources respectively (figure 5-8). Once again a decrease in the quality of water was observed with respondents experience brownish and muddy coloured water in most cases.

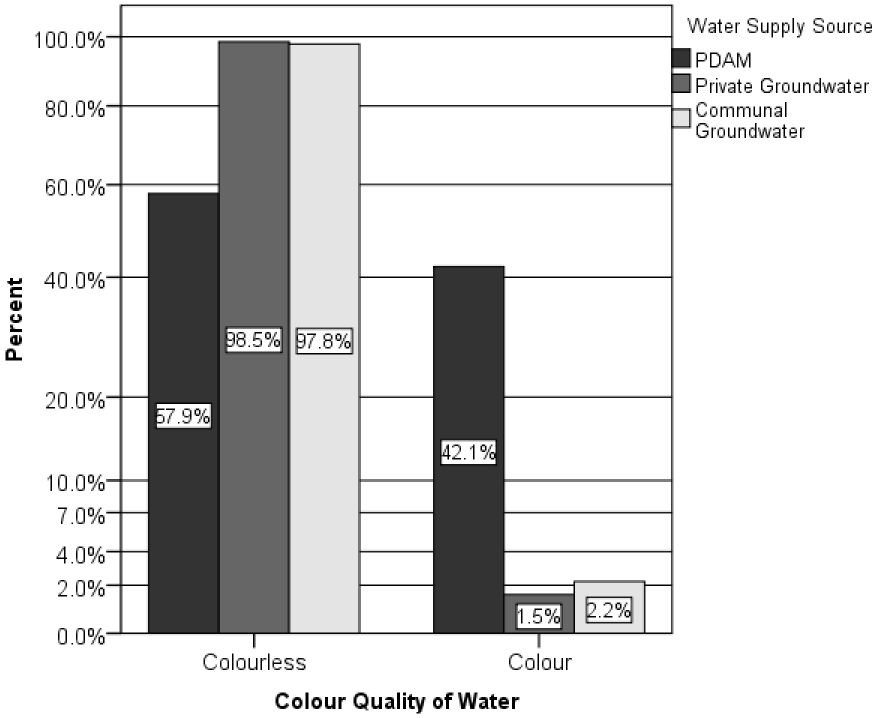


Figure 5-7: Colour Quality of Water before Flooding

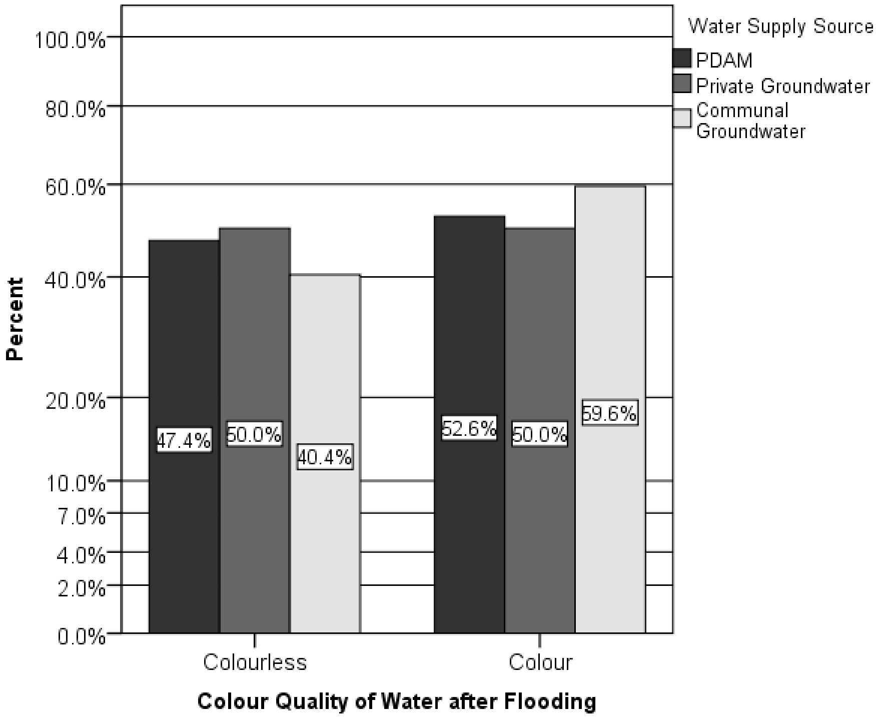


Figure 5-8: Colour Quality of Water after Flooding

- **Continuity of water supply**

Continuity of water supply indicate whether consumers have uninterrupted water supply or not. With users of PDAM, continuity of water supply was assessed from the continual flow of water through the taps every time. Continuity from groundwater supply was assessed from its availability throughout the different seasons such as the dry season. From the survey, about 71.1%, 93.1% and 91.2% of the respondents with PDAM, private groundwater and communal groundwater had continuous supply of water (figure 5-9). The rest of the respondents reported shortages of water supply been seasonally or otherwise.

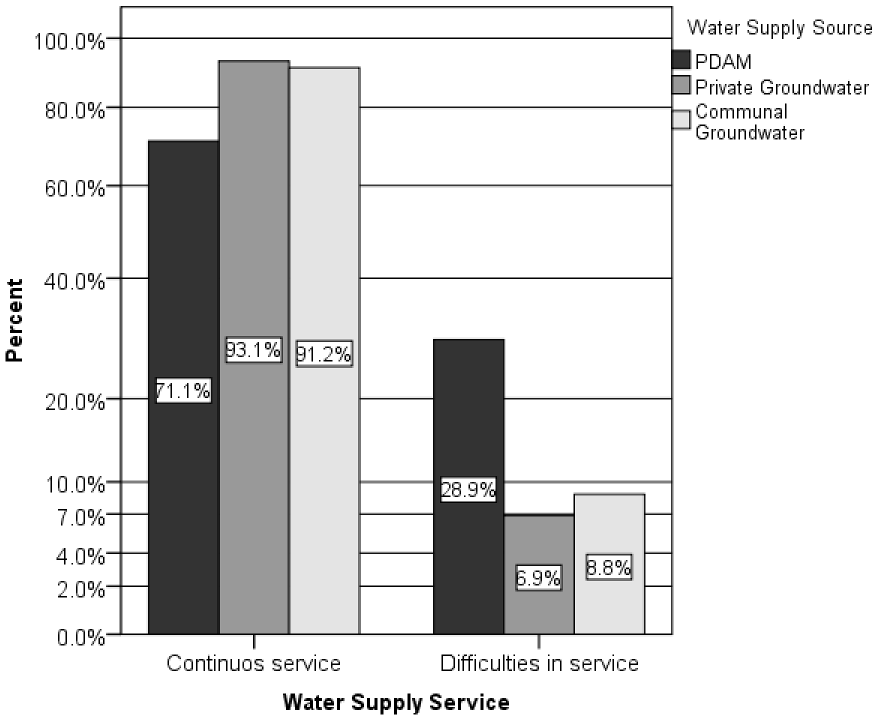


Figure 5-9: Continuity of Water Supply

- **Water supply index from user's perceptions**

To evaluate the performances of the three sources of water supply from the consumers perspective, , a water supply index was developed. This index is composed of seven indicators, thus; percentage of water without smell both before and after flooding, percentage of water with good taste both before and after flooding, percentage of water colourless both before and after flooding and the percentage of consumers with continuous water supply. The scores for each water source were standardized in ILWIS 3.3.The maximum standardization value function was used because of the lack of other knowledge. Also none of the sources were to be portrayed as worst. The various indicators were giving the same weighting as data about the weightings were not available.

$$Standard\ score_i = \frac{Raw\ score_i}{Maximum\ score}$$

A water supply index of 0.732, 0.999 and 0.878 were recorded for PDAM, private groundwater and communal groundwater sources respectively in the normal condition and during flooding (figure 5-10). From the results, private groundwater was seen to be the best in view of the consumers.

Criteria Tree	PDAM	Private Groundwater	Communal Groundwater
Water Supply Index -- ExpVal	0.732	0.999	0.878
0.17 Odor Quality before Flooding	0.54	1.00	1.00
1.00 Percentage of water without scent -- Std:Maximum	53.9	98.5	98.9
0.17 Taste Quality before Flooding	0.50	1.00	1.00
1.00 Percentage of Water Tasting Good -- Std:Maximum	50	100	100
0.17 Colour Quality before Flooding	0.59	1.00	0.99
1.00 Percentage of water colourless -- Std:Maximum	57.9	98.5	97.8
0.17 Odor Quality after Flooding	0.91	1.00	0.73
1.00 Percentage of water without scent after flooding -- Std:Maximum	47.4	52.2	38.3
0.17 Taste Quality after Flooding	0.90	1.00	0.73
1.00 Percentage of water tasting good after flooding -- Std:Maximum	47.2	52.2	38.3
0.17 Colour Quality after Flooding	0.95	1.00	0.81
1.00 Percentage of water colourless after flooding -- Std:Maximum	47.4	50	40.4
0.00 Continuity of Water Supply	0.76	1.00	0.98
1.00 Percentage of Consumers with continous water supply -- Std:Maximum	71.1	93.1	91.2

Figure 5-10 Water Supply Index

- **Condition of water supply post-flooding**

There was also another factor that can be considered as condition of water supply in disaster time. The factor that was considered here was the time duration needed to get access to the clean water after flooding. In this research, the communities that were affected by flooding have been asked about how long they had to wait until they could access the clean water again. From the graph (figure 5-11), it could be concluded that all supply sources could be accessed mostly after 1 until 3 days after flooding (53.8%, 63.2% and 66.7% respondents from PDAM, private groundwater and communal groundwater respectively). Meanwhile, some could be accessed within 24 hours after flooding especially from the PDAM source (38.5%). Few respondents could access the clean water after three days of the flooding (7.7%, 10.5% and 4.8% respondents of PDAM, private groundwater and communal groundwater).

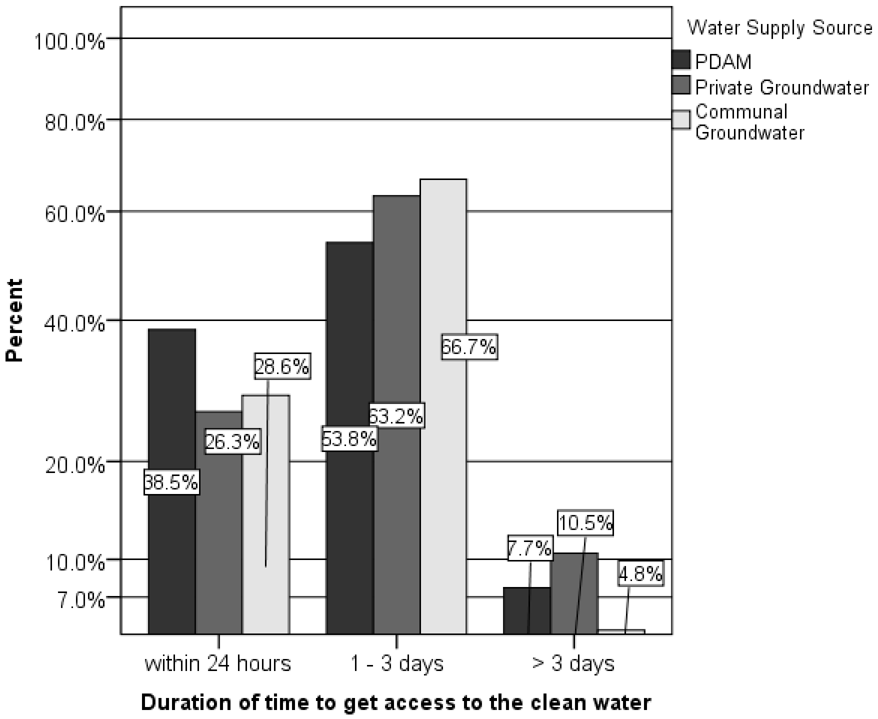


Figure 5-11: Time Duration to Access Clean Water after Flooding

5.1.3. Quantitative Analysis: Total Coliforms and Total Dissolved Solids

Two quality tests were picked to measure the quality of water supply; total coliforms and total dissolved solids (TDS). The aim of quantitative analysis was to assess the quality of water source that the communities consumed. This was important in assessing the water qualities against the perception from the consumers.

5.1.3.1. Total Coliforms

For water to be potable, it must be free of any bacterial contaminants. From the test done, most of the water samples were found to be out of the drinking water standards of 0 MPN/100 ml. Only two cases of tap water from provider PDAM forming about 5.9% of PDAM water sources were found to be good for drinking purposes. Even though water should be free of any coliform, a threshold of 50 MPN/100 ml is considered acceptable as clean water. With that, almost 80% samples of tap water were considered clean water to be consumed and less than 5% samples of groundwater attaining this standard. Meanwhile, there are 20% samples of tap water below the water quality standard either for clean water or drinking water; and around 80% samples of groundwater do not accomplish the standard of water quality. With most of the consumers using groundwater as their source of water supply, this was disturbing.

Table 5-2: Cross Tabulation of Total Coliforms and Water Sources

		Water Source		
		PDAM	Groundwater	Total
Total Coliforms	0 MPN / 100 ml	2 (5.9%)	0 (0%)	2
	1 – 50 MPN / 100 ml	25 (73.5%)	2 (3.4%)	27
	51 – 500 MPN / 100 ml	7 (20.6%)	18 (30.5%)	25
	501 – 1000 MPN / 100 ml	0 (0%)	1 (1.7%)	1
	1001 – 2000 MPN / 100 ml	0 (0%)	8 (13.6%)	8
	> 2000 MPN / 100 ml	0 (0%)	30 (50.8%)	30
	Total	34 (100%)	59 (100%)	93

Spatially, wells with higher bacterial contaminants were found along the river within distances of 0 – 33 meters. Water samples with a low level of contamination (< 50 MPN/ 100ml) were located within distances 34 – 100 meters from Code River (figure 5-12). Especially the water sampling with a contamination level of *E.coli* more than 50 MPN/100ml are in close distance to the river. From the map, there were also concentration of high level contamination that showed with the dark brown colour.

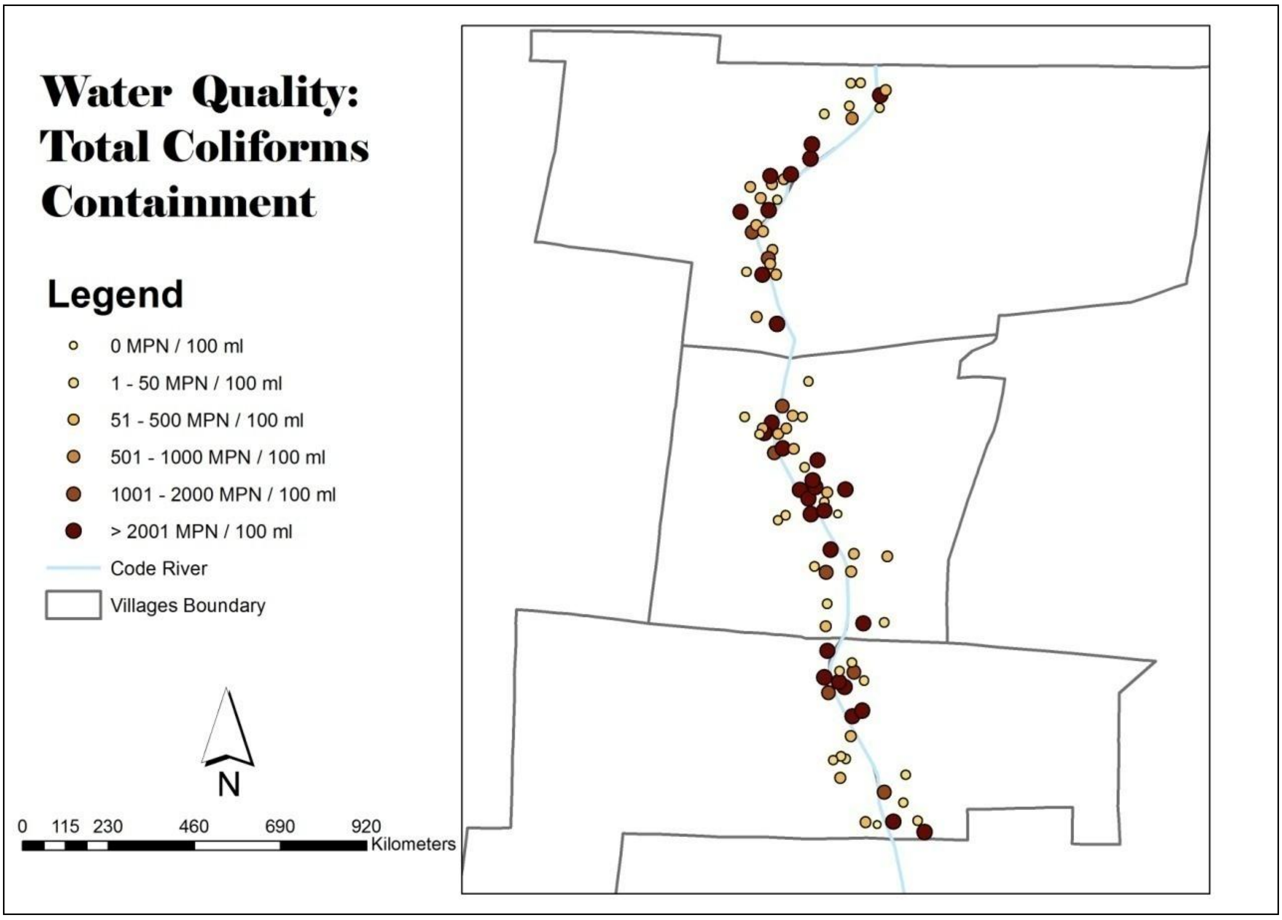


Figure 5-12 Total Coliforms Containment

5.1.3.2. Total Dissolved Solids

Total dissolved solids include inorganic salts and small amounts of organic matter present in water, usually of calcium, magnesium, sodium and potassium cations and carbonate, hydrogen carbonate, chloride, sulphate and nitrate anion (WHO 2003). The containment of total dissolved solids in water may affect its taste. According to WHO (2003), water with TDS below 300mg/litre are considered to be with excellent taste. Those with TDS between 300 – 600 mg/litre considered good; between 600 – 900 mg/litre, fair; and 900 – 1200 mg/litre considered to be with poor taste. Water sources with TDS above 1200 mg/litre are considered to be unacceptable. Water with very low concentration of TDS is also not acceptable as they have flat and insipid taste. TDS in water supplies originate from natural sources, sewage, urban and agricultural run-off and industrial wastewater. No health related problems have been recorded with high levels of TDS in drinking water (WHO 2003). Few health problems have however been found to be from very hard water (high dissolved minerals that consist of mineral and magnesium). Some component of TDS including chlorides, sulphates, magnesium, calcium and carbonates make water corrosive, causing distribution systems to wear out. Water with high TDS levels (> 500 mg/litre) causes excessive scaling in water pipes, water heaters, boilers, etc... (WHO 2003). Thus, TDS may not have much effect on human health but it may be objectionable for customers to assess the taste of water.

From the test carried out, most of the water sources were seen to be below 400mg/l (table 5-3). Thus water tastes could be classified to be with excellent to fair water tastes. About 80% of water samples from PDAM were categorized as excellent with the containment of total dissolved solids less than 250 mg/l and only 20% sample that categorized as good and fair according. With groundwater sources, about 70% of water samples were classified as good with 30% of the water samples considered to be with fair taste to be consumed. Comparing the results between groundwater and PDAM water sources for TDS measurement, it can be concluded that there is not much variation in contamination. However, water in the tap which is provided by PDAM had a slight edge over taste quality than from groundwater sources.

Table 5-3: Cross Tabulation of Total Dissolved Solids and Water Sources

		Water Source		
		PDAM	**Groundwater**	**Total**
Total Dissolved Solids	101 – 150 mg/l	1 (2.9%)	0 (0%)	1
	151 – 200 mg/l	21 (61.8%)	8 (13.6%)	29
	201 – 250 mg/l	4 (11.8%)	13 (22%)	17
	251 – 300 mg/l	3 (8.8%)	30 (50.8%)	33
	301 – 350 mg/l	4 (11.8%)	6 (10.2%)	10
	351 – 400 mg/l	1 (2.9%)	1 (1.7%)	2
	> 401 mg/l	0 (0%)	1 (1.7%)	1
	Total	34	59	93

The contamination of water in terms of the total dissolve solids did not have any spatial pattern (figure 5-13). There wasn't much variation in the recorded figures. There are no dominant classes of contamination levels within distances from the river.

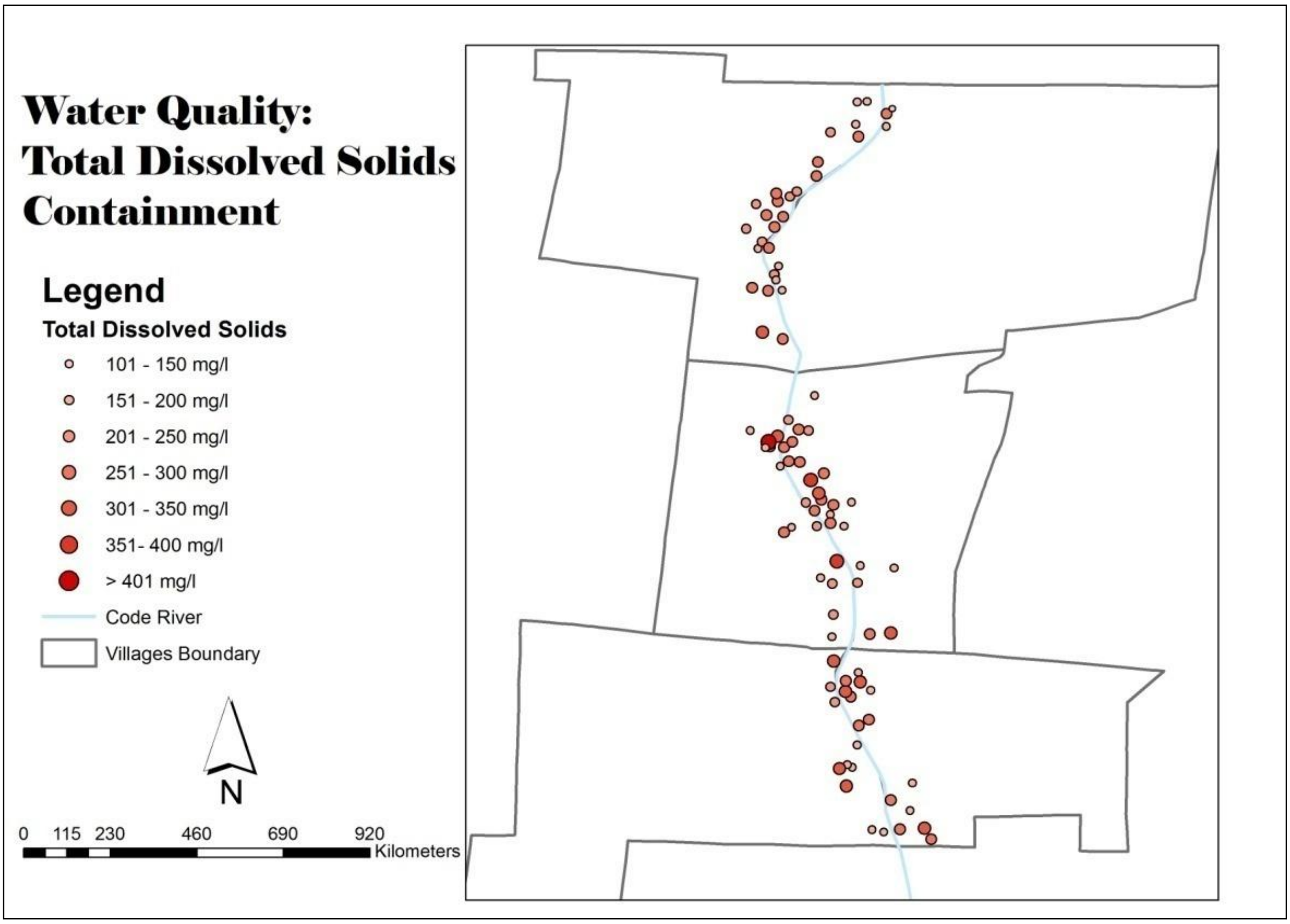


Figure 5-13 Total Dissolved Solids Containment

From the water quality tests, it can be concluded that the water sources were generally of good quality when looking at the total dissolved solids. All the water sampled did not exceed the acceptable limit for drinking purpose. Contrary to this, the results of water quality for total coliforms indicated low quality of water. Specifically, for the groundwater, 96% of sampled water did not even fulfil the standard of clean water while for the tap water (PDAM), 80% of water sampling fulfilled the criteria of clean water (low containment of total coliforms). Some clusters were observed spatially for the distribution of water quality for total coliforms. Further analysis about the spread of groundwater pollution will be done in the sub-chapters following.

5.1.4. Relationship between User's Perceptions and Quantitative Analysis

A comparison of user's perception about water quality and quality test carried out was done. This was to see if there was any correlation between them. It was also to serve as a basis for confirming water quality assessment from the user's perspective. Because of the scale of the data, thus categorical scale data from the user perspective and the scale data from the water quality test, the independent t-test was employed to investigate this relationship. Independent t-test are used in the conditions where there are two experimental conditions and different participants have been used in each condition (Field 2005). The relationships between the observed total coliforms and the taste, colour and odor were investigated.

In order to measure the strength of the relationships, between two conditions that were tested in the independent t-test, an effect size between two variables was calculated to estimate an apparent relationship beside the significance level. It is necessary to know whether the size of the observed relationship is small or large. The type of effect size is Pearson's correlation that donated with *r*. The equation to calculate r is (Field 2005):

$$r = \sqrt{\frac{t^2}{t^2 + df}}$$

r is effect size

t is the result independent t-test

df is degree of freedom

The guideline to identify whether the correlation coefficients are high or low is as followed:

- r = 0.1 – 0.23 (small effect size)
- r = 0.24 – 0.36 (medium effect size)
- r = > 0.37 (large effect size)

On average, respondents reported good taste for higher total coliforms (M=1185.03, SE= 123.5) as compared to those reporting bad taste for lower total coliforms (M=60.90, SE=12.2). This difference was significant with $t(72) = 9.05$, $p < 0.05$. A large effect size (r) of 0.73 was observed. This gives an indication of high relationship between the taste quality of consumers and the total coliforms. Water with high total coliforms was expected to have bad taste but this was not observed from the data collected.

The relationship between odor quality and total coliforms was also investigated. A significant difference with $t(76) = 8.85$ and $p < 0.05$ was found between respondents reporting good odor quality for high total coliforms (M = 1140.36, SE = 121.19) and those reporting bad odor quality for low total coliforms water (M = 59.67, SE = 14.64). An effect size of 0.71 representing large effect was observed. Once again a relationship between total coliforms and odor quality of water was established. However this was not expected as water with higher total coliforms were reported to have good odor quality.

Thirdly, the relationship between colour quality from user's perception and total coliforms of water sampled was investigated. Once again a significant difference between respondents reporting good colour quality for high total coliform infested water (M = 1035.14, SE = 115.07) and respondent reporting bad colour quality for lower total coliform infested water (M = 68.40, SE = 26.86). A large effect size (r = 0.65) was observed. Once again a strong relationship between colour quality and total coliforms in water was established. Water with higher total coliforms were reported to have good colour quality and vice versa.

With the relationships between the total coliforms and the physical water quality (taste, odor and colour) from the users yielding unexpected relationships, it was hoped their relationship with the total dissolved solids (TDS) would be expected. With most of the water samples having accepted levels of TDS, with small variances, insignificant differences were expected. The same procedure was therefore applied to find the relationships between the taste, odor and colour qualities with the TDS observed. Firstly the relationship between water taste quality and TDS was investigated. On average, respondents with higher TDS in water reported good taste of water (M = 247.82, SE = 7.11) with respondents having lower TDS in water reporting strong taste (M = 208.62, SE = 15.37). This difference in water quality was seen to be significant with t (91) = 2.52 and p = 0.013 < 0.05. However, a medium effect size (r = 0.26) was observed. A relationship was thus observed, indicating good taste for higher TDS. The relationship between TDS and odor quality from user's perspective was then investigated. On average, respondents with higher TDS reported good odor quality for water (M = 244.55, SE – 7.15) with respondents with lower TDS reporting bad odor quality (M = 215.72, SE = 16.79). The difference observed was not significant with t (91) = 1.72 and p = 0.89 > 0.05. This was coupled with a low effect size of 0.18. No distinct relationship was thus observed with the odor quality of water and the TDS..

Lastly, the relationship between the colour quality reported by the users and the TDS observed were investigated. From the analysis, respondents with higher TDS reported good colour quality (M = 243.10, SE = 7.01) whiles respondents with lower TDS reported bad colour quality (M = 204.70, SE = 19.62). This difference in observation was not significant with t (91) = 1.80 and p = 0.075 > 0.05. Once again a low effect size of 0.19 was observed.

In conclusion, significant relationships were observed between the total coliforms in water and the taste, odor and colour qualities of water. These relationships were however not expected as water with higher total coliforms were reported to have good taste, odor and colour qualities and vice versa. This was not so in the case of the TDS. A weak relationship was observed between TDS and taste quality. The rest of the water qualities (odor and colour) were seen not to have any significant relationship with TDS.

5.2. Spatial spread of water pollution

5.2.1. Methodological approach and distribution of data

Figure 5-14 presents the methodological approach and analysis of for estimating groundwater pollution. All data used in the analysis of spatial performance of water quality were primarily collected using transect sampling. Both total coliforms and total dissolved solids were analysed by the Health Agency of Yogyakarta City. There are two types of water supply sources being analyzed for water quality: water from provider or tap water (PDAM) and water from well.

The water sampling points were randomly generated from the household's points that were being surveyed. A total of 93 water samples for both water from provider (PDAM) and groundwater were taken. It consists of 34 water samples from PDAM and 59 water samples from groundwater sources. The majority of people based on household survey (about > 50% households) in the study area use groundwater as their water source, around 30% of the households use water from the provider and other 20% used combined water supply sources. For this reason I have chosen to have a majority of water quality samples taken from households with groundwater sources. The distribution of water quality sampling is shown on the map in figure 5-15 below.

Spatial statistics tools in ArcGIS 9.3 were used in determining whether the pollution of water source were spatially auto correlated. Water sample from groundwater and from PDAM were separated because they were from different sources and were not expected to be correlated.

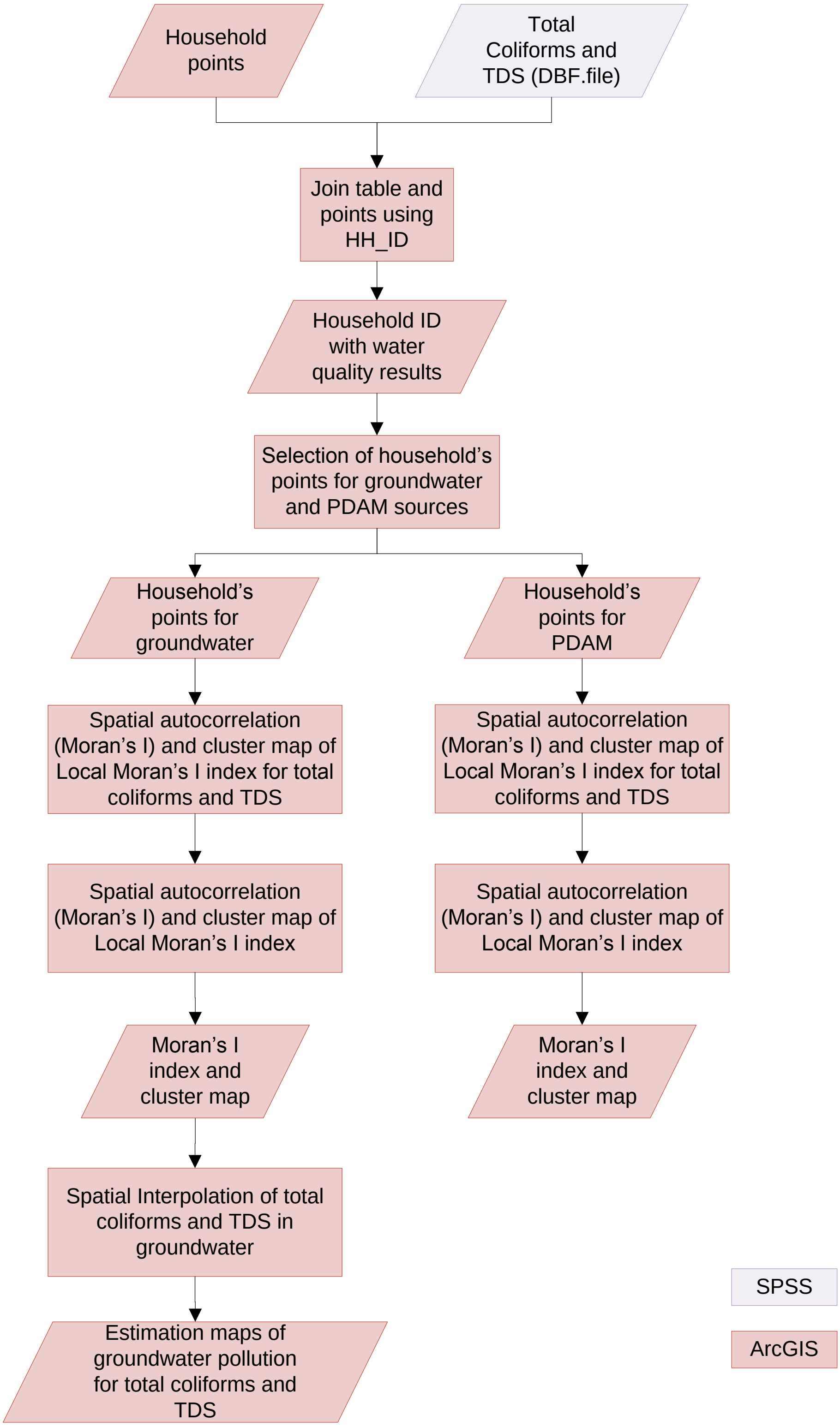


Figure 5-14: Groundwater Pollution Estimation Flowchart

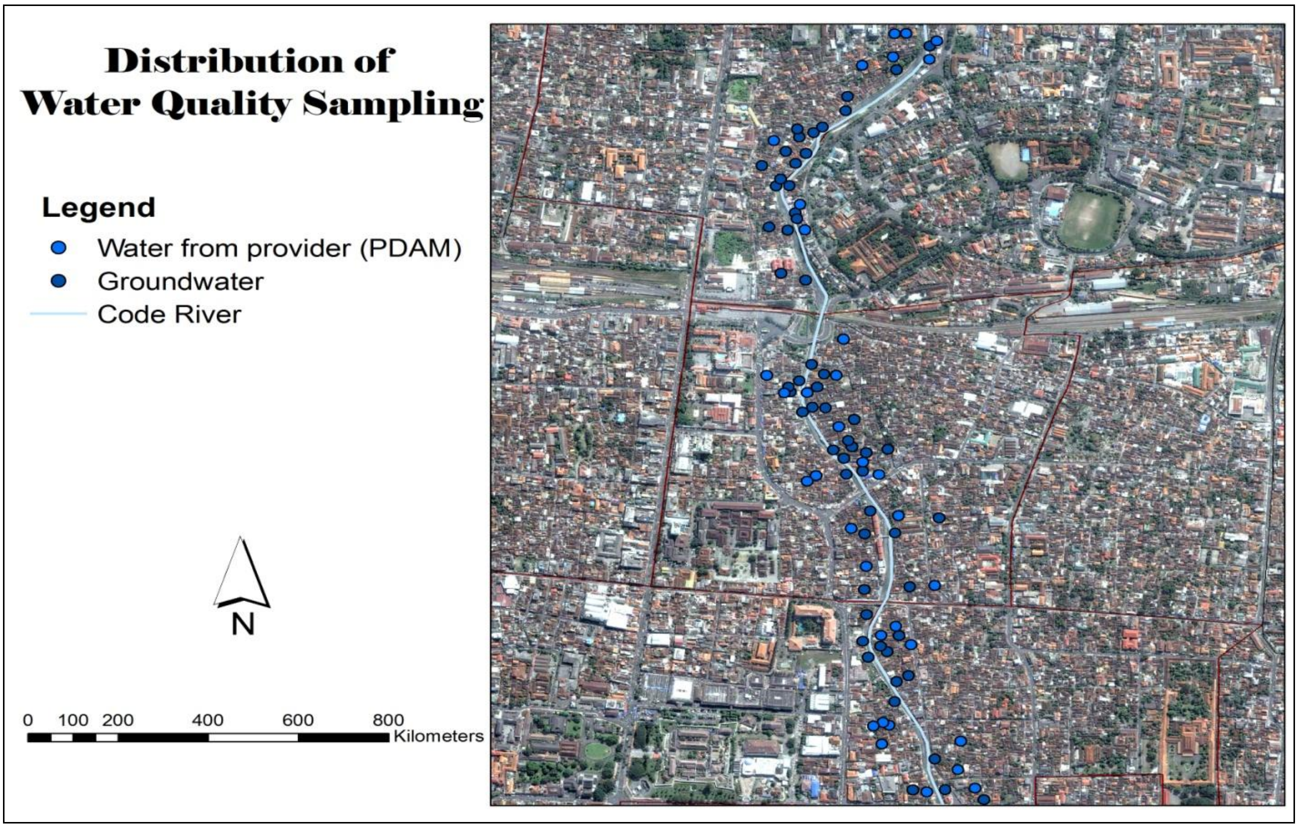


Figure 5-15 Distribution of Water Quality Sampling

5.2.2. Spatial Autocorrelation in Determining Water Pollution Spreading

Spatial autocorrelation is a measure showing correlation within variables over space. It refers to the systematic variation in variables mapped (Haining, Neil et al. 2001; Getis 2007). A positive spatial autocorrelation is observed when adjacent variables had similar values. On the other hand when contrasting values are observed in adjacent points, a negative spatial autocorrelation is observed. According to Haining, Neil et al. (2001), spatial autocorrelation may be as a result of;

- The difference in the large scale variation of a phenomenon and the small scale of spatial framework used in capturing or representing the variation,
- Measurement error,
- Spatial diffusion, spill over, interaction, and dispersal processes,
- Inheritance by one variable through causal association with another and
- Model miss-specification.

The presence of spatial autocorrelation among variables gives the possibility of interpolating spatially. Among the various ways of representing spatial autocorrelation such as the Geary's c, Getis and Ord's G, Ripley's K, Anselin's I and c, etc, the Moran's I is mostly used (Getis 2007). This is a representation of a global covariance. In all these representations, spatial weights need to be measured. These could be direct distances, inverse of distance, etc. These weightings are set rules assigned to value to represent their arrangement in space (Odland 1988).

Using the Moran's I, total coliforms and total dissolved solids in the observed water were examined to see whether they are spatially auto correlated or not.

5.2.2.1. The Operationalization of Spatial Autocorrelation (Moran's I)

Spatial autocorrelation methods are assigned to measure interdependence such as Moran's I, taken into accounts that data should not be independent. Moran's I is a measure of spatial autocorrelation for observing whether a phenomenon are correlated over space. In this research, the interdependency between points of sample is measured by Moran's I to identify the spread of *E-coli* and whether one value corresponds to others. The operationalization of Moran's I in statistic is:

$$I = \frac{N}{\sum_i \sum_j W_{ij}} \times \frac{\sum_i \sum_j W_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)}{\sum_i \left(x_i - \bar{x}\right)^2} \; or \; I = \frac{N}{\sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} w_{ij}} \; x \; \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} z_i \; w_{ij} \; z_j}{\sum_{i=1}^{N} {z_i}^2}$$

$\sum_i \sum_j W_{ij}\left(x_i - \bar{x}\right)\left(x_j - \bar{x}\right)$ is spatial covariance where:

W_{ij} is a weight applied to the comparison between location *i* and *j*

x_i is the variable value at a particular location

x_j is the variable value at another location

$\bar{x}$ is the mean of all values of the variable

N is the number of cases

The results of Moran's I can be:

I > 0: positive spatial autocorrelation in which values of x_i tend to be similar to neighbouring values

I < 0: negative spatial autocorrelation in which neighbouring values are not independent but tend to be dissimilar

Usually, point data are used as input for the determination of spatial autocorrelation among variables (Odland 1988). Area values are assigned to finite locations. This is so because distances between variable need to be measured and would be difficult in cases where polygon data are used. A conversion to point data is therefore needed even if polygon data are obtained.

5.2.2.2. Spatial Autocorrelation of Total Coliforms in Groundwater and PDAM

ArcGIS 9.3 was the primary software package used in this analysis. First of all, the point locations of water sampling were plotted using the coordinates (x,y) from GPS surveyed and link with the table of water pollution result from SPSS. Secondly, the analysis of spatial autocorrelation was carried out using spatial statistic tools. The analysis uses Moran's index specifically to measure global spatial autocorrelation. The Moran's I measures the overall randomness or otherwise of geographical distribution of total coliforms.

The inverse distance weighting was used in estimating the spatial pattern of total coliforms. This meant that variables farther apart were going to have less effect on each other than those closer. The Euclidean distance was used because the movement of groundwater over space does not follow a set of network. They move freely in all directions. In using the total coliforms values estimated at each sampling point, the global Moran's I index was calculated. This gives an indication of the overall spatial distribution of the points. The analysis was divided into two sections between water sources: groundwater and tap water (PDAM). The method applied is described on the figure 5-16.

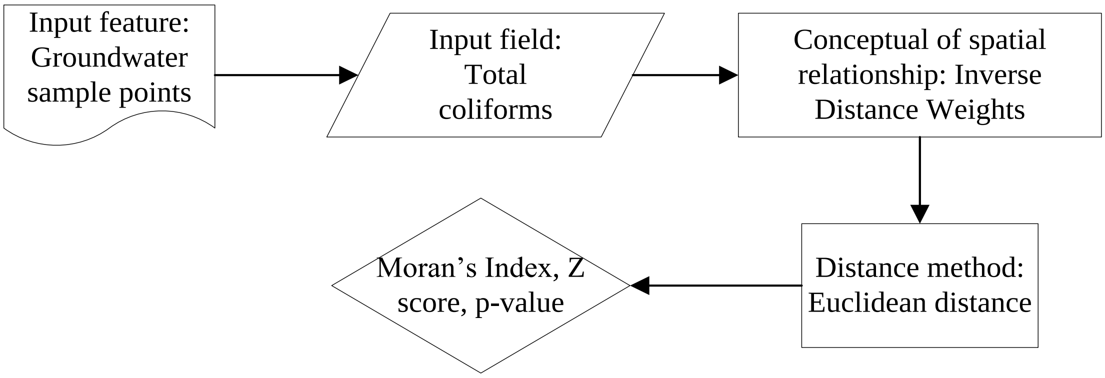


Figure 5-16: Spatial Autocorrelation of Total Coliforms in Groundwater Flow Chart

A global Moran index I value of 0.15 was observed. This showed a positive spatial correlation between water samples points based on the total coliforms observed. This correlation was however not strong.The z score and p-value are also generated by ArcGIS 9.3. The Z score is a test of statistical significance that helps to decide whether or not to reject the null hypothesis and p-value is the probability that we have falsely rejected the null hypothesis (ESRI 2006). With the Z score of 0.63 and p-value of 0.53, it could be concluded that the total coliforms observed were not correlated spatially. The occurrence of the values could there be due to chance. This was not expected as the high total coliforms observed were expected to correlate spatially.

Using the same Moran's I, the spatial pattern of total coliforms found in tap water from PDAM was investigated (figure 5-17). This was expected to spatially correlate since they were all coming from the same provider. The analysis yielded a Moran's I of – 0.07. This indicated a very small variance in the total coliforms observed spatially. It could therefore be said that, they were not spatially correlated. This was confirmed by a z score of – 0.33 and p-value of 0.74.

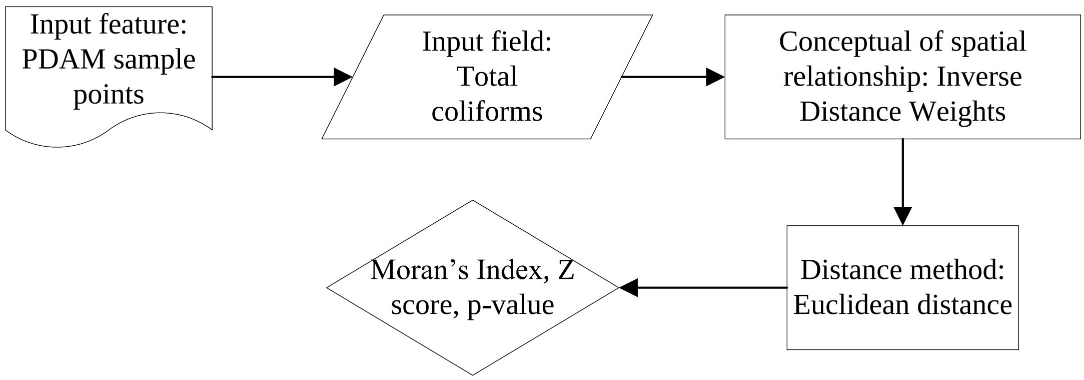


Figure 5-17: Spatial Autocorrelation of Total Coliforms in PDAM source Flow Chart

Apart from the global Moran's I, the local Moran's I was calculated see if the observed values were clustered spatially. The local Moran's I, was going to cluster points with similar values. In figure 5-18 below, the points with the dark red are associated with clusters with high values of Moran's I indicating positive correlation with dark blue indicating negative correlation. The points with the lightest colours either blue or red indicate low correlation. A histogram of total coliforms shows that majority of the points were with high values of total coliforms (2400 MPN / 100 ml). The histogram is showed on the figure 5-19.

The local Moran's I for tap water was also generated in ArcGIS in order to identify clusters of total coliforms in PDAM source. From the result, only one cluster was identified because of the small variation in the Local Moran's I index observed (ranging from -0.070542 to 0.013020). This cluster has been indicated with dark red colour and was located in the middle of map (figure 5-20). The rest of points showed very low correlation, presented with the light colours. The majority of the sample points was seen to have total coliforms values of 100 MPM / 100 ml.

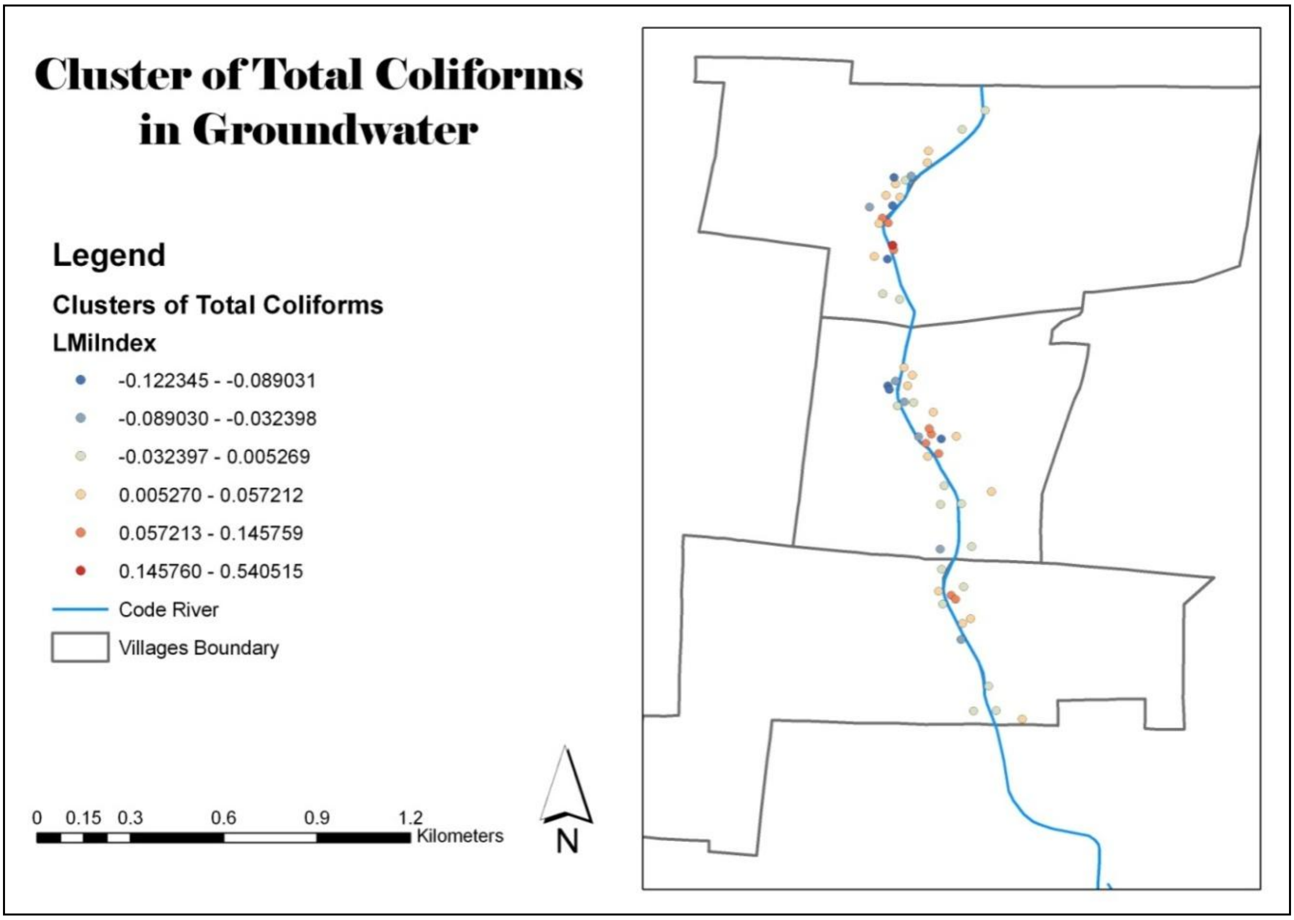


Figure 5-18: Clustering of Total Coliforms in Groundwater

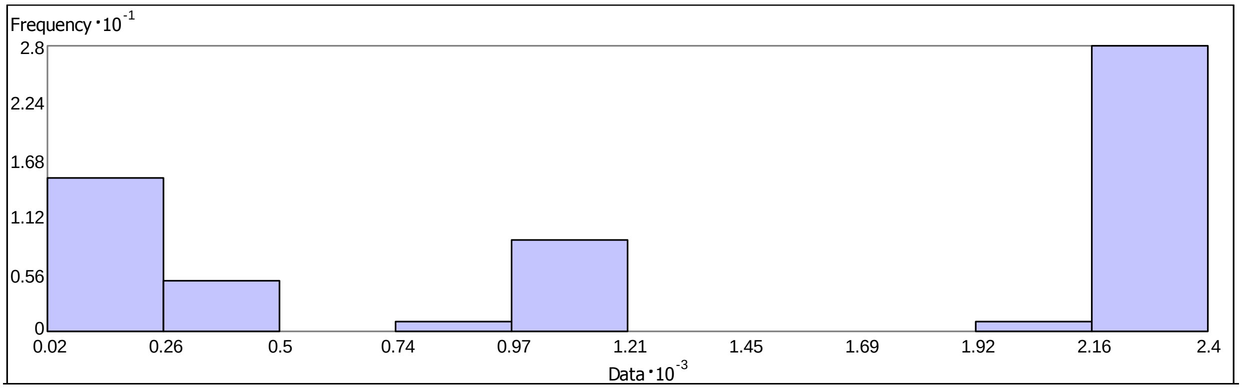


Figure 5-19 Histogram Transformation of Total Coliforms in Groundwater

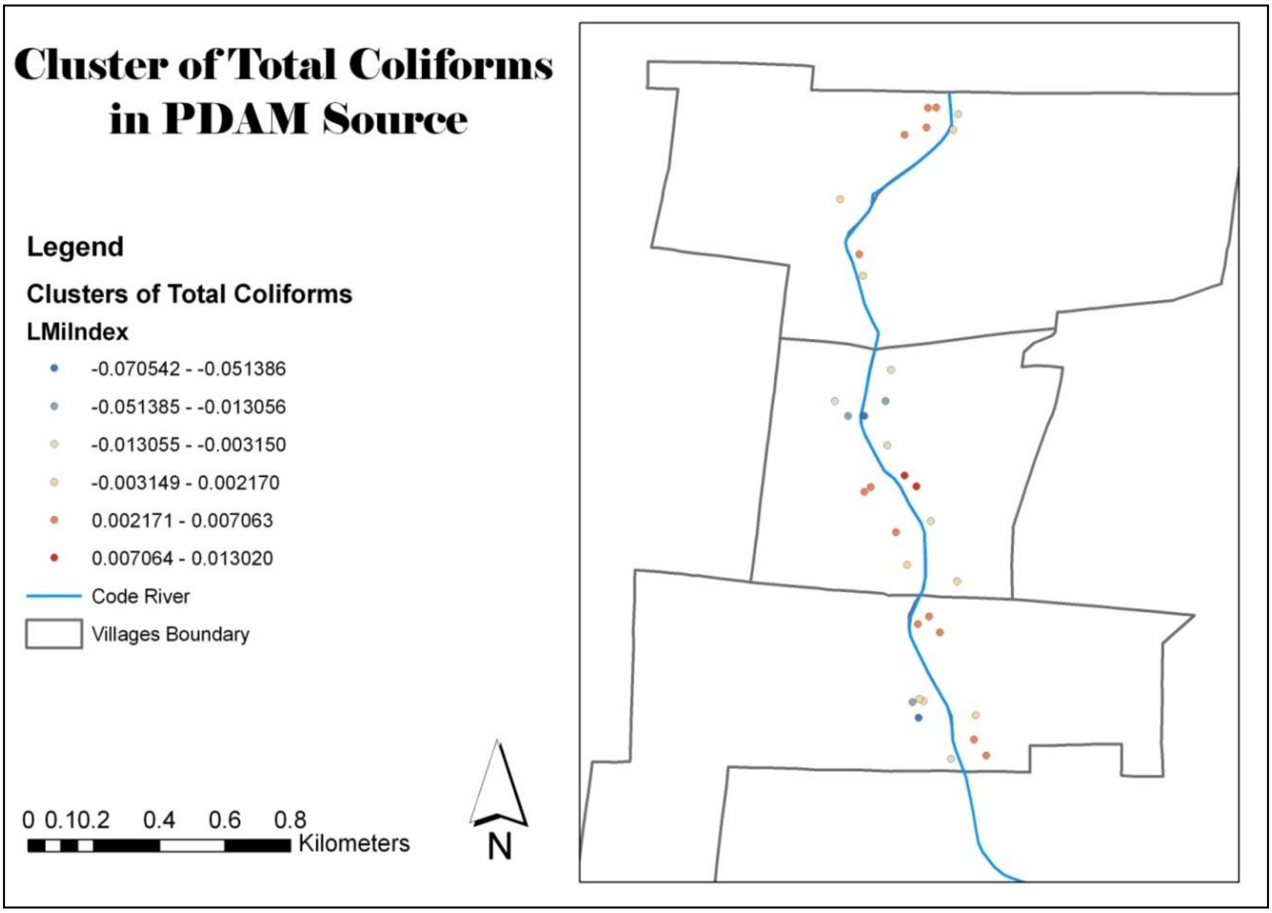


Figure 5-20: Clustering of Total Coliforms in PDAM Source

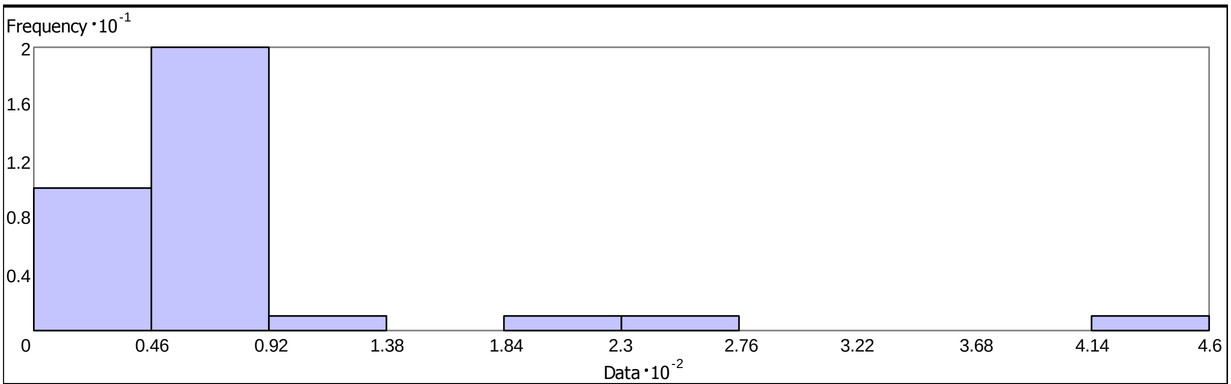


Figure 5-21 Histogram Transformation of Total Coliforms in Tap Water (PDAM)

5.2.2.3. Spatial Autocorrelation of Total Dissolved Solids in Groundwater and PDAM

In determining the spatial pattern of total solids, the same method as explained earlier for the determination of total coliforms pattern was employed (figure 5-22 and figure 5-23). This was done for both groundwater and PDAM source separately. The spatial weightings used were still inverse distances. The total dissolve solids were used as a base for calculating the spatial pattern. The result for spatial autocorrelation of TDS in groundwater showed the Moran's I = 0.22, Z score = 0.99 and p-value = 0.32. This indicated positive correlation between points of sample even though they are of weak relations. A spatial autocorrelation of TDS in PDAM showed Moran's I = -0.03, Z score = -0.02 and p-value = 0.98. These results represent a very weak correlation between TDS in water sample points.

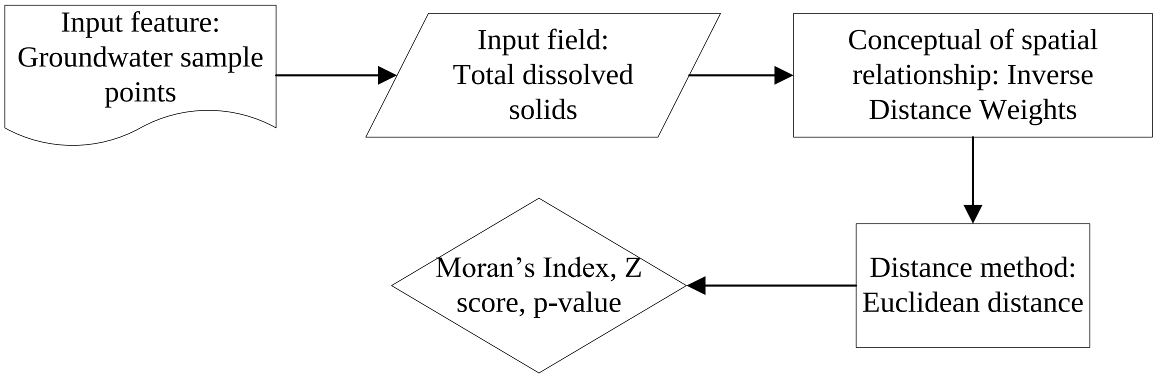


Figure 5-22: Spatial Autocorrelation of Total Coliforms in Groundwater Flow Chart

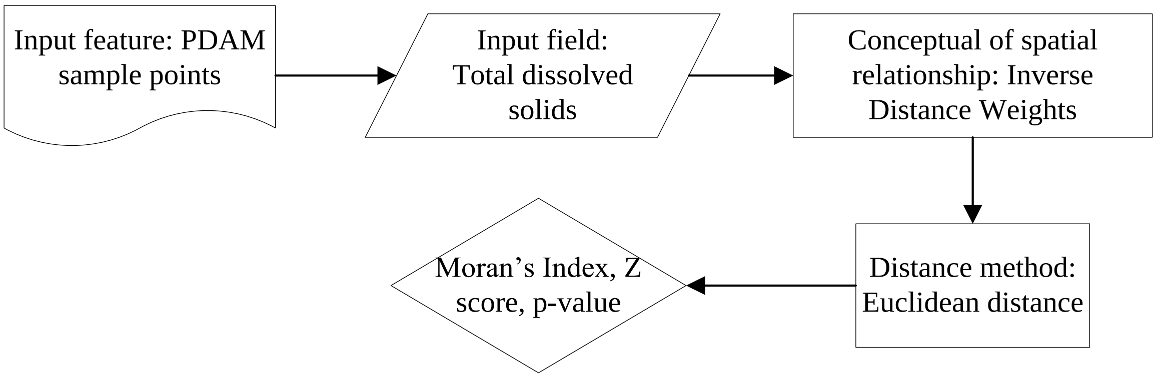


Figure 5-23 Spatial Autocorrelation of Total Coliforms in PDAM Source Flowchart

After measuring the global spatial autocorrelation of TDS for groundwater and PDAM, the local Moran's I was measured to identify clusters of TDS values in the water sample points Figures 5-24 and 5-26 below illustrate the clustering of TDS in groundwater and PDAM sources respectively. Meanwhile, the distribution of the data is showed in the histogram for both groundwater and TDS (figure 2-25 and figure 5-27). The Local Moran's I index for groundwater ranged between -0.13 to +0.82. Most of the points had low Moran's I indicating low spatial auto correlation. The local Moran's Index of TDS in PDAM showed clustering of points ranging from -0.039791 to +0.038502. These were notably low indicating no to very low spatial autocorrelation.

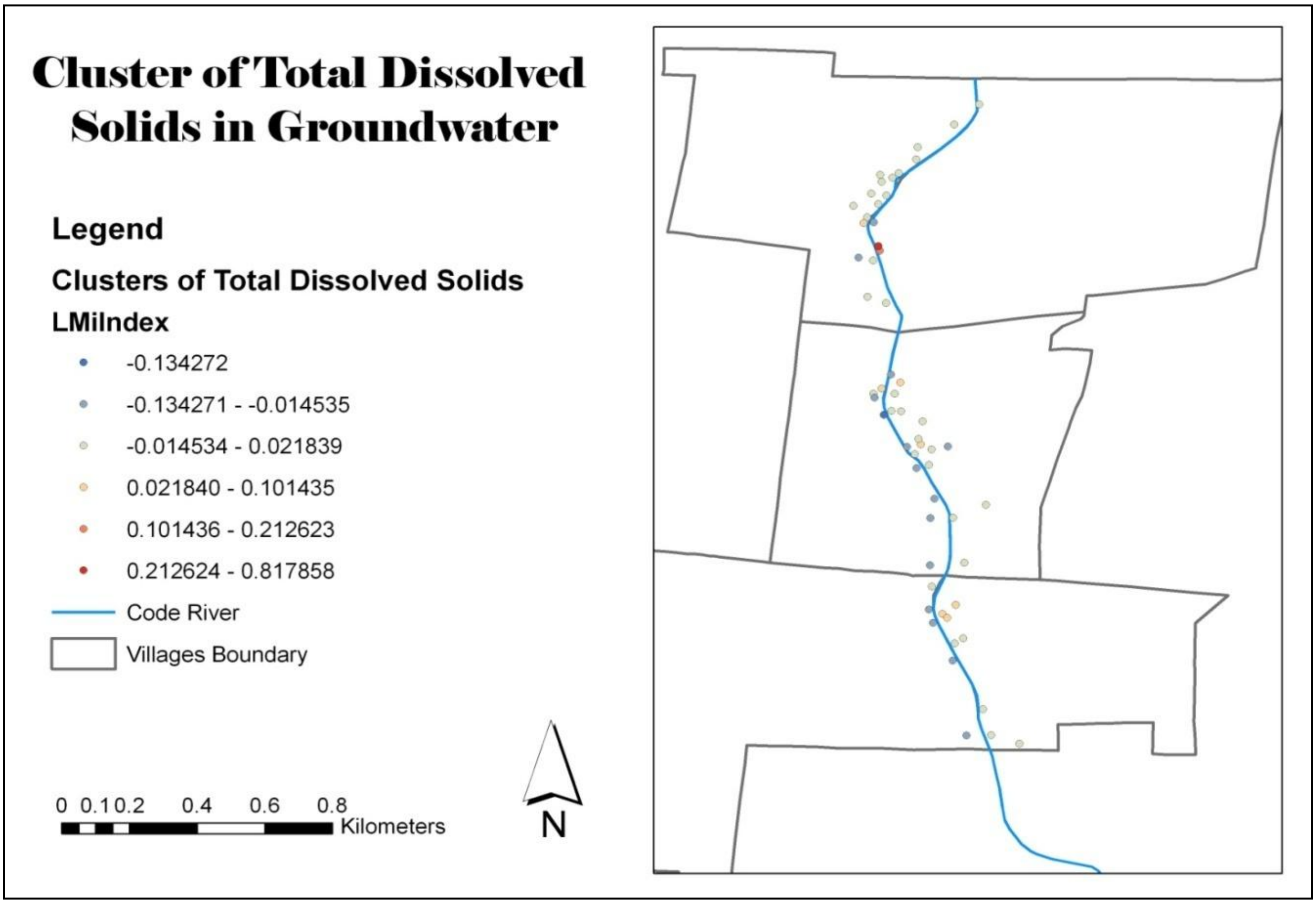


Figure 5-24: Clustering of Total Dissolved Solids in Groundwater Source

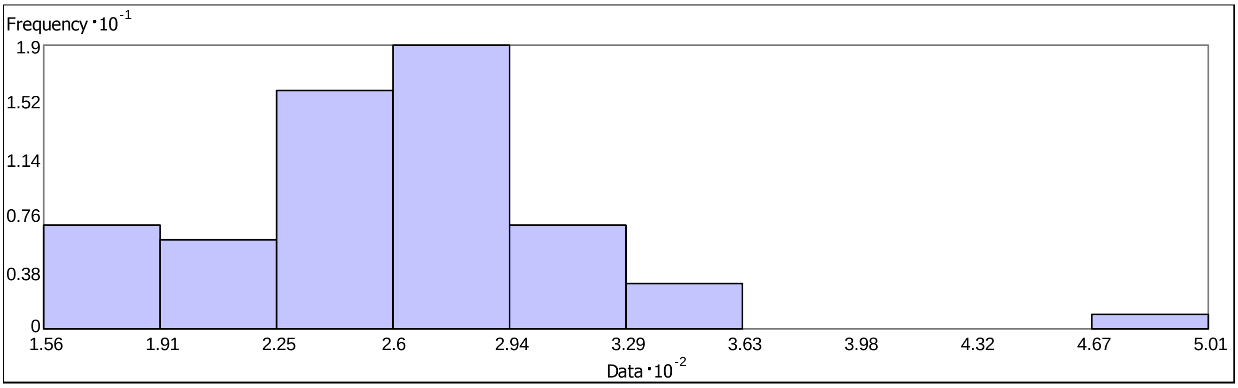


Figure 5-25 Histogram Transformation of Total Dissolved Solids in Groundwater

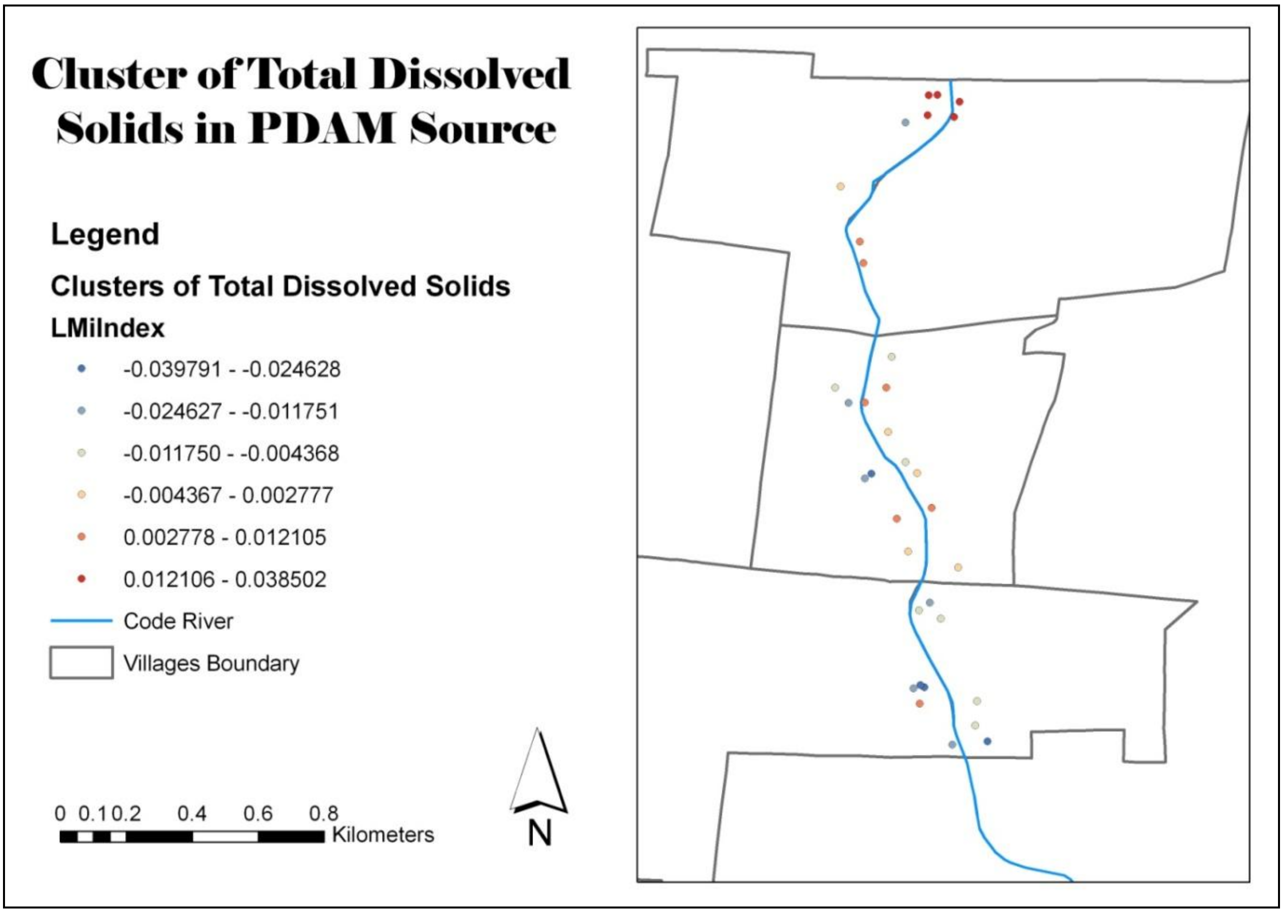


Figure 5-26: Clustering of Total Dissolve Solids in PDAM Source

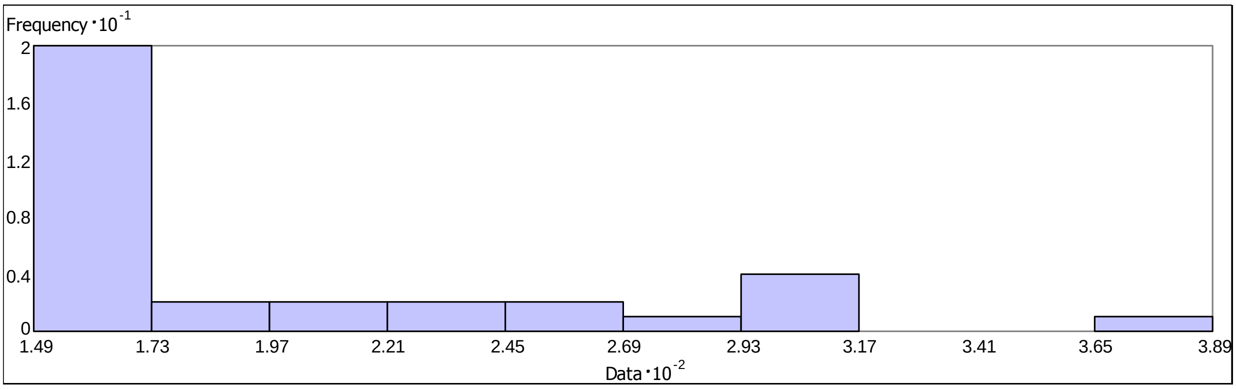


Figure 5-27 Histogram Transformation of Total Dissolved Solids in Tap Water (PDAM)

5.2.2.4. Spatial Interpolation of Total Coliforms and Total Dissolved Solids in groundwater

Spatial interpolation is a method used in estimating unknown values at locations from locations with known values (Childs 2004; Lam, Rob et al. 2009). There are two types of spatial interpolation, thus point and areal interpolation. If input data are of points, then it is referred as point interpolation and if they are from aggregated data for areal boundaries, then it is referred to as areal interpolation. Point interpolation can further be divided into ‘exact’, when values of original sample points are maintained and ‘approximate’, when the values are not preserved. Spatial interpolation is usually based on the principal of spatial autocorrelation (Childs 2004). . Because spatial interpolation is based on spatial autocorrelation, the total coliforms and total dissolve solids observed were investigated to see whether they are spatially auto correlated or not. From the results, most of the sample points were not globally correlated but some were locally correlated. This could be due to some other reasons beyond this research. Despite this result, the pollution of groundwater was estimated over the whole study area.

Figure 5-28 provides the methodological approach for the estimation of ground water pollution. Using geostatistical analysis in ArcGIS, the groundwater pollution was estimated using the water sample points from private and communal wells. Firstly, the total coliforms were used in the spatial interpolation. In order to predict the unmeasured values, the inverse distance weights (IDW) method was used. IDW uses the inverse distance between measured values as weightings for predicting unknown values between these points. Closer values were thus going to have higher influences on each other than those farther apart.

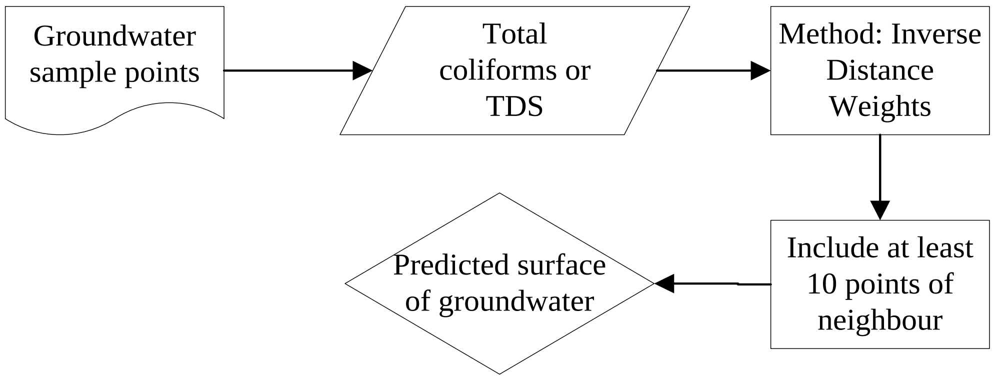


Figure 5-28: Flow Chart for Spatial Interpolation of Groundwater

Figure 5-29 provides the estimation of ground water pollution for total coliforms. Areas with higher pollution of total coliforms are depicted by dark brown colour with areas with low total coliforms depicted with light brown colours. Areas with total coliforms below 50 MPM/100 ml were considered to be within the acceptable limit and considered as clean water. Above this, water was considered to be of bad quality for consumption.

The same procedure was used in estimating the total dissolve solids pollution in the groundwater over the study area (figure 5-30). Areas with high TDS were depicted with dark blue with low TDS depicted with light blue colours. Even though most of the groundwater in the study area were within the acceptable limits, higher TDS were mostly observed.

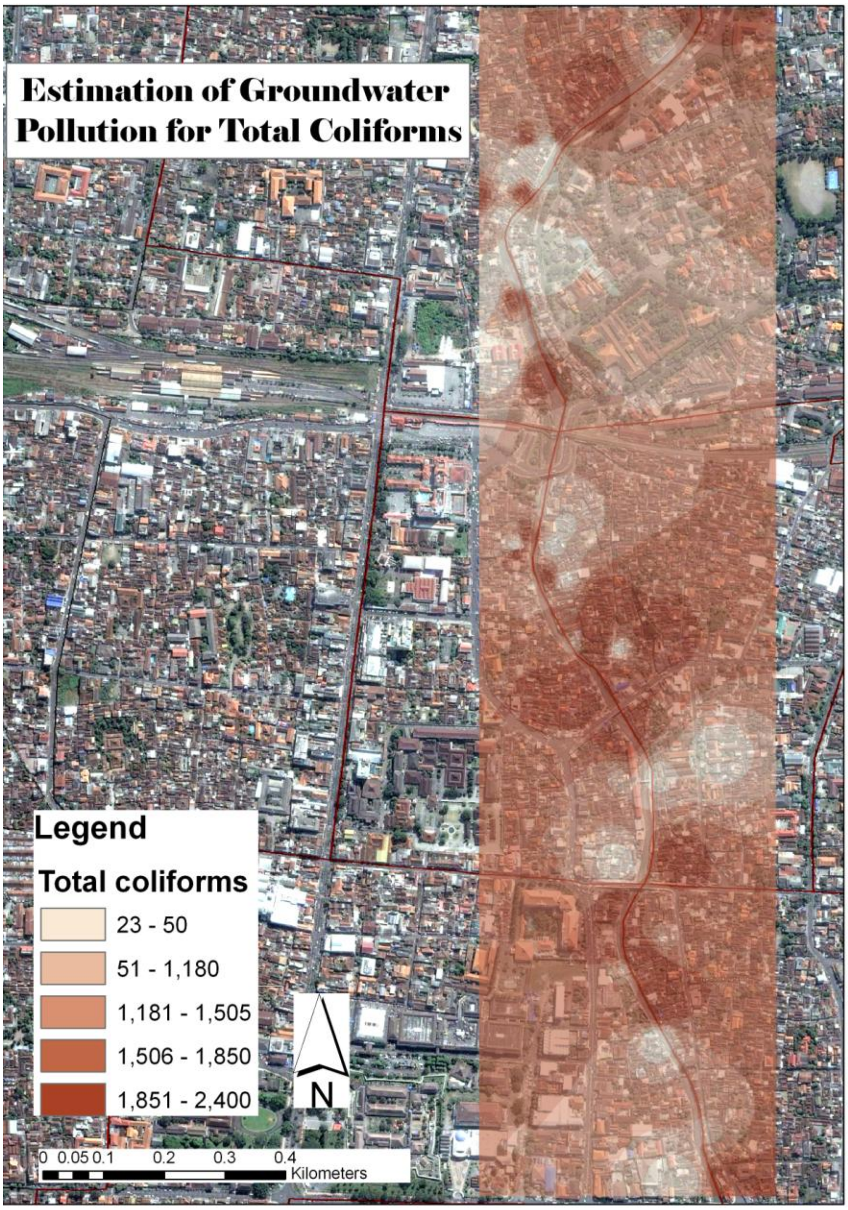


Figure 5-29: Estimation of Groundwater Pollution for Total Coliforms

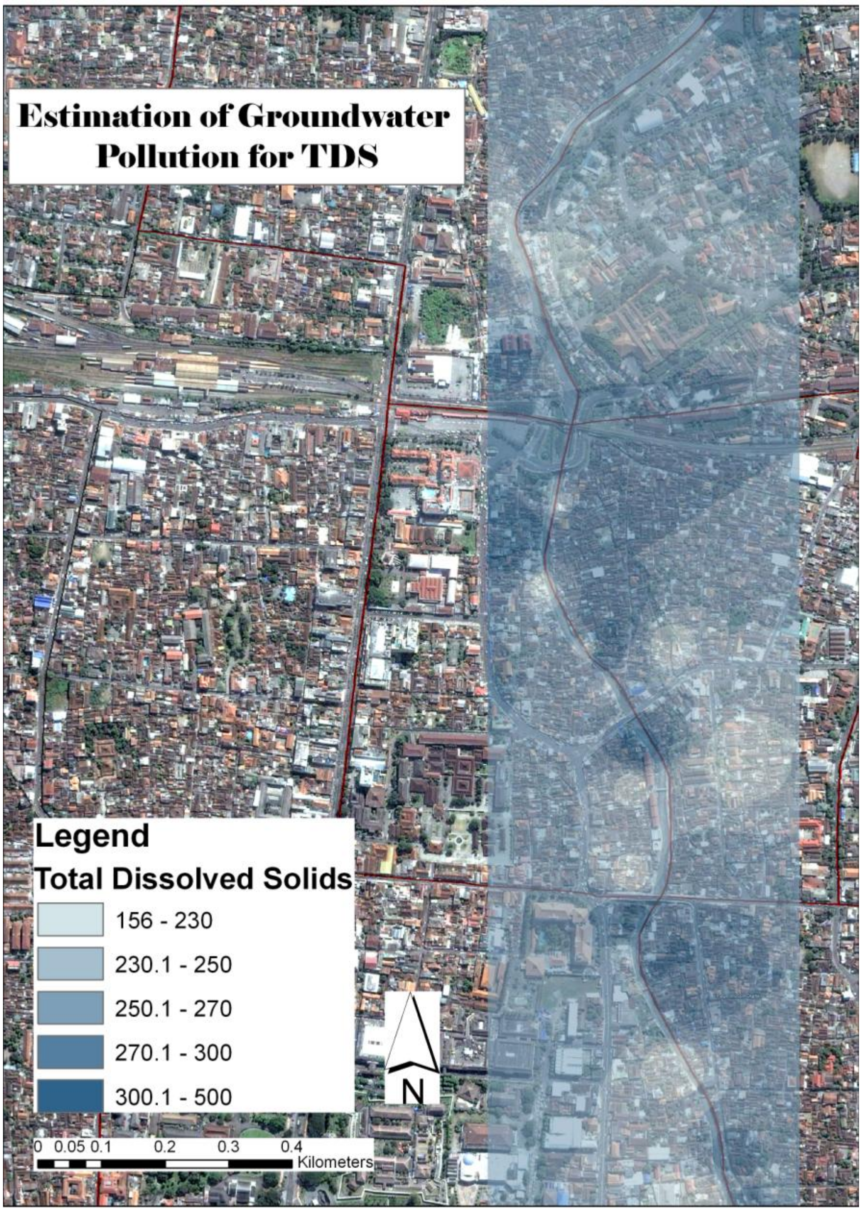


Figure 5-30: Estimation of Groundwater for Total Dissolve Solids

5.3. Predicting Total Coliforms Occurance in Groundwater

In efforts to explain the occurrence of total coliforms in water supply sources, various factors were examined. Factors considered include the distance from septic tank to well, distance from the river to house and the well depth (Pang, Close et al. 2004). These factors are not exhaustive factors influencing total coliforms pollution. In efforts to determine predicting factor for total coliforms the Pearson's correlation was used to measure the relationships these factors and the total coliforms in the groundwater and PDAM. After the correlation, a multiple regression was done to determine a model for predicting total coliforms pollution based on these explanatory factors. Figure 5-31 presents the flowchart for the determination of this model.

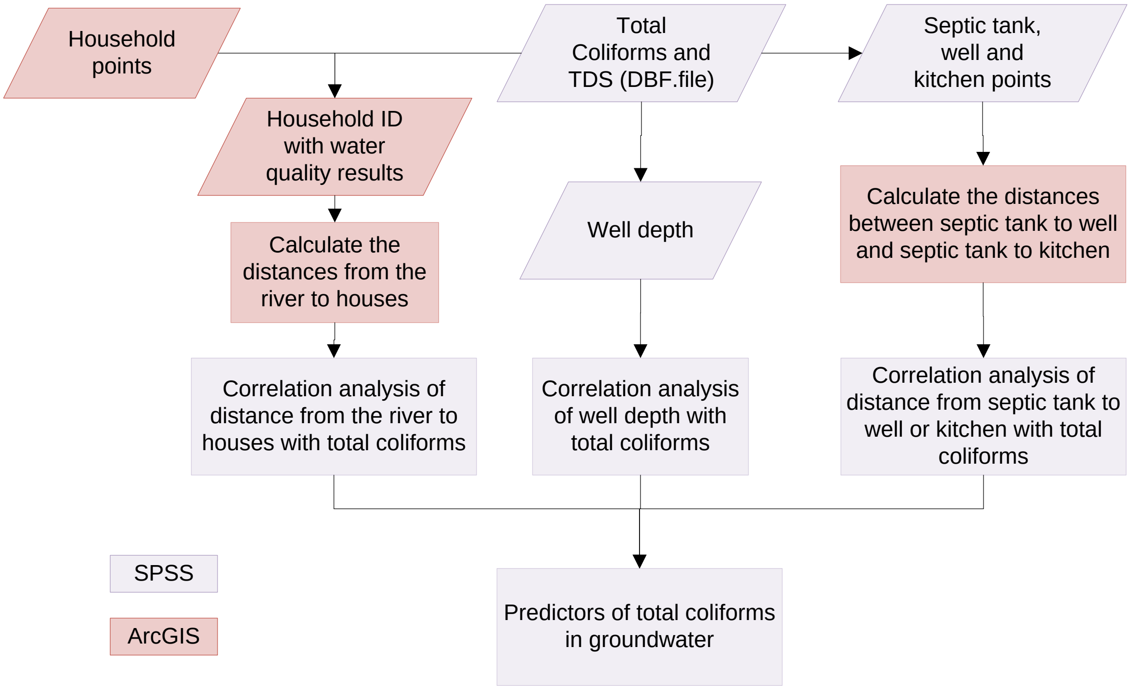


Figure 5-31: Flow Chart for the Determination of Groundwater Pollution Model

Once again because of the different water supply sources and their influences, the correlation was done separately for groundwater and tap water (PDAM). Some of the factors used in explaining the presence of total coliforms in groundwater were; the distance from septic tank to well, the distance from well to river and the well depth. Before the correlations were made, a scatter diagram (figures 5-32 and 5-33) was plotted between these factors and the total coliforms observed to get an idea of the relationships. A bivariate correlation was formed from these factors and the total coliforms (Tables 5-4 and 5-5).

From the graphs, it could already be seen which of the variables was correlated with the presence of total coliforms. Negative correlations of -0.424 and -0.264 were seen with the distance from septic tank to well and the depth of wells with total coliforms respectively. These meant that individually, distance from septic tank to well and the depth of well explained about 42.4% and 26.4% of the occurrence of total coliforms in groundwater. However, an increase in these distance meant a reduction in total coliforms observed. A weak correlation of 0.013 was however seen between the total coliforms and the distance to the river. Distance to river thus explained only about 1.3% of the occurrence.

Low correlations were observed for the factors used in explaining the occurrence of total coliforms in tap water (PDAM). The highest correlated factor was the distance of household from the river with a Pearson correlation of -0.138 with the distance from septic tank to kitchen having a correlation of 0.124. Thus the distance to river explained about 13.8% of the total coliforms with the distance from septic tank to kitchen explaining about 12.4% of the variation. These correlations were however not significant with a p-values of 0.484 and 0.438 for distance from septic tank to kitchen and distance to river respectively.

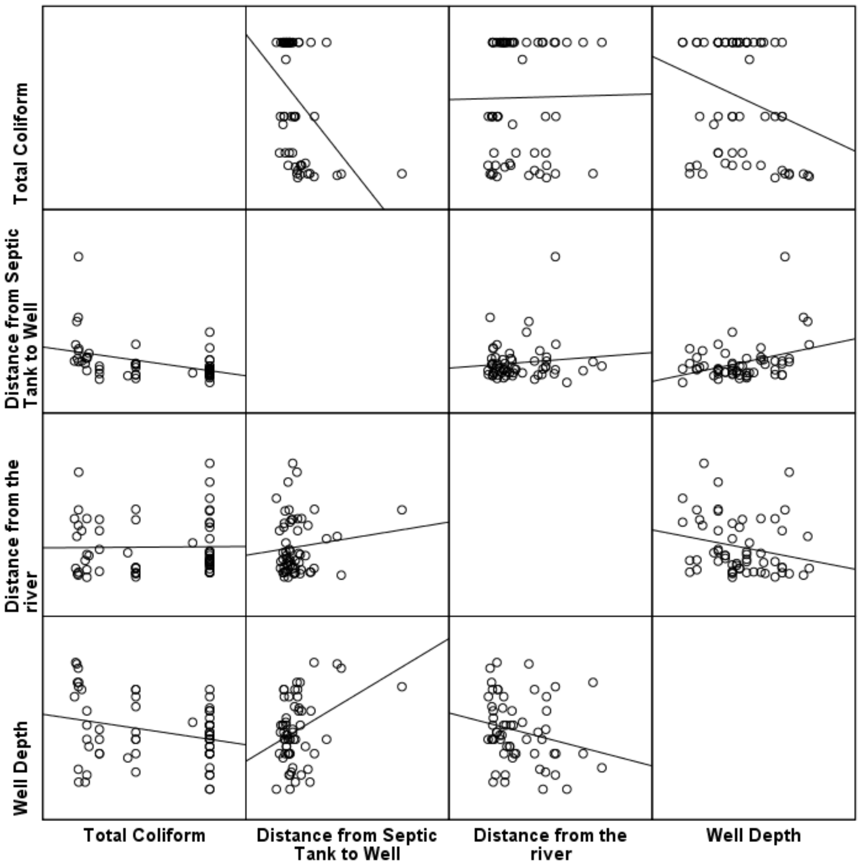


Figure 5-32: Scatter Diagram for Groundwater Coliforms and Explanatory Factors

Table 5-4: Correlation between Groundwater Coliforms and Explanatory Factors

		Total Coliform	Distance from Septic Tank to Well	Distance from the river	Well Depth
Total Coliform	Pearson Correlation	1.000	-.424**	.013	-.264*
	Sig. (2-tailed)		.001	.920	.043
	N	59	59	59	59
Distance from Septic Tank to Well	Pearson Correlation	-.424**	1.000	.112	.356**
	Sig. (2-tailed)	.001		.400	.006
	N	59	59	59	59
Distance from the river	Pearson Correlation	.013	.112	1.000	-.224
	Sig. (2-tailed)	.920	.400		.088
	N	59	59	59	59
Well Depth	Pearson Correlation	-.264*	.356**	-.224	1.000
	Sig. (2-tailed)	.043	.006	.088	
	N	59	59	59	59

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

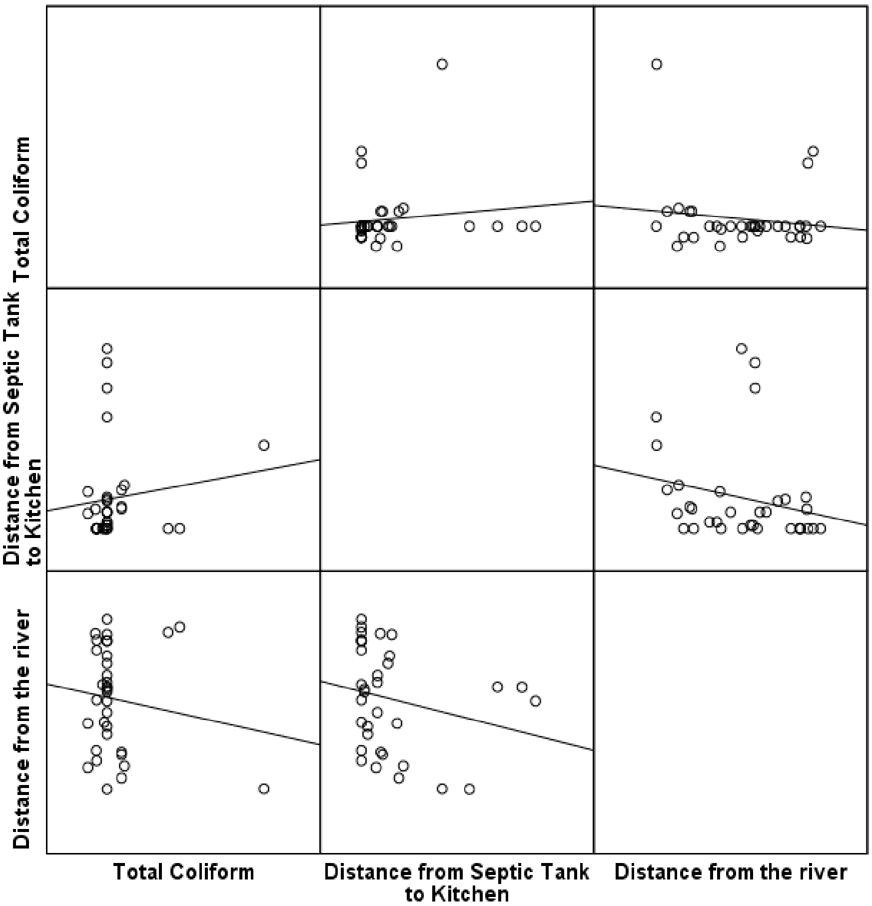


Figure 5-33: Scatter Diagram for Tap water (PDAM) Coliforms and Explanatory Factors

Table 5-5: Correlation between Tap water (PDAM) Coliforms and Explanatory Factors

		Total Coliform	Distance from Septic Tank to Kitchen	Distance from the river
Total Coliform	Pearson Correlation	1.000	.124	-.138
	Sig. (2-tailed)		.484	.438
	N	34	34	34
Distance from Septic Tank to Kitchen	Pearson Correlation	.124	1.000	-.228
	Sig. (2-tailed)	.484		.194
	N	34	34	34
Distance from the river	Pearson Correlation	-.138	-.228	1.000
	Sig. (2-tailed)	.438	.194	
	N	34	34	34

After the correlation between the explanatory factors and the total coliforms were observed, the regression models for predicting total coliforms were developed. Because no significant correlation was observed between the total coliforms in tap water (PDAM) and the explanatory factors, the regression model was only estimated for groundwater pollutions.

Distance from septic tank to well and well depth were used in the prediction model because they were significantly correlated with the total coliforms. The distance from the river was also added to the prediction model even though it was not significantly correlated with the total coliforms observed. The multiple regression model in SPSS was used in estimating this model. Multiple regression seeks to predict an outcome model from several predictors. The equation for the regression is:

$$Y_i = (b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_n x_n) + \varepsilon_i$$

Y is the outcome of variable, b_1 is the coefficient of the first predictor (x_1), b_2 is the coefficient of the second predictor (x_2), b_n is the coefficient of *n*th predictor (x_n), and ε_i is the difference between predicted and the observed value of Y for the *i*th participant.

Because of the insignificant correlation observed between the distance to river and the total coliform, a stepwise regression was made. Two steps were made, first inputting the distance from septic tank to well and well depth and later adding the distance to river variable. It was realised that about 44.1% of the occurrence of total coliform in groundwater were explained by the distance from septic tank and the well depth (Table 5-6). When the distance to river was added to the regression model the coefficient of regression increased by 0.001 representing an improvement of about 0.01%. Looking at the adjusted R square, a reduction was seen by adding the distance from the river to the model. Adjusted R square of 0.166 was observed when well depth and distance from septic tank to well were used. A difference of 0.028 from R square was observed. This meant that if the model had been derived from the whole population, rather than from the sample, about 2.8% variance could have been observed.

The distance from well to river was thus excluded from the model because it was increasing the variance of the model from reality. The resulted total coliform in groundwater model thus had the distance from septic tank to well and depth of well as the predictors (Table 5-7). From the model the total coliform ground water could be predicted using the distance from the well to the septic tank and the well depth.

Table 5-6: Summary of Regression Model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.441[a]	.194	.166	916.806
2	.442[b]	.195	.151	924.663

a. Predictors: (Constant), Well Depth, Distance from Septic Tank to Well

b. Predictors: (Constant), Well Depth, Distance from Septic Tank to Well, Distance from the river

Table 5-7: Regression Model for Total Coliforms

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	2281.658	445.384		5.123	.000
	Distance from Septic Tank to Well	-47.082	16.004	-.378	-2.942	.005
	Well Depth	-57.387	56.619	-.130	-1.014	.315

a. Dependent Variable: Total Coliform

$$Total\ Coliform = 2281.66 - 47.08\ (Distance\ from\ Septic\ Tank\ to\ Well) - 57.39\ (Well\ Depth)$$

6. Discussion of the Findings

This chapter mainly discusses about the finding of the results from chapter 5. This chapter will give the insight of the result. The discussion in this chapter is aiming at examining the findings. The first part is discussing about the water supply assessment especially different choice of water sources. The second part is discussing about quantitative analysis of water quality including the factors behind the higher level of total coliforms. The third part of this chapter is discussing about the estimation of groundwater pollution and the reflection on spatial autocorrelation between sample points. The last part is explaining the finding of the factors of water pollution.

6.1. Introduction

A detailed analysis and results about the type of water sources and the quality have been presented in the previous chapters. The perceptions of water quality from the users were assessed against the various quality test carried out on the water sources. Some explanatory factors for the occurrence of total coliforms in water were then sought yielding a regression model for predicting total coliforms. Also done is an estimation of the groundwater pollution over the study area. The following chapter discusses the results obtained in the previous chapters

6.2. Water Supply Assessment

6.2.1. Availability and the use of water supply

From the analysis, groundwater source of water supply was seen to be the main source of water for the people in Yogyakarta City. Wells are dug in extracting groundwater. Some of these wells were privately owned while others were for the community in general. The other main source of water was seen to be the used of tap water from the PDAM provider. Some of the people were seen be use a combination of tap water and groundwater, either private or communal. Initially the dominance of groundwater use was thought to be due to its affordability in comparison to tap water (PDAM). With the main cost of groundwater extraction been the cost of construction, it was going to be much affordable than water from the provider (PDAM) where monthly cost of using the water has to be paid. A classification of water sources and income levels however showed a substantial percentage of PDAM users been of the low income group. This showed that the high use of groundwater sources may not be due to financial reasons but about the trust of water quality from the providers. Bad experiences and user perceptions have effect on the usage of water sources.

6.2.2. Water Supply Index

After identifying the various water sources been used by the people in Yogyakarta, the water quality was assessed. Six water quality indicators were used in assessing the different water sources, thus, the odour, taste, and colour quality of the water, both before and after flooding. In forming the water supply index, the continuity of water supply was included.

From the analysis, about 53.9%, 98.5% and 98.9% of the people reported no scent for water sources from tap water (PDAM), private groundwater and communal groundwater respectively before flooding. However after flooding, these percentages dropped to 47.4%, 52.2% and 38.3% for the tap water (PDAM), private and communal groundwater respectively.

Similar cases were reported for the taste quality of water. Before flooding, about 50.0%, 100% and 100% of the people reported good taste for tap water (PDAM), private and communal groundwater respectively. After flooding, these percentages reduce to about 47.4%, 52.2% and 38.3% for tap water, private and communal groundwater respectively.

The case for the colour quality was not different with the before flooding scoring 57.9%, 98.5% and 97.8% for the tap water, private and communal groundwater respectively. Again after flooding, these percentages dropped to about 47.4%, 50.0% and 40.4% for tap water (PDAM), private and groundwater respectively.

In all three water quality assessment, a drop in water quality was reported especially with that of communal groundwater after flooding. It was therefore obvious flooding have influence on water quality. High runoffs from flooding can transport pollutants including sediment, nutrients, dissolved organic carbons, pathogens, etc. Some of these pathogens may come from over flown sewer lines and septic tanks. Without the a good water supply and sanitation infrastructure, high pollutions of water sources are observed (Kundzewicz, Mata et al. 2007). Usually surface water such as river, streams, lake and open wells are mostly affected. These may explain the huge drop of water quality in wells after flooding. The smaller drop in quality of tap water (PDAM) may be due to the purification process of this water source before distribution centrally to that from dug wells. The increase in sediment may also be the reason for the muddy taste, colour and scent experienced by most of the people after flooding.

Even though there wasn't a huge difference in the tap (PDAM) water quality before and after flooding, the observed score were low across all the water qualities. Most of the people using this water source complained about chlorine taste and odor. This could be due to the use of chlorine as a disinfectant chemical before the water is distributed. Even though chlorination has been seen to be effective in the reduction of microbiological pathogens, it has been seen to react with organic materials in water forming potentially harmful compounds including trihalomethanes, haloacetic acids etc. (Bull, Birnbaum et al. 1995; Galal-Gorchev 1996; Boorman 1999). These compounds may not have immediate health issues but they tend to have long term health effects when they are in high concentrations.

After assessing the different water qualities from the users' perception, the continuity of water supply was investigated. Users with uninterrupted water supply without difficulties were considered to be with continuous water supply. About 71.1%, 93.1% and 91.2% of the people reported continuous water supply for tap water (PDAM), private and communal groundwater sources. The high responses of the private groundwater may be due to the relatively constant supply of groundwater and easiness of accessing it because they are located in their compounds.

In order to evaluate and compare the various water supply sources based on these indicators, a water supply index (combination of indicators) was formulated. From the water supply index, private groundwater was seen to be the best scoring 0.999 with communal groundwater and tap water (PDAM) scoring 0.878 and 0.732 respectively. In most countries with reliable water supplies, most users perceive tap water to be safe even in areas with water-treatment deficiencies (Doria 2010). This was not the case in Yogyakarta as people rather considered tap water from providers as unsafe. This may have resulted from the unreliability of water supply from these providers in the city. This may have affected the trust of the people in the quality of water from these providers. This could have been due to previous experiences of users with water from these providers. Strang (2001) as cited in (Doria 2010), explained how past experience of consumers with water providers can have effect on water quality perceptions.

6.3. Quantitative Analysis of Water Quality

With the background of the users' perception about the quality of the different water source, a quantitative water quality test was carried out. Two water quality tests thus total coliforms and total dissolved solids were used.

From the result, most of the water sampled from groundwater sources (96.6%) were seen to be above 50 MPN/100 ml of total coliforms, the acceptable threshold for water to be considered as clean (Ministry of Health 2002). This was however not the case in the total coliforms observed from tap water (PDAM), with about 20.6% of the water samples above this threshold. Considering the level of total dissolved solids in water sources, both sources, thus tap water and groundwater were seen to be below the acceptable threshold of 1200 mg/liter (WHO 2003).

These observed results from the quantitative test proving groundwater to be of low quality than tap water was not so in the perception of the users. These can be explained by factors including biased perception of users to familiarity to water quality. The perceptions of people have been seen not to be positive or neutral always. It can sometime be bias, been influence by information about water quality from others. These information sharing can be interpersonal or impersonal (Doria, Pidgeon et al. 2009). In this case it could be at the interpersonal level where people share information among themselves and not at the impersonal level which affect the whole community. Bad experience of someone with a water source when shared among people may influence their perception of water quality of that particular source even if they have not experienced those themselves. Familiarity may also influence the quality perceptions of users (Doria 2010). A certain water quality of water over a prolonged time may be considered as good. A study by Owen et al (1999), shows how the complaints level of consumers were increased when a change in water source of public water supply caused an increase in water hardness even though they were familiar with hard water in the area. People using groundwater may be much familiar with the quality of the water and that does not change much. From a developing country, the continuous quality of tap water may be difficult to maintain due to breakages and leakages. The variance in water quality may have induced this mistrust of tap water from the providers resulting in the overall low quality from the users' perception contrary to the results from the water quality tests.

6.4. Spatial Spread of Water Pollution

After investigating the water quality both from the users' perspective and from the water quality and the reasons behind the disparities between these findings, the spread of groundwater pollution of the study area was estimated. In estimating the groundwater pollution, the occurrence of pollution from the water sampled were analysed to see if they are spatially autocorrelated as it would serve as a base for the estimation

6.4.1. Spatial Autocorrelation of Total Coliforms Pollution and Total Dissolved Solids

From the analysis, a low global spatial autocorrelation was observed (Moran's I = 0.15) for the occurrence of total coliforms in groundwater sampled over the area. However a local spatial autocorrelation revealed high autocorrelation among some of the groundwater samples locally. Looking at tap water sampled, total coliform occurrence were not spatially autocorrelated globally (Moran's I = -0.07). A look at the local autocorrelation did not differ much from the global autocorrelation for the total coliform occurrence in tap water.

The occurrence of total dissolved solids were also analysed to see if they are spatially autocorrelated or not. Globally, weak spatial autocorrelation (Moran's I = 0.22) was observed for total dissolved solids in groundwater with that in tap water (PDAM) showing very low or no spatial autocorrelation (Moran's I = -0.03). However high local autocorrelations (Moran's I ranging from -0.13 to +0.82) were observed with total dissolved solids in groundwater. This was however not the case for the occurrence of total dissolved solids in tap water, revealing very low or no local spatial autocorrelation (Moran's I ranging from -0.04 to +0.04).

These general low or no spatial autocorrelations with the occurrence of total coliforms and total dissolved solids in both groundwater and tap water (PDAM) may be due small number of observed samples compared to the elongated study area, and the measurement errors (Haining, Neil et al. 2001). Taking a look at the equation for the Moran's I, the number of samples and the distances between them may affect the outcome. Overmars, de Koning et al (2003) investigated the effect of data aggregation on spatial dependency and found out a decrease in spatial dependency with low aggregation data having longer interdistances. Considering the elongated nature of the study area and the number of observed water samples, longer distances between points and data at the lowest aggregation levels were evident. The inverse distance used as weighting in this research was therefore going to give very small weighting values. The limitation of the total coliform measuring instrument been able to measure only up to2400 MPN/100ml resulted in most of the water samples having this value. This may have had an effect on the mean value which is also important in calculating the Moran's I. The difference between the observed values and the mean was thus going to be small. A multiplication of this small difference between the observed values and the mean with the small weightings may have been a factor in the small Moran's I observed globally. Contrary to these, the smaller distances considered during the local Moran's I estimation might have explained some of the reasons why higher Moran's I were observed locally.

6.4.2. Estimation of Groundwater Pollution for Total Coliforms and Total Dissolved Solids

With the uncontinuous nature of water through pipelines, the interpolation of pollution was only done for groundwater sources. This was aimed at predicting the level of pollution at locations that were not sampled.

Generally, high total coliforms and total dissolve solids pollutions in groundwater were mostly concentrated in areas with high housing density and along the river. Lower pollutions were observed in areas with much lower housing densities even though some were also observed in highly densed areas. Highly dense areas could result in closer proximity of waste disposal infrastructures and well water because of the lack of space contrary to low dense areas. Total coliforms are mostly in soils and water and can originate from human sewage and animal droppings (U.S. Environmental Protection

Agency ; Water Stewardship Division 2007). Highly dense areas with more people and animals could therefore have increased the amount of coliforms in the top soil from the increased human sewages and animal droppings. With wells in close proximity to septic tanks, the transportation of these bacteria may have been much easier as compared to the increase distance between septic tanks and wells which are usually observed in low dense areas.

6.5. Predicting Total Coliforms Occurance

With the background of high coliforms been observed in high dense areas, as compared to low dense areas, some of the explanatory factors for the occurrence of total coliforms in well were sought.

Three explanatory factors were employed in efforts to explain the occurrence of total coliforms; the depth of well, the distance of well to septic tank and the distance of well to the river. Before the formulation of the prediction model, a correlation of these factors and total coliforms were investigated.

The distance of well to septic tank was found to have the highest significant correlation ($r = -0.424$, $p = 0.001$) with total coliform occurrence with the well depth also having a significant correlation ($r = -0.264$, $p = 0.043$). However the distance to the river did not have any significant correlation ($r = 0.012$, $p = 0.920$) with total coliforms. Both distance to septic tank and the well depth revealed negative correlation, indicating an increase in total coliforms as these factors reduces. This was expected. The lack of significant correlation between distances to river with total coliforms was however not expected. Groundwater levels near rivers are usually higher and people living near the river may not have to dig deeper to get water. This may result in shallow wells which were seen to have a significant correlation with the occurrence of total coliforms. High dense areas as explain earlier may indicate close proximity of well to septic tank which was also seen to have a significant correlation with total coliforms. The occurrence of high pollutions in areas near the river which are mostly dense may have resulted from proximity of well to septic tank and shallow wells rather than just due to the closeness to the river.

A regression model was therefore made for predicting the occurrence of total coliforms. A stepwise regression modelling was used. The two factors (distance to septic tank and well depth) which were correlating with total coliforms were first put into to model, and then the third factor (distance to river) which was seen not to correlate to total coliform was also added. This was to see how much the third factor could improve the model. The model with distance to septic tank and depth of well explained about 44.1% of the occurrence of total coliforms ($R = 0.441$, $R^2 = 0.194$, adjusted $R^2 = 0.166$). When the distance to river was added to the model, about 44.2% of the occurrence of total coliforms ($R = 0.442$, $R^2 = 0.195$, adjusted $R^2 = 0.151$) was explained. The distance to the river was thus explaining only about 0.1% of the occurrence of total coliforms. A reduction in adjusted R^2, which when compared to the R^2 indicates the closeness of your model to reality was observed. This meant that if the distance to river was included in the prediction model, it would decrease the closeness of the model to reality. Because of this reason the distance to river was removed from the model.

However, the model was only able to explain about 44.1% of the occurrence of total coliforms, leaving about 55.9% unexplained. This indicates that, there were other factors which may influence total coliforms occurrence which were not taken into consideration. Some of these factors include the type of soil in the area, the construction of the well etc.(Tanik and Comakoglu 1997; Bureau of Environmental Health 2004; Levy, Sun et al. 2007; Water Stewardship Division 2007) Improper construction in well may allow the leakages of coliforms into the well water. Tanik and Comakoglu (1997), showed that the reduction in bacteria through soils depends on the distance travelled and not on the time. Bacteria movement are also seen to be much easier through cracks in rock, gravelly soils and sandy soils. They are much difficult in clayey soils. From these literatures, it was clear other factors apart from the distance to septic tank and well depth may influence the occurrence of total coliforms pollution. The inclusion of some of these factors could have therefore improved the model.

7. Conclusion and Recommendation

The concluding chapter includes the general conclusion about this research, an insight about the research objectives, and the study area recommendation specifically on policy responses about the findings as well as the limitation of the research.

7.1. Introduction

The research assesses the water quality and identifies the interrelation between water supply and sanitation, a case study was carried out in Yogyakarta City. It identified different water sources in the communities that led to the physical assessment (such as odor, taste and colour) and water quality testing (total coliforms and total dissolved solids). The effect of sanitation system on water quality was investigated. The groundwater pollution of the study area was estimated.

This chapter conclude the research base on the analysis and results obtained. Recommendations are then made for the improvement of water quality in the study area and for further research works. The limitations of this research are then identified.

7.2. General Conclusion

From the results, groundwater was seen to be the main water source used by people of Yogyakarta even though they showed less water quality. This may be due to bad perceptions of the people about tap water (PDAM).

Generally higher total coliforms pollutions were seen to be concentrated in high dense areas as compared to those in low dense areas. The distance of well from septic tank and the depth of the well were seen to be the explanatory factors for the occurrence of total coliforms in the study area.

7.3. Specific Conclusions

- **Review about assessing water quality**

The different water sources in the study area (Yogyakarta) and their water quality have been assessed. The following findings were made.

1. Groundwater is the main source of water for the people of Yogyakarta even though tap water from providers was also available. People also bought portable water (sachet water) for drinking purposes. This wide use of groundwater may be as a result of mistrust of water from the providers. People considered this water source to be of low quality as compared to groundwater.

2. In contrary to the consumers' perception, groundwater was seen to be more polluted (higher total coliforms) as compared to tap water (PDAM). Most of the groundwater sampled were

found be contaminated with total coliforms above the acceptable threshold. Concerning the total dissolved solids, all sampled water were below the acceptable threshold.

- **Review on identification the factors of water pollution**

After determining the water quality of the various sources, the spatial occurrence of water pollution was determined. The pollution of groundwater over the study area was then estimated. The following findings were made;

1. Globally, very little or no spatial autocorrelations were observed between the occurrence of total coliforms and total dissolved in water. High local spatial autocorrelations were however observed in some cases. These might have been due to the number of observations taking in the elongated study area.

2. An estimation of groundwater pollution however generally showed high pollutions in high dense areas along the river. Some spots of high pollutions were also found in low dense areas.

- **Review on identification the factors of water contaminations**

After estimating the spatial spread of groundwater pollution over the study area, a model for predicting the presence of total coliforms was made. This was to see the effect of sanitation systems on water quality. These were the main findings;

1. The occurrence of total coliforms in wells does not necessarily depend on the distance of the well to the river. No significant correlation was found between the distance of well to river and the total coliforms observed.

2. The occurrences of total coliforms were about 44.1% explained by the distance of the well from septic tank and the well depth. This showed that other factors such as the soil type and construction of well which were not considered may also have effect on the total coliform contamination of water sources.

7.4. Study Area Recommendations

In line with the findings of this research about the water sources used and their quality, some recommendations are made. These may be seen as policies which could help in ensuring quality water for improving the quality of lives of the people of Yogyakarta.

Different policies have been made concerning the different problems found.

1. *Problem*: Most of the people of Yogyakarta, the study area, use water from wells (groundwater) been private or communal as compared to tap water (PDAM). With a substantial amount of low income earners using tap water from PDAM, this general low usage may be due to mistrust of water from the provider about its quality. Contrary to this, water quality testing proved groundwater to be much more polluted than tap water. Increase in groundwater extraction may cause ground settlements.

Possible response: People can be synthesized about the quality of water from the PDAM. This could be done through advertisement through the media. Impersonal information sharing, that is information through media has been seen to affect the perception of people and if water supplies from PDAM are portrayed to be better, people may turn to use it more. People can also be educated about the various cause and effects of total coliforms. Purification process such as boiling can also be thought.

Institution: PDAM, Health Agency and neighbourhood authority.

2. *Problem*: people that used tap water from the provider (PDAM) complaint about chlorine taste and odor. Excessive chlorine may have been used in the purification. Users may also have not known the importance of chlorine as disinfectants.

   Possible response: Tap water providers (PDAM) should ensure the continual use of the correct amount of chlorine used in the purification process. Public education about the importance of chlorine as disinfectant in their drinking water could be made.

   Institution: PDAM, Health Agency and neighbourhood authority.

3. *Problem*: Many complaints about the colour quality of water from providers (PDAM) were made. Colours like dark brown and yellow were reported. This could be due to leakages and rust in the distribution lines used for supply water to consumers.

   Possible response: Proper construction material and procedures could be used in distribution lines. These distribution lines could be check on regular bases for leakages and bursts.

   Institution: PDAM and neighbourhood authority.

4. *Problem*: Some people that used tap water complaint about the continuity of water supply during peak hours in the morning. This could be due to low pressure in the distribution lines because of insufficient water supply. Leakages in distribution lines could also lead to the reduction in pressures.

   Possible response: Continual supply of water should be ensured by the providers. More sources of water could be explored by providers to ensure the right quantity of water for the communities. Leakages in distribution lines could also be check and repaired regularly.

   Institution: PDAM and Public Works Agency.

5. *Problem:* The distance of well to septic tank and depth of well were found to be the some of the predictors of total coliform contamination in groundwater. People with shallow well closer to septic tanks were found to have high total coliforms.

   Possible response: A threshold for the distance between septic tank and well should be set in connection with the other factors such as soils types. Proper construction materials for both septic tanks and well should be used with the correct procedures. This may reduce the leakages of total coliforms from septic tanks to wells.

   Institution: Public Works Agency and Health Agency.

6. *Problem*: people could not distinguish the high level contamination of microbiological (total coliforms) and total dissolved solids based on their experiences. People were used to the actual

condition now even though the water source had been contaminated. Most of the coliform bacteria are harmless to humans but however a small percentage of faecal coliform bacteria may cause intestinal distress or nausea and vomiting. People were not aware about their water quality.

Possible response: public health education about different causes and effects of water contamination and the way to purify the water.

Institution: Health Agency and neighbourhood authority.

7.5. Limitation of the Research

During the research some limitations were met. These were due to reasons ranging to time to financial resources. Some technical difficulties were also experienced.

1. The interrelation or interdependency between infrastructures is a broad concept. This research mainly focused on the spatial interrelation and quality assessment. There are many types of interdependency that could have also been measured in the research. The physical locations of pipe lines and sewer lines could also have been measured to see their interactions. Apart from these, the integration of these infrastructures at the management levels could have been investigated. Apart from that, the condition of infrastructures during the disaster has been a concerned in some of the theories of interdependency. However, this research is mainly focused in the normal condition of water quality. This could be seen from the water quality assessment that majority happened during daily life and also the indicator of water quality measurement of total coliforms and dissolved solids were only observed in a particular time without influence from hazards.

2. The water quality index that was generated in this research was from user's perceptions. With personal past experience and that of other influencing their responses, this index may be misleading. Using perceptions of outsiders or tourist who may not have been much influence could have provided a much neutral responses. This may be difficult considering the amount of time available for this research.

3. Only two indicators (total coliforms, total dissolved solids) were used in assessing the water quality. Other chemical quality tests such as nitrate and fluoride concentrations could have been done for a much more quality analysis of the different water sources. Limited financial and time resources however did not allow this.

4. One main sanitation infrastructure was looked at, thus the septic tank. Other sanitation infrastructures such as drainages may also have effect on water quality especially when there are flooding. These infrastructures were however not examined because of the lack of data.

5. A lot of the sample water were seen to have total coliforms of 2400 MPN/100 ml. This was so because the measuring equipment could only measure up to this level. All water sources with higher total coliforms than this were therefore assigned a value of 2400 MPN/100 ml. This could have had an effect on the spatial autocorrelation calculated.

6. The condition of each well could also have an effect on the level of contamination. A determination of the construction material and its conditions could therefore have provided extra explanation about the total coliforms occurrence.

7.6. Further Research

Future result should cope some of the limitations that discussed in the previous sub-chapter (7.3.). In the further development of this research would be interesting to consider some factors such as:

- Interrelation including other elements of sanitation apart from septic tank. The spatial interrelation between water supply and sanitation (drainage or sewage) still can be considered in the future research.
- Observing the interrelation between water supply and sanitation in this case can be drainage with pipe water, the water quality assessment also can be extended to measure the microbial especially after the disaster events (flooding or earthquake).

A study in water quality assessment as an influence of sanitation would also be an alternative of future study. The indicator of water quality can be added more such as user's experiences that cause risks as an effect of the drinking water as well as the indicators of water quality testing should be more related to the complaints.

References

Akbar, H. M. D., J. R. Minnery, et al. (2007). "Community water supply for the urban poor in developing countries: The case of Dhaka, Bangladesh." Habitat International **31**(1): 24-35.

Ashbolt, N. J. (2004). "Microbial contamination of drinking water and disease outcomes in developing regions." Toxicology **198**: 229-238.

Ashley, R. and P. Hopkinson (2002). "Sewer systems and performance indicators--into the 21st century." Urban Water **4**(2): 123-135.

Beck, M. B. (2005). "Vulnerability of water quality in intensively developing urban watersheds." Environmental Modelling & Software **20**(4): 381-400.

Boorman, G. (1999). "Drinking Water Disinfection Byproducts: Review and Approach to Toxicity Evaluation." Environmental Health Perspectives **107**(Suppl 1): 207.

BPS Statistics of Yogyakarta City (2007). Kota Yogyakarta dalam angka 2006/2007. Yogyakarta, BPS Statistics of Yogyakarta City,.

Bull, R. J., L. Birnbaum, et al. (1995). "Water Chlorination: Essential Process or Cancer Hazard?" Toxicol. Sci. **28**(2): 155-166.

Bureau of Environmental Health (2004). Total & Fecal Coliform Bacteria - Answers to Frequently Asked Health Questions. Ohio Department of Health. Ohio, U.S.

Childs, C. (2004). "Interpolating surfaces in arcGIS spatial analyst." Retrieved 01/02/2010, from http://www.esri.com/news/arcuser/0704/files/interpolating.pdf.

Chinn, T. D. (2003). Water supply. Environmental Engineering. J. A. Salvato, N. L. Nemerow and F. J. Agardy. New Jersey, John Wiley & Sons, Inc.

Choguill, C. L. (1996). "Ten steps to sustainable infrastructure." Habitat International **20**(3): 389-404.

Davidson, F. (1996). "Planning for performance: requirements for sustainable development." Habitat International **20**(3): 445-462.

Davies, J.-M. and A. Mazumder (2003). "Health and environmental policy issues in Canada: the role of watershed management in sustaining clean drinking water quality at surface sources." Journal of Environmental Management **68**(3): 273-286.

DC Water and Sewer Authority. "Combined sewer system overview." from http://www.dcwasa.com/education/css/combined_sewer.cfm.

Dimitriou, H. T. (1991). "An integrated approach to urban infrastructure development : a review of the Indonesian experience." Cities **8**(3): 193-208.

Doria, M. d. F. (2010). "Factors influencing public peception of drinking water quality." Water Policy **12**: 1 - 19.

Doria, M. d. F., N. Pidgeon, et al. (2009). "Perceptions of Drinking Water Quality and Risk and its Effect on Behaviour: A Cross-national Study." Science of The Total Environment **407**(21): 5455-5464.

Drinking Water Inspectorate (2003). Information leaflet chlorine, smell, taste. D. W. Inspectorate. London.

Erbe, V., L. P. Risholt, et al. (2002). "Integrated modelling for analysis and optimisation of wastewater systems - the Odenthal case." Urban Water **4**(1): 63-71.

Eriksson, E., K. Auffarth, et al. (2002). "Characteristics of grey wastewater." Urban Water **4**(1): 85-104.

ESRI. (2006). "What is Z score?" ArcGIS 9.2 Desktop Help, from http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=What is a Z Score?

Field, A. (2005). Discovering statistics using SPSS. London, SAGE Publications.

Firman, T. (2002). "Urban development in Indonesia, 1990-2001: from the boom to the early reform era through the crisis." Habitat International **26**(2): 229-249.

Fu, G., D. Butler, et al. (2008). "Multiple objective optimal control of integrated urban wastewater systems." Environmental Modelling & Software **23**(2): 225-234.

Galal-Gorchev, H. (1996). "Chlorine in Water Disinfection." Pure and Applied Chemistry **68**(9): 1731-1736.

Getis, A. (2007). "Reflections on Spatial Autocorrelation." Regional Science and Urban Economics **37**(4): 491-496.

Gillette, J., R. Fisher, et al. (2002). Analyzing water/wastewater infrastructure interdependencies. 6th International Conference on Probabilistic Safety Assessment and Management, San Juan (PR).

Government of Yogyakarta Province (2009). Penetapan upah minimum provinsi daerah istimewa yogyakarta 2009. Yogyakarta.

Gray, S. R. and N. S. C. Becker (2002). "Contaminant flows in urban residential water systems." Urban Water **4**(4): 331-346.

Guy, S. e., S. e. Marvin, et al. (2000). Urban infrastructure in transition : networks, buildings, plans. London, Earthscan.

Haining, R. P., J. S. Neil, et al. (2001). Spatial Autocorrelation. International Encyclopedia of the Social & Behavioral Sciences. Oxford, Pergamon**:** 14763-14768.

Health Agency City of Yogyakarta (2009). Rekapitulasi hasil pemeriksaan sampel air bersih bakteriologis swadaya masyarakat tahun 2009. January - August 2009. Yogya, Health Agency City of Yogya.

Hirst, E., C. Goldman, et al. (1991). "Integrated resource planning : electric and gas utilities in the USA." Utilities Policy **1**(2): 172-186.

Hoque, B. A., K. Hallman, et al. (2006). "Rural drinking water at supply and household levels: Quality and management." International Journal of Hygiene and Environmental Health **209**(5): 451-460.

Jorgensen, B., M. Graymore, et al. (2009). "Household water use behavior: an integrated model." Journal of Environmental Management **91**(1): 227-236.

Kiefer, J. R. (2003). Wastewater treatment and disposal. Environmental Engineering. J. A. Salvato, N. L. Nemerow and F. J. Agardy. New Jersey, John Wiley & Sons, Inc.

Kolsky, P. and D. Butler (2002). "Performance indicators for urban storm drainage in developing countries." Urban Water **4**(2): 137-144.

Kundzewicz, Z. W., L. J. Mata, et al. (2007). Freshwater Resources and their Management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change

M. L. Parry, O. F. Canziani, J. P. Palutikof, v. d. L. P.J. and H. C.E. Cambridge, UK, Cambridge Univ Press**:** 976.

Kyessi, A. G. (2002). Community participation in urban infrastructure provision : servicing informal settlements in Dar es Salaam, Tanzania. Dortmund, SPRING.

Lam, N. S., K. Rob, et al. (2009). Spatial Interpolation. International Encyclopedia of Human Geography. Oxford, Elsevier**:** 369-376.

Lemer, A. C. (1998). Progress toward integrated infrastructure-asstesmanagement systems: GIS and beyond. APWA International Public Works Congress NRCC/CPWA Seminar Series "Innovations in Urban Infrastructure"

Las Vegas, NV.

Levy, J., K. Sun, et al. (2007). "Transport of escherichia coli bacteria through laboratory columns of glacial-outwash sediments: estimating model parameter values based on sediment characteristics." Journal of Contaminant Hydrology **89**(1-2): 71-106.

Lindley, T. R., Buchberger, S. G. (2002). Using GIS and hydraulic modeling to evaluate susceptibility of water distribution systems to intrusions: a case study. Urban Water Supply Handbook. L. W. Mays, McGraw-Hill.

Ministry of Health (2002). Standards and Monitoring of Drinking Water Quality. Ministry of Health. Jakarta, Indonesia.

Mkandawire, T. (2008). "Quality of groundwater from shallow wells of selected villages in Blantyre District, Malawi." Physics and Chemistry of the Earth, Parts A/B/C **33**(8-13): 807-811.

Nas, B. and A. Berktay (2006). "Groundwater contamination by nitrates in the city of Konya, (Turkey): A GIS perspective." Journal of Environmental Management **79**(1): 30-37.

Ntengwe, F. W. (2005). "Designing a domestic water supply system--The engineer's perspective and considerations as a challenge to consumers." Physics and Chemistry of the Earth, Parts A/B/C **30**(11-16): 850-858.

Odland, J. (1988). Spatial autocorrelation. California, SAGE Publication, Inc.

Overmars, K. P., G. H. J. de Koning, et al. (2003). "Spatial Autocorrelation in Multi-Scale Land Use Models." Ecological Modelling **164**(2-3): 257-270.

Owen, A. J., J. S. Colbourne, et al. (1999). "A Mental Model's Approach to Customer Perception of Drinking-Water Supply and Quality." Water and Environment Journal **13**(4): 241-244.

Pang, L., M. Close, et al. (2004). "Estimation of septic tank setback distances based on transport of E. coli and F-RNA phages." Environment International **29**(7): 907-921.

Parkin, J. and D. Sharma (1999). Infrastructure planning. London, Thomas Telford.

Pederson, P., D. Dudenhoeffer, et al. (2007). "Critical infrastructure interdependency modeling: a survey of U.S. and international research." 2010, from http://www.inl.gov/technicalpublications/Documents/3489532.pdf.

Peter-Varbanets, M., C. Zurbrügg, et al. (2009). "Decentralized systems for potable water and the potential of membrane technology." Water Research **43**(2): 245-265.

Pitt, R., S. Clark, et al. (1999). "Groundwater contamination potential from stormwater infiltration practices." Urban Water **1**(3): 217-236.

Pokrajac, D. (1999). "Interrelation of wastewater and groundwater management in the city of Bijeljina in Bosnia." Urban Water **1**(3): 243-255.

Pritchard, M., T. Mkandawire, et al. (2008). "Assessment of groundwater quality in shallow wells within the southern districts of Malawi." Physics and Chemistry of the Earth, Parts A/B/C **33**(8-13): 812-823.

Public Works (2002). Profil kabupaten / kota Yogyakarta. Public Works. Yogyakarta, Public Works Department.

Rainer, G., PE (1990). A guide for architects and planners. Understanding infrastructure. Toronto, John Wiley & Sons, Inc.

Reid, D. C., A. C. Edwards, et al. (2003). "The quality of drinking water from private water supplies in Aberdeenshire, UK." Water Research **37**(2): 245-254.

Rietveld, L. C., J. Haarhoff, et al. (2009). "A tool for technical assessment of rural water supply systems in South Africa." Physics and Chemistry of the Earth, Parts A/B/C **34**(1-2): 43-49.

Rinaldi, S. M., J. P. Peerenboom, et al. (2001). Identifying, understanding, and analysing critical infrastructure interdependencies. IEEE Control Systems Magazine. USA. **0272-1708/01**.

Ringvall, A., G. Stahl, et al. (1998). Guided transect sampling - a new design combining prior information and field surveying. Integrated Tools for Natural Resources Inventories in the 21st Century, Idaho, USA.

Roccaro, P., G. Mancini, et al. (2005). "Water intended for human consumption -- part I: compliance with European water quality standards." Desalination **176**(1-3): 1-11.

Rondinelli, D. A. (1991). "Asian urban development policies in the 1990s: from growth control to urban diffusion." World Development **19**(7): 791-803.

Sheat, A. (1992). Public perception of drinking water quality. Should we care? New Zealand Water Supply and and Disposal Association Annual Conference.

Singh, K. and F. Steinberg (1996). "Integrated urban infrastructure development in Asia." Habitat International **20**(1): 1-3.

Stasinopoulos, P., M. H. Smith, et al. (2009). Whole system design an integrated approach to sustainable engineering. London, Earthscan.

Steinberg, F. (1991). "Urban infrastructure development in Indonesia." Habitat International **15**(4): 3-26.

Strang, V. (2001). Evaluating water: cultural beliefs and values about water quality, use and conservation, Oxford.

Tanik, A. and B. Comakoglu (1997). "The Role of Soils in the Removal of Total Coliforms from Domestic Wastewater." Environmental Technology **18**(4): 441 - 447.

U.S. Environmental Protection Agency. (10th April, 2009). "Drinking Water Pathogens and Their Indicators: A Reference Resource." Retrieved 10th February, 2010, from http://www.epa.gov/enviro/html/icr/gloss_path.html.

UNESCO. (2007). "UNESCO water portal newsletter No. 161: water-related diseases." from http://www.unesco.org/water/news/newsletter/161.shtml#know.

Voice of human rights. (2007). "Permukiman astri tepi kali Code." from http://www.vhrmedia.com/vhr-news/bingkai,Permukiman-Asri-Tepi-Kali-Code-53.html.

Water Stewardship Division (2007). Total, Fecal & E.coli Bacteria in Groundwater. Ministry of Environment. British Columbia, Canada.

Wegelin, E. A. (1990). "New approaches in urban services delivery: a comparison of emerging experience in selected Asian countries." Cities **7**(3): 244-258.

WHO (2003). Total Dissolved Solids in Drinking-water. Background Document for Development of WHO Guidelines for Drinking-water Quality. Geneva, WHO.

WHO (2006). Guidelines for drinking-water quality.

Wikipedia. "Valve." Retrieved 16th November 2009, from http://en.wikipedia.org/wiki/Valve.

Wilkes University Environmental Engineering and Earth Sciences. "Total dissolved solids." Retrieved 14th November 2009, from http://www.water-research.net/totaldissolvedsolids.htm.

Appendix

Household Questionnaire

Household questionnaire on water supply & sewage system interdependencies

Date :
Surveyor : ______________________

Question number : ______________________

Village name:

Household number:

Household data

1. Details of respondent:
   Position in the family: Husband ☐ Wife ☐ Other ☐ Specify:

2. Number of persons in household:

Household members	Relationship	Age	Sex	Occupation	Education
1					
2					
3					
4					
5					
6					
7					

3. Household preference
   - Do you own / rent this land?
     Owned ☐ Rented ☐ Others:................
   - Do you own / rent this house?
     Owned ☐ Rented ☐ Others: …………..
   - Household income (accumulation from the whole family):
     ☐ < Rp.100.000
     ☐ Rp.100.000 – Rp.700.000
     ☐ Rp.700.000 – Rp.2.000.000
     ☐ Rp.2.000.000 – Rp.3.000.000
     ☐ Rp.3.000.000 – Rp.4.000.000
     ☐ Rp.4.000.000 – Rp.5.000.000
     ☐ >Rp.5.000.000
   - House type
     Temporary: Semi-permanent: Permanent:
   - Number of rooms in the house
     Bedroom: Kitchen: Bathroom: Toilet:

- Telephone
  Home line ☐ Mobile ☐ Both ☐

- Type of toilet:
  Private toilet ☐ Public toilet ☐ others:

- Which of the following facilities are available in your residence?
  Electricity ☐ access to water supply (either well or from provider) ☐

4. Regular supply for electricity:
   Every day ☐ not working properly sometime ☐ reasons: ....

Water supply provision

General Question about water supply:

5. Water supply source (it can be more than one): more than 1 answer

Source	Circle the answer
Provider (PDAM)	A
Rain Water	B
Groundwater	C
Communal groundwater	D
Buying from vendors	E
Surface water (river)	F
Other sources, specify:	

6. Please indicate your water supply quality (if it is more than one please fill the form for each of them):
   Source:

Odor	Taste	Colour
Smell / Not smell	Strong taste / good / chlorine	Colour / Colourless
Specify:	Specify:	Specify:

Source:

Odor	Taste	Colour
Smell / Not smell	Strong taste / good / chlorine	Colour / Colourless
Specify:	Specify:	Specify:

Source:

Odor	Taste	Colour
Smell / Not smell	Strong taste / good / chlorine	Colour / Colourless
Specify:	Specify:	Specify:

Source:

Odor	Taste	Colour
Smell / Not smell	Strong taste / good / chlorine	Colour / Colourless
Specify:	Specify:	Specify:

7. Do you purify your drinking water? Yes / No If Yes, How:

Purifying	Answer (√)
Straining	
Alum tablets	
Ordinary filter	
Electronic filter	
Boiling	
Others:	

8. Do you buy potable water supply for drinking water? Y / N
   If Yes, how many gallons do you spend per week?

9. How much do you spend for the water supply per month? ....

10. If there is any other sources of water supply that you want to use instead that you have it now, what would it be, and why?

11. Have you or any family member ever suffered from any of these diseases? When was the last time you got the disease?
    Diarrhoea ☐
    Cholera ☐
    Typhoid ☐
    Others:

Respondents using any of each or a combination of the sources below:

A. Provider (PDAM)

12. How much water do you use per month according to your monthly bill from PDAM?
    < 10 meter ³ ☐
    10-20 meter ³ ☐
    20-30 meter ³ ☐
    >30 meter ³ ☐

13. From the water source from PDAM, how is the condition of service per day? How do you deal with non PAM water and water from other sources? Ask in different way?

Circumstances	Y / N or other explanation
Difficulties on peak hour from 7:00 – 9:00	
Continuously service the whole day	
Difficulties in the evening 17:00 – 21:00	
Only in some hours	Specify:

Not every day service	Specify:

14. Specify the water uses:

Uses	Answer (√)
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

B. **Rain water source**

15. Do you store your rain water in storage (tank)? Y / N If Yes:

Storage	Answer (√)
Underground storage	
Roof storage	
Others:	

16. (If using storage) Do you use any electrical power to get the water from the storage? Y / N

17. Do you really depend on electricity to get your water? Y / N. If No, Why:

18. (If not using specific storage as mentioned above) Where do you collect your rain water? ......

19. How is the condition of service per-day?

Circumstances	Y / N or other explanation
Continuously service the whole day	
Not every day service	Specify:
Difficulties in dry season	Specify:
Problems during the rainy season	Specify:
Other condition:	

20. Specify the water uses:

Uses	Answer (√)
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

C. **Groundwater source (private)**

21. Type of well

Type of well	**Answer (√)**
Shallow well (uppermost part of soil, near to the surface)	
Deep well (machine-dug, hundred meters deep)	

22. How do you pump the water from the ground?

Water well power	**Answer (√)**
Jet-pump (electricity)	
Hand pump / manual	

23. If you are using jet-pump: do you really dependent on electricity power from provider or you use your own generator? ....

24. If you are using hand pump / manual, how much water do you use per-day:
   ..... Pails/ buckets or by asking (surveyor may indicate the capacity of container by observation)
   ..... Other containers, specify:

25. For groundwater source, is your septic tank located close to the well? Y / N , specify distance: …………..meters

26. Do you have any problem during the dry season? Y / N

27. How is the condition of service per-day?

Circumstances	**Y / N or other explanation**
Continuously service every day	
Not every day service	Specify:
Difficulties in dry season	Specify:
Other condition:	Specify:

28. Specify the water uses:

Uses	**Answer (√)**
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

D. Communal groundwater

29. How do you get the connection of communal ground water?
    Pipe connection ☐ taking from the source ☐

30. Distance of household from the main source of communal groundwater
    < 0.5 km ☐
    0.5-1 km ☐
    >1km ☐

31. How much water do you use per day?
    ..... Gallons
    ..... Other containers, specify:

32. In general, have you ever experienced the difficulties to get water during the dry season? Y / N
    If yes, how often? ....

33. How is the condition of service per-day?

Circumstances	Y / N or other explanation
Continuously service every day	
Not every day service	Specify:
Difficulties during in-take (ex: waiting time, higher price, etc.)	
Difficulties in dry season	Specify:
Other condition:	Specify:

34. Specify the water uses:

Uses	Answer (√)
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

E. Buying from vendor

35. What type of container do you use in buying the water?
    Gallon ☐ Bucket ☐ Other, specify:

36. How many containers do you buy per day?

37. How is the condition of service per-day

Circumstances	Y / N or other explanation
Continuously service every day	

Not every day service	Specify:
Other condition: (ex: the price is too expensive, they don't sell it every day)	Specify:

38. Specify the water uses:

Uses	Answer (√)
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

F. Surface water (river)

39. How do you get the surface water to your house?
    Installation by pipe to house ☐ getting from the source using container ☐

40. What type of container do you use in getting the water?
    Gallon ☐ Bucket ☐ Other, specify:

41. How many containers do you take per day?

42. How is the condition of service per-day?

Circumstances	Y / N or other explanation
Continuously service every day	
Not every day service	Specify:
Difficulties in dry season	Specify:
Other condition:	Specify:

43. Specify the water uses:

Uses	Answer (√)
Drinking and cooking	
Washing	
Gardening	
Other activities (specify) :	

Sewer system provision

44. Indicate the characteristic of your sewer system?
    Combined sewer (sewage and storm water) ☐ arate sewer from ☐ ectly to the river

45. Septic tank that you use:
    Your own septic tank ☐ communal septic tank ☐

46. Indicate the drainage service line in your house?
    Underground carriage system ☐ open drains (concrete) ☐

47. If your drainage is located in front of your house: Have you ever inspected your drainage condition in front of your house? Y / N
    Full of solid waste ☐ sometime there are was ☐ always clean ☐

48. If you use the pipe from house to the river: Do you know the condition of your pipe either using filter or not before it goes to the river? Y / N, specify: ......

49. Does the drainage in front of your house work properly especially during rainy season?
    Yes ☐ No (flooded) ☐ Don't know ☐

50. Have you ever had a problem related to domestic waste water or septic tank? Y / N , specify problem:

Natural hazard condition

51. Has your house ever been affected by flooding? Y / N (If yes, go to Q.44)

52. How frequent does the flooding occur?
    Several times a year ☐
    Every rainy season ☐
    Once every 5 years ☐
    Once every 10 years ☐
    >10 years ago ☐

53. How long did it happen?
    <1 hour ☐
    1-6hours ☐
    6-12hours ☐
    12-24hours ☐
    1-3days ☐
    >3days ☐

54. The last time you experienced flooding, how tall was it when you stood in?
    Knee level ☐
    Waist level ☐
    Others, specify: ☐

55. During flooding and some days after that, did you get water supply from PDAM or your well? Y / N

56. Indicate your water condition after flooding (especially from well): ....

57. Do you clean up your well after flooding? Y / N, How do you clean up the well?

58. How long do you have to clean up your well until it can be used? ......

59. Indicate the water supply quality during flooding and some days after that:

Odor	**Taste**	**Colour**
Smell / Not smell	Strong taste / good / chlorine	Colour / Colourless
Specify:	Specify:	Specify:

For surveyor:

	Number of steps	
Where you stand 1st	Step to septic tank	Step to well

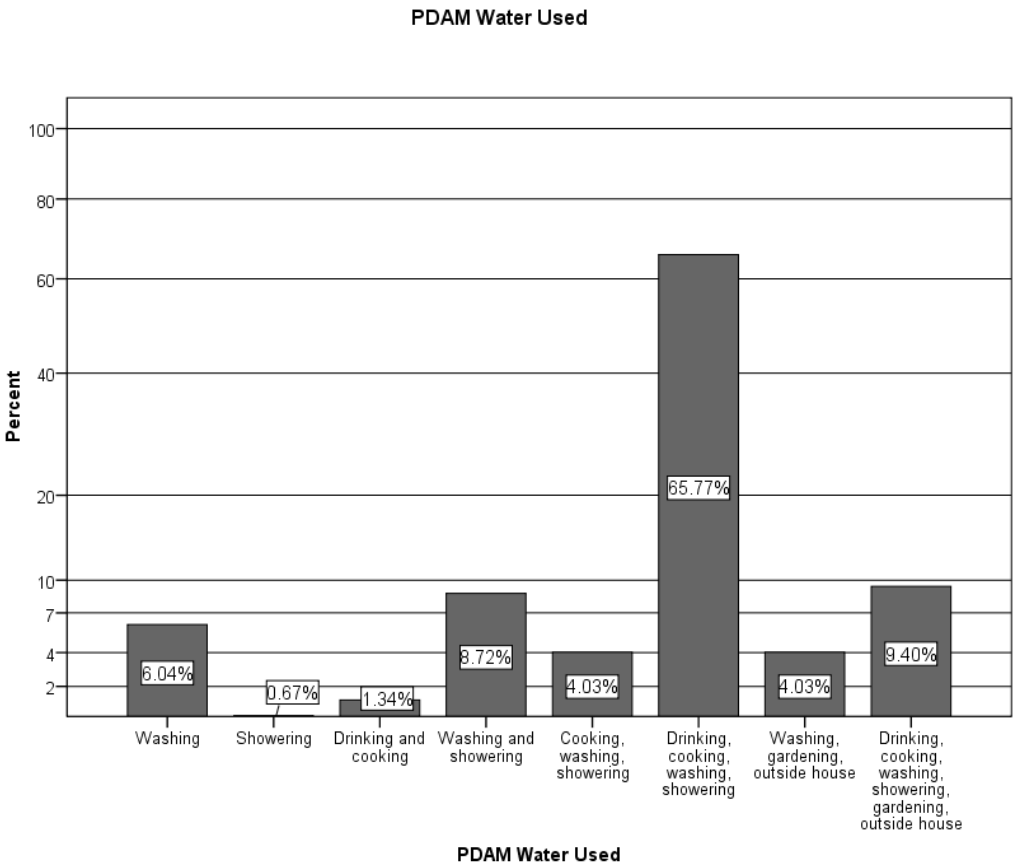
Drawing:

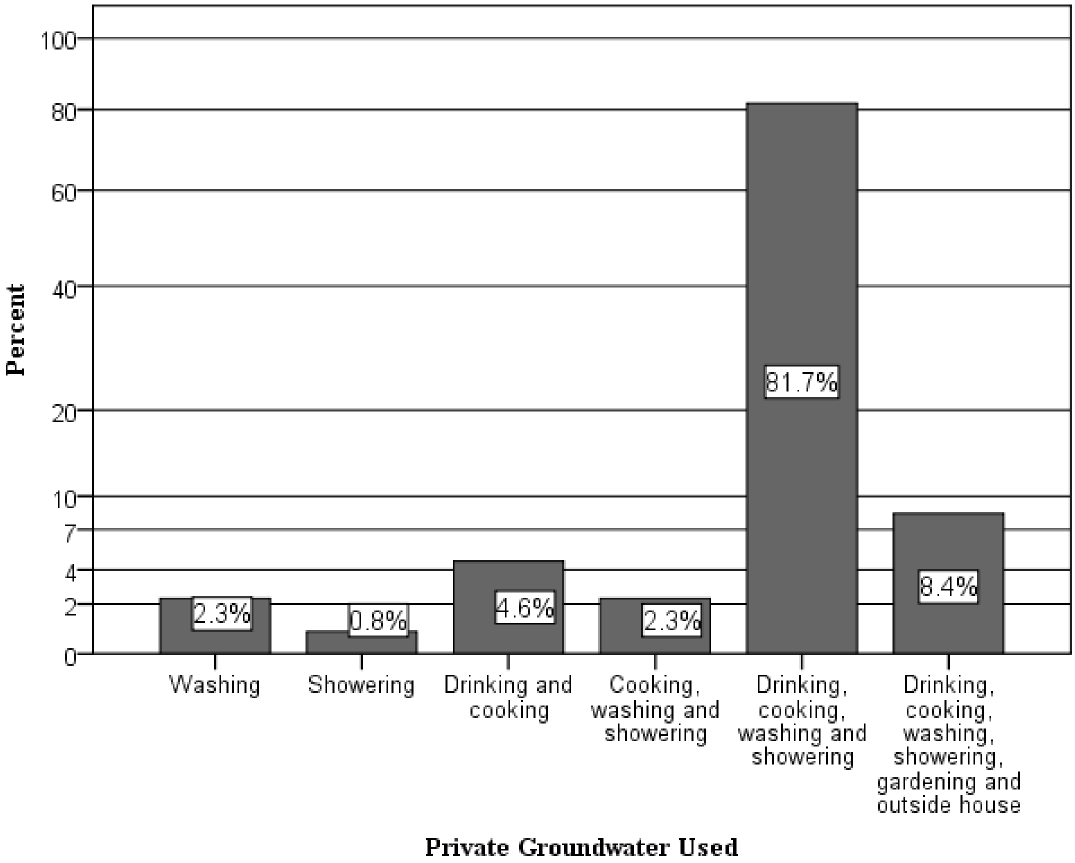
GPS POINTS:

	Coordinates pick by GPS	
Points	X Coordinate	Y Coordinate
Household NO:		

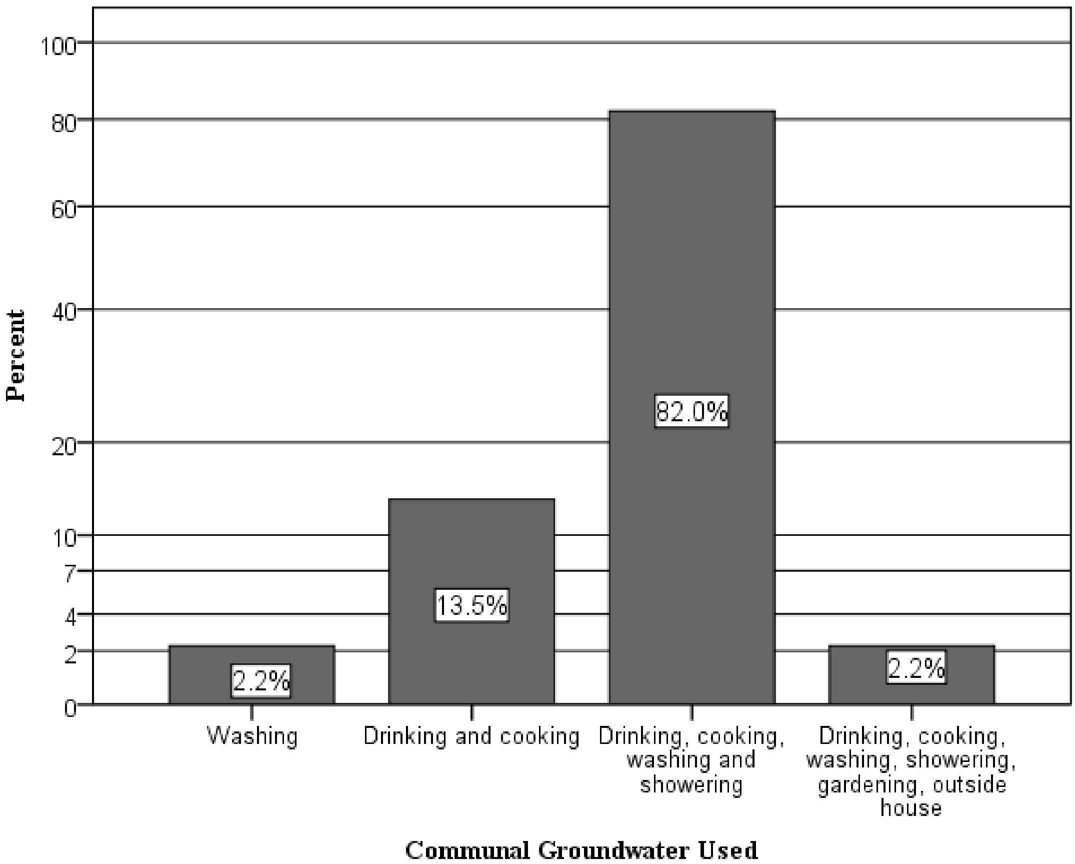
	Coordinates pick by GPS	
Points	X Coordinate	Y Coordinate
Septic Tank		
Well		
Provider PDAM(outside wall near kitchen)		

The Result of household questionnaires





Percent
100
80
60
40
20
10
7
4
2
0
2.3%
0.8%
4.6%
2.3%
81.7%
8.4%
Washing
Showering
Drinking and cooking
Cooking, washing and showering
Drinking, cooking, washing and showering
Drinking, cooking, washing, showering, gardening and outside house
Private Groundwater Used



Percent
100
80
60
40
20
10
7
4
2
0
2.2%
13.5%
82.0%
2.2%
Washing
Drinking and cooking
Drinking, cooking, washing and showering
Drinking, cooking, washing, showering, gardening, outside house
Communal Groundwater Used