Policy analysis in relation to spatial variation of groundwater in urban settlements: a case study of Yogyakarta city, Indonesia

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March, 2011

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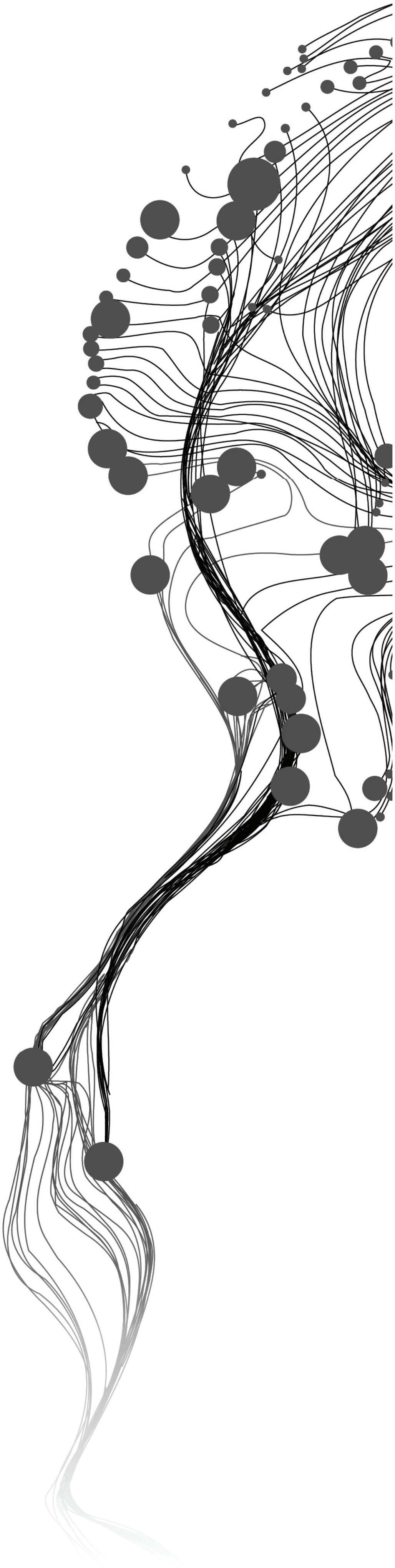

Policy analysis in relation to spatial variation of groundwater in urban settlements: a case study of Yogyakarta City, Indonesia.

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ABSTRACT

Management of groundwater abstraction is increasingly recognised in environmental economics which aims to steer economic development in harmony with environmental resources, which are pillars of production resulting to economic growth. It has been realised that, growth oriented policies which do not put in consideration these environmental resources conservation measures, alongside sustainable use are detrimental to the overall goal for quality of life. This is more so in many Nations of the World, where its time they cannot abandon restrictions on resources utilisation and emissions thinking they will achieve quality of life. It's essential to formulate, implement and review policy to manage use of these natural resources and avoid exploitation for whatsoever purpose.

Policy analysis in relation to spatial variation of GW in urban settlements analysis has focused on three core elements, which form the foundation and basis for discussions. The first idea is to investigate spatial variation of GW contamination by E.coli in the six urban villages within Yogyakarta city. This is achieved through quantitative analysis of GW samples from shallow wells in the laboratory, and later on visualising their MPN values. Likewise, two factors are addressed, which are predicted to be major sources of contamination of shallow wells with total coliforms.

The second idea involves analysis of specific capacity to determine spatial units with abundant GW levels. In addition, analysis for amount allocated and amount withdrawn are processed to demonstrate trend in GW use. Analysis of GW levels is carried out through computing specific capacity values of different deep wells. The values obtained are consequently visualised to indicate spatial units with high potential levels of GW and as such, possible areas of drilling new wells.

The third basic idea is about assessing GW management by validating the outcome of policy operationalisation. This is to find out if GW policy produces intended results once implemented. It's expected that there is a mismatch between results of policy operationalisation and policy in document. Methods used to carry out the analysis are mainly spatial analysis on Arc GIS 10 and running Pearson's correlation on SPSS. Field survey was also undertaken to collect both primary and secondary data within Yogyakarta city. An important process has been to incorporate literature review at all stage of analysis to reflect a critical approach required to enhance synthesising results achieved.

Results realised from analysis indicate spatial variation of GW contamination at varying levels. It's also demonstrated that specific capacity as analysed through spatial analysis can be used to identify areas of potential wells by identifying GW levels for different aquifers. Likewise it has been realised that policy elements have varying degrees of success depending on their nature either as cost recovery or cost incurring.

In the end, the study has proposed a couple of policy recommendations with the main one being formulating policy to regulate, monitor and manage shallow wells. This is an area largely missing policy elements to coordinate its importance in contributing towards domestic water supply. Another key activity recommended is to privatise data collection and management, for this is basic requirement in decision making, which concerns GW allocation and withdrawals. Last and not least is to adopt a public participatory approach towards GW resource management.

Key words: groundwater, spatial variations and policy performance.

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EC	European Community
E.coli	Escherichia coli
FAO	Food and Agriculture Organisation
GIS	Geographical Information System
GPS	Global positioning system
GW	Groundwater
HAA5	Haloacetic acids
IPPC	Integrated Pollution Prevention Control
MPN	Minimum probable number
PDAM	Perusahaan Daerah Air Minum
SC	Specific capacity
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environmental Programme
WHO	World Health Organisation

1. INTRODUCTION

The purpose of this chapter is to create an understanding of general components of this academic research and their interrelation with one another. The research themes which largely revolves around groundwater management policies, groundwater quality and groundwater quantity, are captured in two broad objectives and then disaggregated into a couple of research questions. The epitome is depicted in research problem and scientific justification which clearly captures the essence of analysing the mismatch of policies as outlined in document and as witnessed in practice. Last and not least, the data required is emphasized in research matrix and design which is core inclusive to success of this factual academic thesis.

1.1. Groundwater general introduction

In the history of mankind ground water (GW) has been a valuable natural resource, a reliable source of water for industrial, commercial, domestic, agriculture and for ecological use. It's a natural drinking water resource subjected to severe human impact. Strategies for sustainable use are required to preserve optimum quality (Andreo et al., 2006).

Presently, the resource vital roles are increasingly under stress due to great demand from industrial activities, population growth, succession of drought years, strict conservation measures and climate change (Weatherhead & Howden, 2009).
For instance the Intergovernmental Panel on Climate Change (IPPC) reports that by 2020 climate change will expose between 75 and 250 million of Africans to increased water stress (ESA, 2004) .

To these views, appropriate management in use of this critical resource is a significant issue and activities affecting consumption and demand should be well coordinated. To this effect the African water vision 2025 has called for actions aiming to strengthening governance of water resources, improving wisdom and meeting urgent water needs (ESA, 2004).

Unlike other natural resources or raw materials ground water is available in all nations and its abstraction varies greatly from place to place (Struckmeier, 2006). The resource is replenished by rainfall conditions and contributes significantly to increasing demand of clean water. It's a solvent which contains all 92 naturally occurring chemical elements at widely varying concentrations as long as there is no polluting human activity occurring (Banks et al., 1998, Reimann and Caritat, 1998 and Frengstad et al., 2000 cited in,Reimann & Banks, 2004).

1.1.1. The dominant role of groundwater

According to Chilton (1996), ground water constitutes of about two thirds of the fresh water resources of the world. If the polar ice caps and glaciers are not considered, ground water accounts for almost all usable fresh water (Chilton, 1996). Rivers, lakes, swamps, and reservoirs account for 3.5% and soil moisture accounts for only 1.5% (Chilton, 1996).
This underlines the fundamental importance of the use of ground water to human life and economic activity. The resource has advantages over surface sources of convenience, good quality and low cost development.

1.1.2. Impacts of urbanization on groundwater

Kazemi (2009), defines urbanization as a major user and contaminant factor of GW. The author cites a case of Iran where waste water disposal wells and deep cesspits have caused nitrate pollution thus raising serious challenges to management of the resources.

In cities of developing nations, poor sanitation, especially inadequate public toilets, open defecation, inadequate storm drains, low sewer connection and possibilities of frequent flooding are the cause of wide spread contamination. This is also attributed to prevalence of water related disease vectors which increases risk of diarrhoea and other related diseases.

The draining of mixed sewerage and storm water runoff to water bodies coupled with poor solid waste disposal such as open dumping or burning of mixed wastes increases contamination of GW and exposure to diseases. In addition these lead to clogging of storm drains and sewers during high rainfall which results to flooding and further contamination of GW resources.
On the other hand, pit latrines and septic tanks have a relation to severe GW contamination Leaking sewer systems can release raw sewage, and landfills generate leachate which contaminates GW (Chilton, 1996) .

Additionally the urban population requires a lot of water for their day to day activities. Local authorities who are responsible for supply are severely challenged. The urban population results to GW to supplement institution water. In many cases wells are the better option but their increased use is a cause of GW stress.

1.1.3. Striking characteristics of formal and informal areas

Striking non-similar characteristics are evident as seen in spatial pattern, house hold income levels, population density, land ownership, access to public infrastructures and in access to water and health services between urban formal and informal settlements. Quantity of water used is different and is influenced by affordability, accessibility, and availability concepts.

Informal settlements are characterized by a dense proliferation of small, make–shift shelters built from diverse materials, and rely on onsite domestic waste disposal which contaminates the GW resources and contributes to human health problems. Formal settlements lead to a further development of transport systems thus loss of vegetation and reduced infiltration, which has effect on potential of GW.

1.1.4. Overview of ground water policies

Some of recommended strategies in management of ground water are, regulation of industries and waste disposal sites, monitoring of groundwater, and having appropriate policy on allocation which gives weight to competing uses. The policies contain legislations which strive towards regulating ownership rights subject to government controlled permit system. More so regulations, within the framework of legislation, should define the actions to be taken by competent authorities in case of accidental pollution or other emergencies impacting on ground water.

A culture of charging user fees to the commodity users is generally agreed. Options like charging according to amount used or exploring various appropriate user fee charges will contribute to sustainable use. Polluters should be charged too to enhance safety of ground water or any other water source. This is supposed to come along with penalty system which controls any activity affecting use of GW.

1.2. Scientific justification

1.2.1. Quality and quantity concerns

Current debates on water availability suggest that supply of the commodity is inadequate to meet all individual demand at certified quality standards and quantity. Study by WHO (2004) indicate that by 2002, 1.1 billion people lacked access to improved water resources, which represented 17% of global population.

In addition water-related diseases kill a child every 8 seconds, and are responsible for 80% of all illnesses and deaths in the developing world. More so water-related diseases kill more than 5 million people every year, more than ten times the number killed in wars (UNESCO, 2007).

1.2.2. Effects of global cities to GW use

On the other hand cities have grown to global / world cities playing host to cooperate headquarters, legal and financial services, and research and development whereby these cities like Jakarta favours growth oriented policies (Shatkin, 2007). This has complicated sufficient distribution of water and other services from the municipalities. Many settlement areas are unserviced or sparsely served and they have resulted to depend on ground water sources for provision (Shatkin, 2007).

Towards this is the quality of ground water and susceptibility to contamination, for instance the case of city of Bijeljina, Bosnia where ground water was found to be contaminated by coliform bacteria from domestic septic tanks upstream of the well field (Pokrajac, 1999). Also in Aberdeenshire UK, the quality of water was found to be wanting due to contamination by faecal coliform and nitrates (Reid, 2003).

Amount required for urban use has dramatically increased due to many competing uses.
With this respect urban managers have a role to ensure water supplied to users meets the laid down standards and is sufficient to all persons. Policy measures to protect overuse and contamination should be well formulated and enforced.
Indeed, the variation in quality, quantity, and density of ground water is a concern to users due to detrimental effects of ill health which strongly contributes to low economic productivity. Any effort towards ensuring sufficient portable water supply in cities will offer relief to the users and urban managers and generally improve quality of life

1.2.3. Societal problems in Yogyakarta city

Currently, water supply by local authority in Yogyakarta city is insufficient, due to rapid urbanization from an increased population growth, leading to increased community housing development and urban activities.
The urbanization process has transformed Yogyakarta City to beyond it administrative area with about 1,000,000 inhabitants (Azzam, 2007). On average 35% and 79% of Indonesian urban population have no access to safe drinking water and sanitation respectively (Azzam, 2007). The rapid and unregulated urbanization process coupled with inadequate/poor sanitation system is a recipe for ground water contamination to unacceptable levels.

Although the city have a sewerage system and a waste water treatment plant with a coverage capacity of about 110,000 peoples, only about 45,000 peoples (9%) or 9,000 connections use this facility (Kamulyan, 2005). The rest of population uses onsite treatment i.e. septic tank and drain field to maintain domestic waste water.
Area limitation in maintaining domestic wastewater by onsite treatment and unreliable system on sandy soils will accelerate GW contamination.

Previous researches show the distance of septic tank to dug wells to vary from 4-8 meters as compared to ideal distance of 10m. The researchers found almost all wells are polluted by total coliform out of 145 samples taken from various wells (Kamulyan, 2005).
This is made worse by the fact that many people are not able to build septic tank system, and thus they dispose domestic wastewater directly in the garden, drainage channel or river (Kamulyan, 2005).

A critical challenge is to ensure existing GW management policies are complied with in practice and their operationalisation produces desired results. Where gaps exist its worthwhile policy makers to note them and further develop the policies and additionally control urbanization activities from infringing on quality and quantity of the GW resource.

1.2.4. Research problem

Throughout Asia Urban GW mining is seriously impairing GW availability and quality, for example in Beijing , Tiajing, Bangkok and in Jakarta where water tables have dropped raising pumping cost and sea water intrusion is evident caused by over pumping (Das Gupta, Paudyal and Senevirante, 1987, cited in, Braadbaart, 1997).

In Indonesia, policies have been formulated to guide the sustainable abstraction of GW and protection from pollution. However, in spite of the setting up of environmental agencies, the control of activities leading to pollution, and enforcement of policies, overexploitation and quality contamination is at an alarming rate as discussed by Braadbaart (1997). Government has not found it easy to regulate GW amidst need for accelerated economic growth and industrialization.

Within the part of study area, as researched by Salendu (2010), on quality assessment of GW among other issues, results has evidence of GW contamination, but there is a gap in knowledge of spatial variations in GW (quality and quantity). Similarly, disparities (gap) are assumed to exist between what the policies are in document and results in practice regarding the quality standard and abstraction level. These issues create a gap in science which needs research.

These ideas present threefold research problems within the area that need to be addressed. First is to evaluate spatial variation in GW potential. Second is to identify the spatial variation in GW quality and third is to identify disparities (gaps) in policy operationalisation i.e. identify which policies are failing and which are performing and reasons of their discordance. This will help develop the policies further, evaluate compliance to regulation and standard and identify intervention areas for further enforcement.
Last, evaluation of policies will be done for those elements which can be addressed by results of this analysis i.e. not all policies elements will be evaluated.

1.3. Research objective

The main aim of the study is to analyse spatial variation of groundwater characteristics in relation to policy operationalisation

1.3.1. Specific objective one

To investigate and analyse the spatial variations of GW (quality and quantity) in urban areas.
Sub – objective one:
To evaluate the spatial variation of GW quality
Sub - objective two:
To determine spatial distribution of GW levels (i.e. defining GW potential zones).

1.3.2. Specific objective two:

To establish the link between policy operationalisation and spatial variation in ground water in order to create an understanding of key elements in policy that are failing

Sub – objective 1:

To establish how GW quality and GW levels link to policies in practice.

Sub – objective 2:

To identify the key elements in policies that are failing and that are performing and provide reasons for the failure.

1.3.3. Research questions

Objective 1 - Sub - objective 1:

What are key elements in GW quality and how can these be assessed?
Is there spatial variation in GW quality of these elements, in the study area?
What are the spatial patterns of variation in GW quality?

Sub - objective 2:

How can spatial patterns in GW level be assessed?
Is there spatial variation in GW level, in the study area?
What are the patterns of variation in groundwater levels?

Objective 2 - Sub - objective 1&2:

Which elements of policies are related to GW quality variations and how well do they match in practice?
Which elements of policies are related to GW level and to what extent do they match in practice?
Which key elements in policies (GW quality and level) are failing and which are performing?
What are the causes of failure in operationalisation of key elements in policies?

A summary of research objectives and questions is in table below (see table 1-1).

Research objective	**Research question**
To evaluate the spatial variation of GW quality	What are key elements in GW quality and how can these be assessed? Is there spatial variation in GW quality of these elements, in the study area? What are the spatial patterns of variation in GW quality?
To determine spatial distribution of GW levels (i.e. defining GW potential zones).	How can spatial patterns in GW level be assessed? Is there spatial variation in GW level, in the study area? What are the patterns of variation in groundwater levels?
To establish how GW quality and GW levels link to policies in practice.	Which elements of policies are related to GW quality variations and how well do they match in practice? Which elements of policies are related to GW level and to what extent do they match in practice?
To identify the key elements in policies that are failing and that are performing and provide reasons for the failure.	Which key elements in policies (GW quality and level) are failing and which are performing? What are the causes of failure in operationalisation of key elements in policies?

Table 1-1 - Research objectives and questions

1.3.4. Conceptual framework

This is a frame work for policy analysis to map spatial variability of ground water in urban areas as influenced by human pressure and population growth. The arrangement and content of steps is geared towards analysing spatial variability of groundwater quality, GW levels, and link it to policy practice. Analysis will be according to the user perception in addition to GW levels and quality analysis.

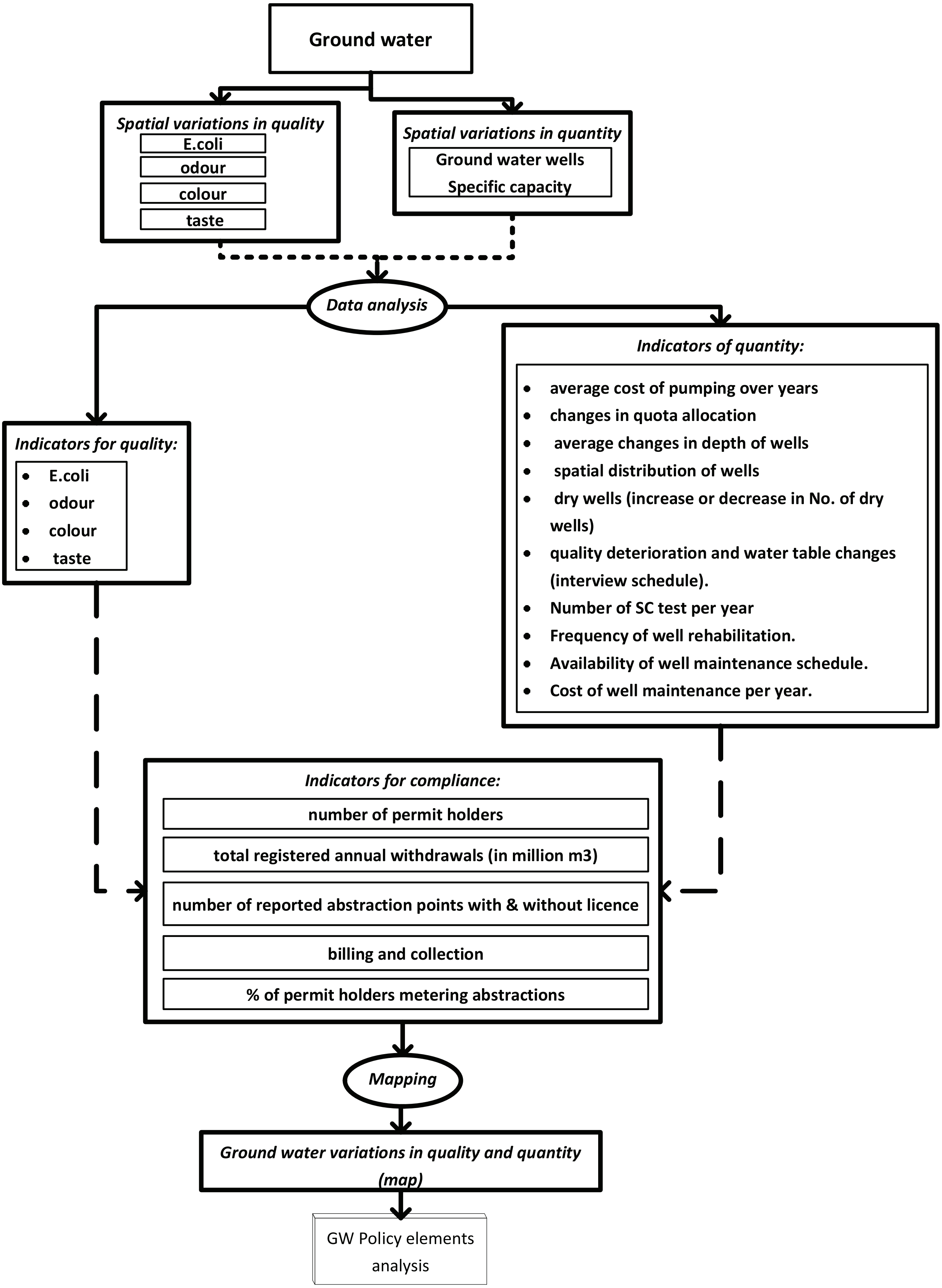

Figure 1-1 - Conceptual framework

1.3.5 Research design

The structure of this research to obtain answers to research questions which includes the following variables.

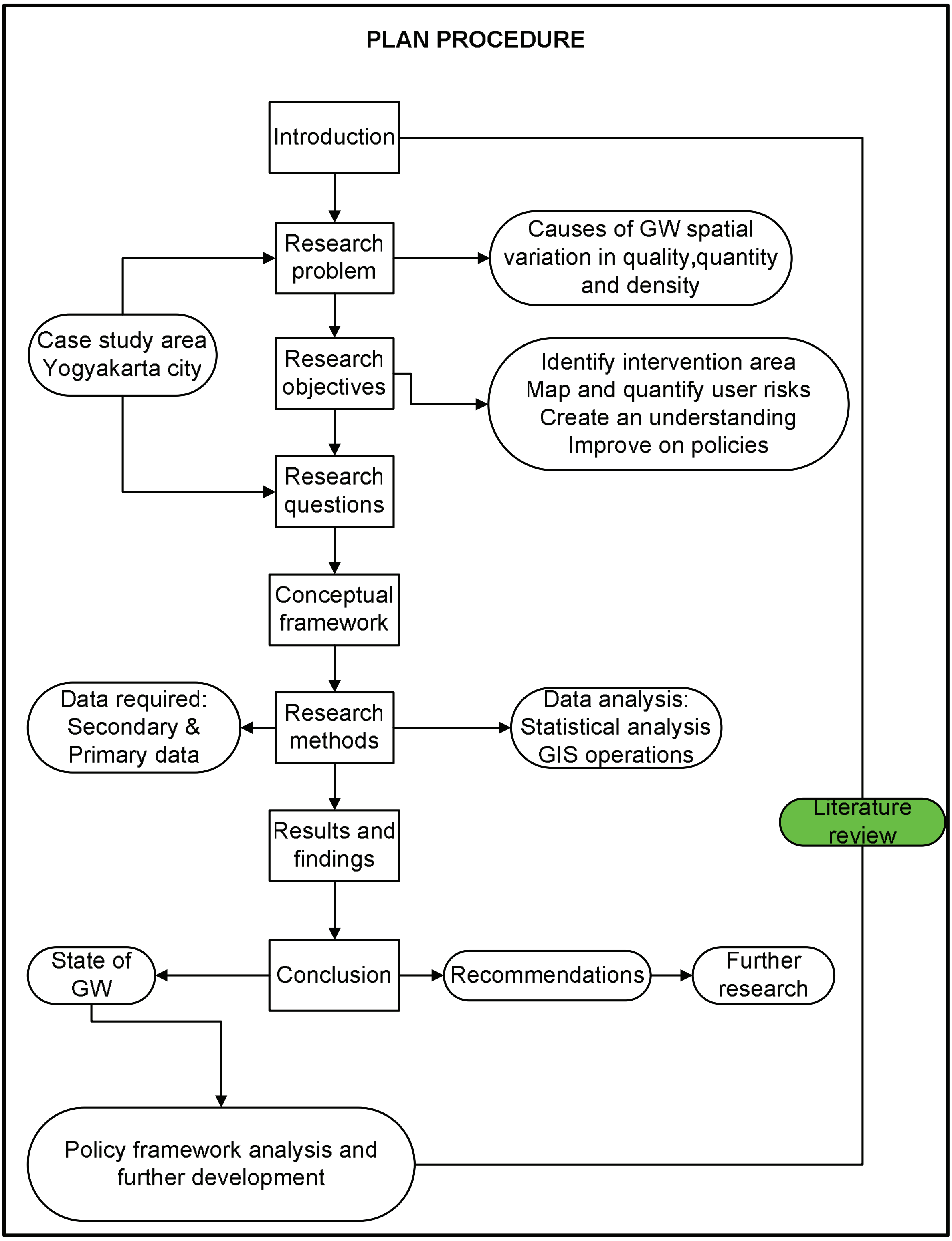

Figure 1-2 - Research design

1.3.5. Research matrix

No.	Specific research objective	Data required	Data source	Methodology
1	What are key elements in GW quality and how can these be assessed?	Water samples – to asses presence of E.coli. Interview schedules on colour, odour, and taste of GW to assess user perception of water.	Primary	Water sampling and household survey.
2	Is there spatial variation in GW quality of these elements, in the study area?	Water samples	Primary	GPS measurements & Spatial autocorrelation
3	What are the spatial patterns of variation in GW quality?	Water samples spatial distribution	Primary	Spatial interpolation
4	How can spatial patterns in GW level be assessed?	Specific capacity Ground water zones	Primary Secondary	Spatial autocorrelation
5	Is there spatial variation in GW level, in the study area?	GPS points for the wells Specific capacity	Primary	Spatial interpolation
6	What are the patterns of variation in groundwater levels?	Spatial distribution of specific capacity	Primary	Arc Map 10 spatial interpolation
7	Which elements of policies are related to GW quality variations and how well do they match in practice?	Water act	Secondary	Analysis of policy document for Yogyakarta city
8	Which elements of policies are related to GW level and to what extent do they match in practice?	Policies act	Secondary	Analysis of policy document for Yogyakarta city
9	Which key elements in policies (GW quality and level) are failing and which are performing?	Analysis of statistical data	Primary/ secondary	Statistical analysis (SPSS)
10	What are the causes of failure in operationalisation of key elements in policies?	Discussion on policies performance	Primary/secondary	Results discussion

Table 1-2 - Research matrix

1.4. Organization of this thesis

In bid to elaborate the relevance of each component, this work is classified into seven chapters each with unique information coordinated to fulfil the purpose of the research. An introduction of each chapter is as follows;

Chapter One

In chapter one, an introductory to GW and GW management principles appears and are the main block of this thesis. The sub topics address the research objective, research problem and justification of this study. This three are explained further in research questions in the research design and in research matrix.

Chapter two

Chapter two describes the major GW component and in what way they interact especially with elements that are a measure of quality and quantity. Some of the issues discussed are overexploitation, essence of specific capacity, major policies, quality standards and regulation procedures.

Chapter three

A critical component is data collection process which is assessed in this chapter three. It contains diverse type of data collection method and tools. A commonly used method is administering of questionnaires for household survey. This is categorized as primary and the other source been secondary which is used to arraign information on specific capacity of wells amongst other data required.

Chapter four

This chapter dwells on the study area defining the demographic characteristics and physical characteristics. It's important as it explains the geology of the area and Merapi rock formation which is critical to recharge process and GW levels.

Chapter five

Chapter five is expounding on analysis of both primary and secondary data to identify the quality and levels of GW water. The analysis tools include SPSS and GIS – ESRI and the end profile is spatial variation maps for quality and GW levels together with policy analysis graphical outputs.

Chapter six

In chapter six the discussion is on the findings from the analysis of chapter five, and linked to policies whereby key elements in policies related to spatial variations are processed. These key elements are, first, connection of boreholes to water meter, registered abstraction cases for deep wells, percentage (%) of clients with licence for abstraction, and total amount abstracted vs. total amount available amongst others.

Chapter seven

Issues for chapter seven are general and specific conclusion, study area recommendations, limitation of the research and suggestions for further research. These are set to improve on policies which will have an impact on improved management of GW resource in the city.

2. REVIEW OFGROUNDWATER COMPONENTS

In this chapter a couple of issues are described on the way they relate and affect GW quality, its availability and management. They include GW exploitation, quantity monitoring and quality standards. In addition there is a detail analysis of different policies elements as applied to manage GW at national level and possible similar application at local areas. Myriad challenges related to pollution and overexploitation experienced by cities of developing nations, as they struggle to find a balance between extraction and need for development, are addressed in depth and possible solutions advanced too. The chapter offers a broader perspective of GW issues which underpins the notion of not studying quality, quantity and policy issues in isolation but integrating them to find answer to sustainable GW use.

2.1. Global use of groundwater

Water is drawn from the ground for various uses. In United States of America (USA) where GW is important in all climatic regions less than 40% is used for public water supplies (Chilton, 1996). There are cases where large cities are totally dependent on GW. For instance in Latin America, Mexico City, Lima, Buenos Aires and Santiago Municipalities rely heavily on GW (Chilton, 1996).
The below proportion of GW in drinking water supplies in some European countries indicates its wide spread use. Denmark 98%, Portugal 94%, Germany 89%, Italy 88%, Switzerland 75%, Belgium 67%, Netherlands 67%, Luxembourg 66%, Sweden 49%, UK 35%, Spain 20% and Norway 15%. Source (UNEP, 1989).

As seen above the use of world GW resources is intensifying. Unfortunately there is little or no prospect for resolving the detrimental impacts through convectional management approaches (FAO, 2003). This raises the question as to whether such convectional water management approaches are inherently limited with respect to GW or whether the policy space need to be radically expanded to accommodate the drivers of demand for limited GW resources. A more specific question is how GW management institutions position themselves to best effect programmes in their cities. This requires a thorough examination of existing policies to find ways of strengthening them.

2.1.1. Policies Framework

The policies of GW protection in Europe aims to protect GW from contamination and over exploitation as a source of drinking water in order to avoid water stress already occurring in some member nations (Judd & Nathanail, 1999). The European community (EC) has developed integrated policies for management of GW as detailed below.

First is the GW Directive 80/86 EEC which aims to prevent the pollution of GW by certain substances, through a polluter pay principle and to reduce or eliminate any damage caused by pollution (Wolf and White, 1997 cited in (Judd & Nathanail, 1999). It also incorporates a set of regular quantitative measures of identifying quantity of GW to ensure a balance between abstraction and recharge. The controls of GW use require a register or registers of water abstractions, a seal on level of abstraction and a requirement for prior authorization for abstraction and impoundment. A prior authorization is needed for artificial recharge or augmentation of GW. Overall principles should be laid down for abstraction and impoundment.

Second is the 1996 Directive 96/61/EC (OJ No L257/6) which requires all member states to establish system of Integrated Pollution Prevention Control (IPPC) which establishes systems to control the polluting activities. The system requires approval through permits for all new installations. The permits details out reasons for permit cancellation, renewal period and conditions for pollution control for environment as whole, relevant to that particular jurisdiction and activity.

Third is Directive 76/464EEC on Dangerous Substances into Water which aims to control dangerous substances released into the aquatic environment like mercury, and cadmium. The legislation state pollution through the discharge, emission or loss of priority hazardous substances must cease or be phased out. Still, it has water pricing policies which provide adequate incentives for users to use water resources efficiently. The revenue from use should be able to recover costs of water services.

Other relevant EC Directives are EC GW Directive which states GW should remain pure, Directives 75/440 and 80/778/EEC on drinking water, and Directive 76/160/EEC on bathing waters (Wolf and White, 1997 cited in (Judd & Nathanail, 1999). This has a registration based on general binding rules, laying down emissions controls for pollutants concerned. It also prohibits direct discharge of pollutants to GW. On the other hand the regulations ensure sufficient density of monitoring points to assess the impact of abstractions and discharges on the water level.

EC states do recognize the need to protect GW specifically that used for water supply for example in Ireland, the Environmental protection Agency issues Integrated Pollution Control licences for scheduled activities. By so doing preventive measures are outlined to avoid contamination of GW. The licence holder has to make timescale plans for remedial works of GW.

In Austria the law for the Clean - up of Contaminated Sites (ALSAG) include GW as contaminated site. It follows the polluter pay principle but where the contamination is from public purpose, public funds are used for the clean - up exercise. Schamann (1998) as cited in (Judd & Nathanail, 1999) argues GW is incorporated as that which is important for water supply and that which is not exploited.

The author explains that The Netherlands has a high water table and is dependent on GW for 80% of its drinking supply. Prevention of soil pollution measures entails protecting GW too from any contamination and formulates a sustainable use approach. Every household in Netherlands pays pollution tax. Companies and organization pays according to the quantity of waste they produce. Companies that use GW as raw material have to pay GW taxes.

Greece has an intensive agriculture system with large quantities of fertilizers and pesticides. To control their impact on GW a Joint Ministerial Decision 16190/1335/1997 was issued (Kavvadas,1998 as cited inJudd & Nathanail, 1999). The procedure requires the payment of fees and licensing of all bulk water use related activities. This set conditions to be fulfilled before licencing these water related projects.

From the above examples its clear there exist policies in regard to GW sustainable use. This situation in EC is expected to differ from situation in developing countries due to level and activities of economic growth, urbanization, industrialisation and population increase. Even so, the following similar policy elements have been investigated in this study.

First are articles aiming on pollution prevention as caused by biological substances which can be identified through analysis of E.coli. This also includes a survey of waste disposal mechanisms to verify if they deviate from agreed standards. Second, are policies of regular quantitative measures like existence of monitoring wells and artificial recharge wells which are used to indicate trend in recharge and abstraction balance.

Third, is the entire licencing/permit system/process e.g. number of permits holders, charges and taxes i.e. overall principles of abstraction and responsibilities. This will led to identification of mismatch and reasons as to why they exist in practice. To carry out research on these elements appropriate indicators as formulated necessitates accurate data collection. Note that this research has not been limited to the above mentioned elements but a detailed analysis of all elements related to them.

2.1.2. Stake of government in GW management

Governments mainly of developing countries are faced with stiff balancing tactic in regulating and protecting use of GW. Industrial growth creates a host of environmental problem which include GW over pumping and others (Braadbaart, 1997).

Problems state has to deal with include lack of capacity to regulate GW withdrawal. Regulation involves a network of observation wells and water meters to measure how much is being consumed and by who, handling well maintenance and installations, abstraction permits and quotas issuance, GW tariff setting, meter installation, meter reading, water table monitoring and billing and collection (Braadbaart, 1997). Challenge is to cut down exploitation of GW by industries and sustain economic competitiveness i.e. to make GW policies compatible with oriented export industrial growth which evidence has shown that its possible (Braadbaart, 1997).

In the text of Braadbaart (1997) he describes the causes of declining GW to over pumping. He cites two major reasons as to why the Indonesian Government has allowed Industrial overexploitation. First is the high demand from population and second is industrial growth amid finite resources of GW. He identifies these as causes of increased pumping cost, sinking of water table, and intrusion of salty water along the coast line.
The author gives comparative statistics within the Indonesia capital city and states a number of 3 wells are not metered out of every 5 or are unreported and tariff system has failed to regulate over abstraction.

2.1.3. About overexploitation

This is a situation in which, for some years, average aquifer abstraction rate is greater than, or close to the average recharge rate (Custodio, 2002). Overexploitation for aquifer is denoted when some negative changes are persistently observed.
Some of these changes are continuous water level drawdown, progressive water quality deterioration, increase of abstraction cost and ecological damage, decrease of spring discharge of river flow (Custodio, 2002). GW overexploitation may imply benefits of withdrawal are less than total actualized cost of using aquifer. Overexploitation is a call for remedial actions in management of GW use and recharge.

GW overexploitation is considered GW mining (Custodio, 2002) i.e. exploitation of GW at a rate that is much greater than recharge. The word mining is applied since GW is extracted / mined as minerals like oil or natural gas. GW mining means that the total volume of fresh water is reduced and /or replaced by poor quality or saline water, that part of the aquifer may become depleted, and that some springs , oases or other type of surface discharge may dry up (Custodio, 2002).

What is of real importance to the decision makers and well users is the overall reliability and productivity of well (in terms of water levels, volumes and water quality) during a given time period (FAO, 2003). Therefore, if a well taps from a certain aquifer what is its sustainable rate of exploitation given variable periods of recharge and drought? The real indicator of this question is defining maximum admissible drawdowns.

2.1.4. Drawdowns

Drawdowns is related to aquifer whereas aquifer is an underground formation that holds a large amount of water. There is a very slow movement of water through aquifers such that over pumping from wells can cause a long term cone shaped depression in the GW level called drawdown (University of Wisconsin, 2010).
The impacts of large drawdowns (long term drops in GW levels) are decline in water levels for wells, streams and wetlands (or they dry up completely). Additionally it led to increase of arsenic, radium and salinity in drinking water due to wells been drilled deeper (University of Wisconsin, 2010). The entire drying up or reduced flows of this water sources can critically affect habitats for many birds fish and mammals.

Related factors as discussed in FAO (2003) report are the development of pumping mechanized technologies which induce widespread drawdown externalities including the depletion of all important shallow aquifers (FAO, 2003). Other environmental externalities include critical change of GW flow from one aquifer to the other. In addition there are social – economic effects involved which are increased pumping cost and energy usage, land subsidence and damage to surface infrastructure, and reduction to water for drinking particularly for the poor.

Issues of concern to policy makers and implementation process are to control/protect over pumping by coming up with a monitoring strategy like semi-annual evaluation of specific capacity and permit related regulations.

2.1.5. Specific capacity (SC)

The specific capacity (in gallons per day per foot, gpm/ft) of a well is the pumping rate (yield) divided by drawdown. It provides information on maximum yield of well and design pumping rate (Johnson, 2005). According to Johnson (2005), it can be used to identify potential well, pump, aquifer problems, to develop a proper well maintenance schedule and to estimate transmissivity of aquifer tapped by the well perforations. Transmissivity is transmission of water in the aquifer under specific width and unit hydraulic gradient (Johnson, 2005). The higher the transmissivity the prolific the aquifer and less drawdown recorded for the well.

A well should run continuously for 24hrs at a constant yield before recording the drawdown (Driscoll, 1986, as cited in,Johnson, 2005). After immediate drilling the SC established for a well is probably the maximum to be ever realized and is used for comparison with other SC of the same well. According to Driscoll (1986), SC should be done at least semi-annually and well rehabilitation should be started when SC drops by 25%.

SC drops due to physical (sand, silt, clay rust particles) or biological (biofouling or bioslimes) or chemical (mineral incrustation) blockages. Rehabilitation aim is to remove these blockages and restore efficiency of the well. Chemical rehabilitation should take care of environment pollution. The cost incurred can be as low as 6,000 Dollars to a higher of 50,000 Dollars (Johnson, 2005).
Policies issues include performing SC test, undertaking well rehabilitation, and maintaining a proper well maintenance schedule.

2.1.6. Quality standards

According to WHO (2006) drinking water quality standards, E. coli or thermo tolerant coliform bacteria must not be detectable in any 100mL sample. This is the same case for treated water entering the distribution system and treated water in distribution system. However WHO (2006) standards give an exception where large supplies are involved and subsequently sufficient samples examined. These bacteria must not be present in 95% of samples taken throughout any 12 month period. In case E. coli or total coliform bacteria are detected sampling must be repeated. If the repeated samples indicate presence of these bacteria immediate investigation should be started to determine cause (WHO, 2006).

2.1.7. Elements of Policies which can be investigated

From the literature reviewed, it's evident some policies are easy to investigate and others are difficult. Chemical analysis for example lead, arsenic, bromate, chlorite, and haloacetic acids (HAA5) and many others cannot be investigated in this work.
Nevertheless crosscutting issues related to contamination and overexploitation are investigated in this case study. They include and are not limited to, number of permit holders, total registered annual withdrawals (in million m^3), number of reported abstraction points with and without licence, % of permit holders metering abstractions, billing and collection, abstraction levels vs. potential, and biological contamination by E. coli, colour , odour, taste. The later elements would require a spatial analysis process like spatial autocorrelation to find how they are spread in space.

2.2. Spatial analysis of GW water quality

Spatial analysis of GW quality can be through spatial autocorrelation and its attributes. This is a measure of the degree to which a set of spatial features and their associated data values tend to be clustered together in space (positive spatial autocorrelation) or dispersed (negative spatial autocorrelation). This justifies interpolation measurement, a principle that recognizes that data collected at any position will have greater similarity or influence of those locations with its immediate vicinity.

In the literature of Getis (2010), he gives a simple definition of spatial autocorrelation as explained by Hubert et al.(1981, p. 224) " given a set S containing *n* geographical units, spatial autocorrelation refers to the relationship between some variable observed in each of the *n* localities and a measure of geographical proximity defined for all *n(n-1)* pairs chosen from S". This concept is developed from principle of nearness that areas close to one another have strong effect than those far away for example von Thunen theory of 1826 (Zipf 1949 cited in Getis, 2010). The implication is that near spatial units are similar to one another.

On the other hand Toblers first law as cited in (Getis, 2010) has summarised this idea " everything is related to everything else, but near things are more related than distant things"(Tobler 1970, p.234). Getis (2010) notes that spatial autocorrelation is a way of understanding the influence that the shape of spatial units has on a variable. It also used to test the null hypothesis that there is no relationship between values of single variables.

In case of GW the process include collecting of samples from wells for water quality analysis, depth of the well, and any other phenomenon of interest been investigated. The results of samples analysis are stored according to their identification number. These non-spatial datasets are utilized using GIS techniques to obtain spatial distribution of results consequently performing more complex spatial analysis Priyakant et al,(2004).

According to the author, (Priyakant., et al., 2004) it's difficult to measure each point in a study area for GW depth and GW samples and strategically dispersed sample points have found to be representative of a phenomenon in a given location. If these selected points are entered in a GIS as point coverage through their geographic coordinates, they form input base for interpolation process.

Based on sampled data values an estimated value is assigned to all other location using surface creation function in GIS since objects that are near are more important than those which are far away (Priyakant., et al., 2004)

2.2.1. Spatial autocorrelation measure/test: morans 1

This tool measures spatial autocorrelation based on feature locations and feature values simultaneously (ESRI, 2009). It aims at evaluating the patterns represented whether they are dispersed, random or clustered. The tool displays morans 1 index value plus Z score and P value evaluating the meaning of that index (ESRI, 2009). According to ESRI (2009), a morans index value near plus one (+1.0) implies clustering while an index value near minus one (-1.0) shows dispersion.

Getis(2010), notion is that spatial autocorrelation measures can either be local, where measure is focused on one spatial unit or global, where the assessment is for the association of all spatial units one with another included in calculation of spatial autocorrelation.

Always in case of this tool the null hypothesis state that there is no spatial clustering of the values related to geographic features in the study area. But when the P value is small and the Z score large enough out of the confidence level the null hypothesis can be rejected (ESRI, 2009). If the index value is greater than zero (0) it indicates a clustered pattern and while less than zero (0) it's a dispersed pattern. The equation of calculation of morans index is as below (ESRI, 2009).

The Moran's I statistic for spatial autocorrelation is given as:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where z_i is the deviation of an attribute for feature i from its mean $(x_i - \bar{X})$, $w_{i,j}$ is the spatial weight between feature i and j, n is equal to the total number of features, and S_0 is the aggregate of all the spatial weights:

$$S_0 = \sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} \quad (2)$$

The z_I-score for the statistic is computed as:

$$z_I = \frac{I - \mathrm{E}[I]}{\sqrt{\mathrm{V}[I]}} \quad (3)$$

where:

$$\mathrm{E}[I] = -1/(n-1) \quad (4)$$

$$\mathrm{V}[I] = \mathrm{E}[I^2] - \mathrm{E}[I]^2 \quad (5)$$

Source: ESRI (2009).

2.2.2. Spatial interpolators

Selection of interpolator depends on scale of analysis. Grids (Spline and IDW-inverse distance weighting) are usually used more for regions (small scale applications) while TINs (triangular irregular network) are used for more detailed and large scale applications (Priyakant., et al., 2004). With use of GIS techniques you are able to complete the long quantitative assessment of ground water quality within a short time despite the need of a high organized data programme for a long period.

It's clear that much kinds of geographic data are collected at irregular intervals e.g. GW data and require too much effort. At the same time it's not possible to make measurements at all desired points thus need for estimating values for locations where there are no measurements. These values are based on data available and an understanding of spatial variations of an area. In any interpolation, the basic decision is to choose a model for the statistical relationship between the data inputs. The most common models are weighted function and spline which are analytical methods of using what is known to determine the unknown (Priyakant., et al., 2004).

The interpolation process involves input of location points into GIS to be used for interpolation process. Then the GW depth and corresponding bacteriological data are made in a separate data base. This information is linked using a common field (sampling code) for the surface approximation (Priyakant., et al., 2004). The figure below shows various steps involved in surface approximation using different interpolation techniques.

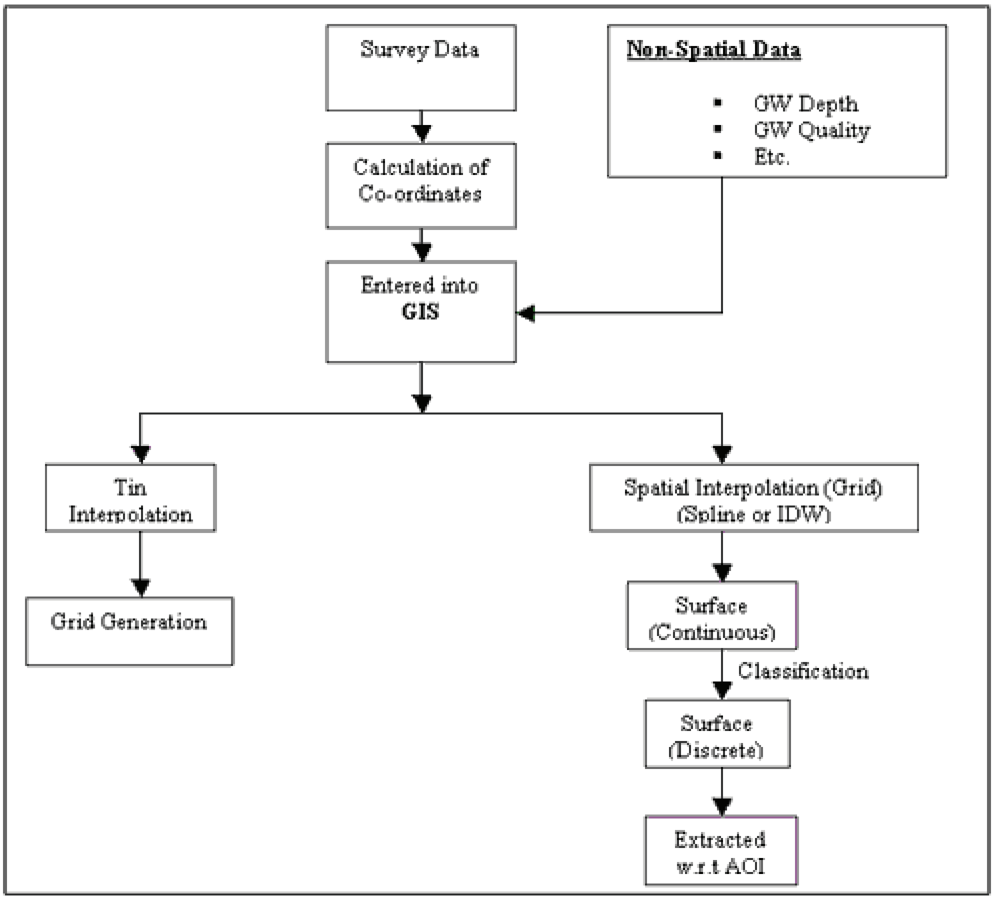

Figure 2-1 - Flow chart showing different steps involved in surface approximation using Grid and TIN methods

The grid analysis represents surface using a mesh of regular spaced point. One estimate values anywhere within the mesh giving more weight to those that are close and a best estimate of what the quantity is on the actual surface for each location. IDW weighs points closer to the processing points, greater value than those further away since it takes each point to have a local influence that diminishes with distance (Priyakant., et al., 2004).

2.2.3. Spatial interpolation methods relevance to this study

The ideal spatial interpolator for this case study should have a standard mean error (ME) nearest to zero, the root mean square (RMSE) should be as small as possible and best for interpolating from known point to unknown. IDW can be used in the assumption that the value of an attribute z unvisited points is a distance-weighted average of data points occurring within a neighbourhood or window surrounding the unvisited point. According to Burrough et al.,(1998) as cited in Dashora (2009) IDW method can be described as follows

$$\boldsymbol{Zx} = \sum_{i=1}^{n} \boldsymbol{Wi} * \frac{\boldsymbol{Zi}}{\sum_{i=1}^{n} \boldsymbol{Wi}}$$

Where $\boldsymbol{Zx}$ is the predation value of unvisited point $\boldsymbol{x}$,
$\boldsymbol{i}$ is the used known data point from 1 to n,
n the number of used known points, $\boldsymbol{Zi}$ is the value of point 1,
$\boldsymbol{D}$ the distance to known point 1,
and $\boldsymbol{K}$ a constant that influences the distance weighting.

This method is commonly used to create raster overlays from point data. Allocates cells value on weighted average formula in terms of inverse distance from unknown to known in the search window (Dashora, 2009). The weights are controlled or managed by the power option provided in IDW method. High power is sign of resemblance of unknown and known point and if small power, the value resembles true mean of all the known points in the search window.

Kriging method is based on geo-statistical methods. It assumes that the spatial variation of any variable is neither deterministic nor random. It's described as follows

$$\boldsymbol{Z(x)} = \boldsymbol{m(x)} + \boldsymbol{\varepsilon}' \ (\boldsymbol{x}) + \boldsymbol{\varepsilon}'' \ (\boldsymbol{x})$$

Where $\boldsymbol{x}$ is a position in 1,2 or 3 dimension, $\boldsymbol{Z(x)}$ is the value of a random variable, $\boldsymbol{m(x)}$ is a deterministic function describing the structural component, $\boldsymbol{\varepsilon}' \ (\boldsymbol{x})$ is the regionalized variables and $\boldsymbol{\varepsilon}'' \ (\boldsymbol{x})$ is a residual, spatially independent Gaussian noise term having zero mean and variance $\boldsymbol{\sigma}2$ (Burrough et al., 1998 cited inDashora, 2009). Other interpolators include local polynomial method, thiessien polygons and spline.

2.2.4. An overview of Groundwater in Yogyakarta Indonesia

Yogyakarta has two seasons that is dry season during April- October and wet season during October-April. Average monthly rainfall on dry season vary from 20 mm to 120mm, and from 150 mm to 380 mm in wet season, while the average annual rainfall is2,090 mm. This season condition will affect groundwater (Kamulyan, 2005).

Water supply by local authority covers only 65% of the population (Kamulyan, 2005) limitation of the water from institutional service makes people to use wells to fulfil their water supply. According to Environmental Office of Yogyakarta (Anonymous) in Kedaulatan Rakyat Daily, 2001 , it could be seen that in year 2001 at Yogyakarta there is 33,829 dug wells aimed to fulfil water supply of about 293,403 peoples(Kamulyan, 2005).

3. DATA COLLECTION

This chapter combines methods used to capture, process, manage, and analyse ground water data relevant for spatial variation of water quality, quantity and policy assessment. This is largely in three steps as seen in conceptual model and research design. These steps are primary data collection, secondary data collection and data input. Basic methods for data gathering are, one, household survey through use of interview schedule, two, picking geographic points by GPS and distance measurements by tape measure, for primary data and three, key informants interview to obtain both primary and secondary data. The actual parameters of the data are detailed out in sampling design which identifies the sampling frame, unit and size as applied in the field.

Figure 3-1 - Primary data collection

3.1. Data collection within the study area

The main purpose of the study area visit was to obtain data to measure the performance of policies in management of GW. Data required for quality analysis was water samples from wells, distances of wells from onsite systems, depth of the wells and user perception on colour, taste and odour. Consequently data needed for GW levels assessment include; yield, drawdown and geographical coordinates of the wells. The other data required was water Act in order to discuss on policy operationalisation process and field data on several indicators. The process of conducting household survey was relatively friendly. On the other hand it was challenging to gather secondary data mainly due to institutional secrecy and unavailability of the same.

3.1.1. House hold survey

Household survey via a questionnaire was used to gather information on the following elements; average amount of GW used by the household per day in m^3, percentage of the population using GW, different uses of GW, supply status of GW, number of wells, contamination level of the GW and user perception.

A pilot project preceded the survey to test the applicability of the questionnaires. The study area was organized in grids of 90m*90m with a unique code in each grid from numbers and alphabets. One questionnaire was administered in each and every grid (see figure 3-2).

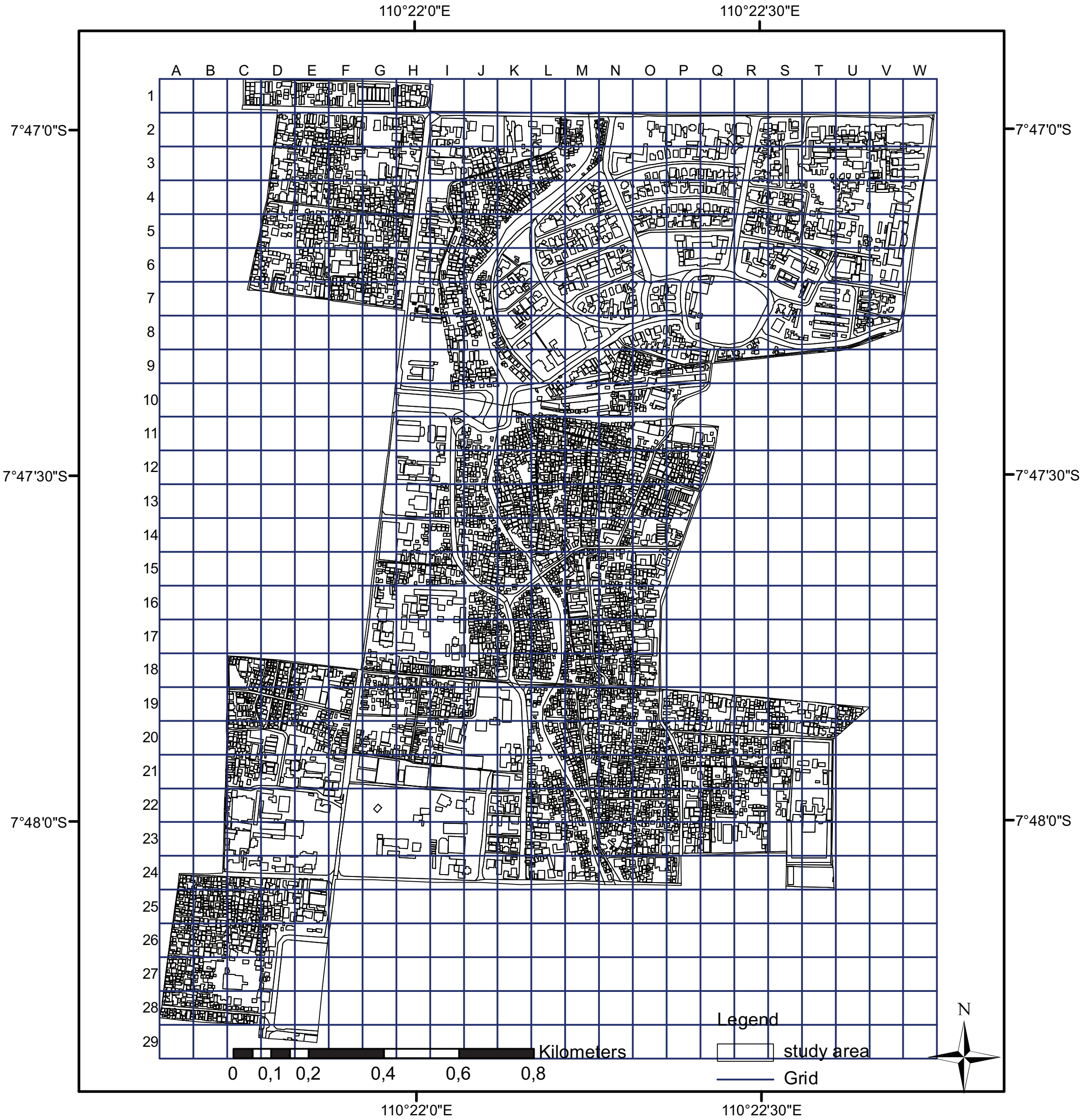

Figure 3-2 - Study area Yogyakarta

There were exceptional cases in that some grids land use was largely or entirely commercial thus no questionnaire was administered in them. The reason behind 90m*90m grid was to have a total number of three hundred and fifty (350) samples. Once in the field it was noted that many different large areas were not residential areas but rather public service areas like play grounds, business centres and other open places and this reduced the number of grids that we could carry out the survey to one hundred and fifty.

Additionally due to the wide nature of the survey area it took a lot of time to cover one grid to the other and also there was a limit on time and budget. Similarly, the language barrier problem led to consuming alot of time through lack of direct participation.

Another main data challenge was to estimate the amount of water used per day since many people did not consider keeping an account of this in their daily use. Additionally there was a shortage of GPS, only two amid six surveyors.
The survey was done by six surveyors and the initial target was three hundred and fifty questionnaires but after excluding some grids, a number of one hundred and fifty questionnaires were filled (see figure 3-3).

Figure 3-3 - Household survey in urban village

3.1.2. Water samples

These were collected by trained field assistance and samples delivered to the laboratory within a period of one hour to ensure the results are reliable. The aim of the exercise was to test spatial spread of water contamination by E.coli bacteria. The samples were coded for each household where a survey was conducted, the name of household owner registered so as results would be delivered to him/her and the bottles hygiene observed as required. Water sample were collected from shallow wells. For the household using PDAM supply or other sources the grid was excluded.

Another point is that some of the households were not reached within the stipulated time due to complexity of sample collection procedure, distance to the laboratory and less time required to deliver the sample. This explains the difference between the numbers of water samples and the number of questionnaires whereby the sample size was fifty.
The fact that the samples had to be delivered in the laboratory within one hour and before 11am and considering that the laboratory opening hours was 8am, only few numbers could be delivered within a day.

Much still there was a long distance to cover from the field to the two laboratories, and traffic congestion contributed to the delay. In a good day the surveyors would deliver 8 samples (see figure 3-4).

Figure 3-4 - Transporting the water samples to laboratory

3.1.3. Interview schedule format

This was classified into two to guide discussions with key informants from ministry of public works, ministry of environment, PDAM, and from institutions using over 48m^3 of water in a day e.g. mosques, and hotel. The information is to be used for mapping variations in GW levels, and discussing policy elements.

There were complexities due to red tape where the process had to start with permission from the Governor and the Mayor as required by the law, in order to be allowed to visit offices. Besides there was delay from the public officials to provide data.

Likewise it was of importance to record GPS points to enhance mapping spatial distribution of wells and recording household surveyed to be used in further analysis.

3.1.4. Defining the study area

The study area involved six urban villages which part of them had been worked on by Salendu (2010). In the part of the study area the quality of GW has been examined by the author. This formed a good basis to continue with further similar analysis i.e. to identify variations in quality and quantity for a far greater scale. With that in mind this research expanded the author study area by incorporating total area of the six urban villages (see table 3-1) and also expanded subject to be analysed to include policy and GW variations.

Village name	Ward
Gowongan	Jetis
Kotabaru	Gondokusuma
Tegalpanggung	Danurejan
Suryatmajan	Danurejan
Ngupsan	Gondomanan
Purwokinanti	Pakualaman

Table 3-1 - Study area urban villages

Initially the author had selected these villages due to their proximity to river but in this case the presence of wells was a strong influencing factor. Still, there was need to conduct a survey in both formal and informal settlements and it was expected an area of this magnitude would contain both.

3.1.5. Data Entry and analysis

This process was relatively friendly since all the questionnaires had geographical coordinates and an area code. It was easy to translate them into excel format by using area codes in all questionnaires which was in form of numbers and letters.

Three classes of database were made, one on general attributes of GW wells from household's survey, two, information pertaining demand of GW, and three, information from interview schedules obtained from institutions using GW. Secondary data on GW levels was also captured and analysed.

3.2. Assessment of water quality and quantity

The assessment of GW quality involves assessing coliform bacteria for E.coli. Faecal coliform bacteria in this group are present in feaces of human and animals and thus can enter water bodies through these media. If a large number of faecal coliform bacteria (over 200 colonies/100 millilitres (ml) of water sample) are found in water, it is possible that pathogenic (disease – or illness – causing) organism are also present in the water. These bacteria just like other bacteria can be killed by boiling water or adding chlorine. One is supposed to wash hands thoroughly with soap after contact with contaminated water. On the other hand water has to be clean, without smell, colour, or taste. The bench mark of analysis is as detailed in Ministry of health (Indonesia) and WHO as shown (see table 3-2).

Parameters	WHO standards	Indonesia standards
Total Coliform		
Drinking water	0 MPN/ 100 ml	0 MPN/ 100ml
Clean water	Not mentioned	Not mentioned

Table 3-2 - GW quality standards

3.2.1. Spatial variation of GW pollution

Results obtained from laboratory tests were used in identifying and mapping the pattern of pollution. Geographical coordinates contributed to relate the source of sample to its location. A database of results in SPSS is joined with the point of houses by aid of Arc Map 10 using spatial statistic tool to identify the spatial autocorrelation between them. This point to the location of polluted well and non-polluted ones.

Since only one sample was collected per grid it's important to carry out spatial interpolation in Arc map 10 to obtain the values of GW pollution in the other possible households.

3.2.2. Spatial spread of water levels

Spatial distribution of GW potential zones can be derived through calculation of parameter that characterizes groundwater potential. Data for calculating this parameter is derived from secondary information recorded during borehole construction and subsequently test pumping operation that last several hours i.e. typically 24 hours.

Parameter needed is specific capacity in gallons per minute per foot, gpm/ft. This is a relationship of yield which is measured in gallons per hour or per day and draw down. Drawdown is the difference between water rest level and pumped water level. Thus
Specific capacity = yield/draw down.

The specific capacity computed from the borehole data reflects the groundwater potential of the aquifer tapped by the borehole. Specific capacity will be calculated of boreholes within the study area. The output will be a groundwater potential map showing spatial variations of different groundwater zones
.
In this case the aquifer with high ground water levels and thus have potential of new wells as seen from a representative of boreholes is mapped using Arc Map10. The values are derived from parameters of specific capacity $m^3/m/hr$.

Parameter	**Function**	**Comment /question**
Yield(pumping rate)	To identify potential well	Shows area with higher specific capacity/GW levels for drilling new wells.
Drawdown (m) = water rest level-water pumped level	To identify potential well	Estimates drawdown that will occur at new well site based on the desired pumping rate.

Table 3-3 - Specific capacity parameters

3.2.3. Relation of policies to GW levels and quality

Changes in GW levels are explained by analysis of GW data as collected using interview schedule from Municipal GW experts or relevant authority. Discussion will link exploitation to performance of policies in practice.

In addition indicators of compliance to regulations and standards are used. The indicators include number of permit holders, total registered annual withdrawals (in million m^3), number of reported abstraction points with and without licence, percentage of permit holders metering abstractions, number of recharge wells, number of monitoring wells, data availability and volume allocation.

To assess the quality of GW an assessment of bacterial contamination and user perception is performed and results subsequently discussed.

The following policies are assessed according to the results of survey obtained (see table 3-4).

Policy Act	**Indicator**
Article 19, part 3 "GW management programme /plan as intended in elaborates further in the plan GW management activities, which includes plans construction operation and maintenance infrastructure on GW basin" Article 28, part 4 "in addition to ministers Governors and Regents/Mayors construction operation and maintenance referred to in paragraph (2) can be done by permit holders, individuals and communities ground water users for their own interests" Article 36 "monitoring of GW aim is to determine changes in the quantity,	-Percentage of permit holders -Total registered annual withdrawals(in million m3)

quality and or gw environments. monitoring include (a) measure and record the position of GW (b) examine the physical, chemical contents, biological or radioactive material in GW (c)total volume of GW that is used or abstracted (d) measure and record changes in water environment on land such as land subsidence. Article 48 " zone to be utilized for allocation of GW after considering (a) distribution and the characteristics of the aquifer (b) hydrological conditions (c) environmental conditions and GW (d) protected area GW (e) water needs for communities and development (f) result of the inventory data (d) availability of surface water Article 54 "use of GW is intended to meet basic needs day to day agricultural people and not business activities. For agricultural it's only when surface water is inadequate. For business permit has to be given by Mayor/Governor to individuals, cooperate business, government or social organizations. Article 58 part 3 defines permits to be license issued by the mayor or Governor.	-user perception on colour, odour and taste -Presence of E.coli -number of reported abstraction points with and without licence
Article 60 the minister has authority to set the allocation of gw Article 61 to prevent/cope with saltwater intrusion and reduce declining of GW buildings should have recharge wells.	-Percentage number of recharge wells
Article 61 land subsidence to be controlled by reducing water consumption for licence holders and stop water intake in critical zones.	-Total volume allocated
Article 77 part (a) each permit holder must submit to the Mayor/Governor a report of drilling activity and extraction/use per month (b) install water meter at each production well (c) pay management fee Article 79 a outlines that permit should be renewed or returned or license revoked	% permit holders metering abstractions
Article 80 and 81 is about management of data through data collection, storage, processing, renewal and publication and dissemination of data and information.	-A discussion on availability of data.
Article 84 mention the source of fund for GW management part of it to be user fee from the GW permit holder implying all permit holders must pay fee.	-% of permit holders paying user fees

Table 3-4 - GW policy

4. DESCRPTION OF THE STUDY AREA

The study area includes a part of the earlier informal area studied by Salendu (2010). It's extended to incorporate the whole area of the six urban villages to have enough points of boreholes and shallow wells. A shape file for buildings of Yogyakarta city and Google image is used to determine sampling frame as explained earlier in data collection phase. Prominent issues as described in this chapter concerns location of the study area, land – use, demographic characteristics and support infrastructures amongst others.

4.1. Location of the study area

The study area is within Yogyakarta city which is located on 110^0 25' 33" - 110 ^{0} 30' 42" of longitude and 7^0 30' 25" – 7 ^{0} 51' 24" latitude. Its cover is 32, 50 km^2 area, and consists of 14 districts with 48 sub-villages. It has a relatively low cost of living as compared to other Indonesia cities as a result of many education institutions which are 137 in number one of it being the second largest and oldest University in Indonesia (Gadjah Manda University). The city is carved out of two regencies, Sleman on the North-Western side and Bantul on South Eastern side (see figure 4-1).

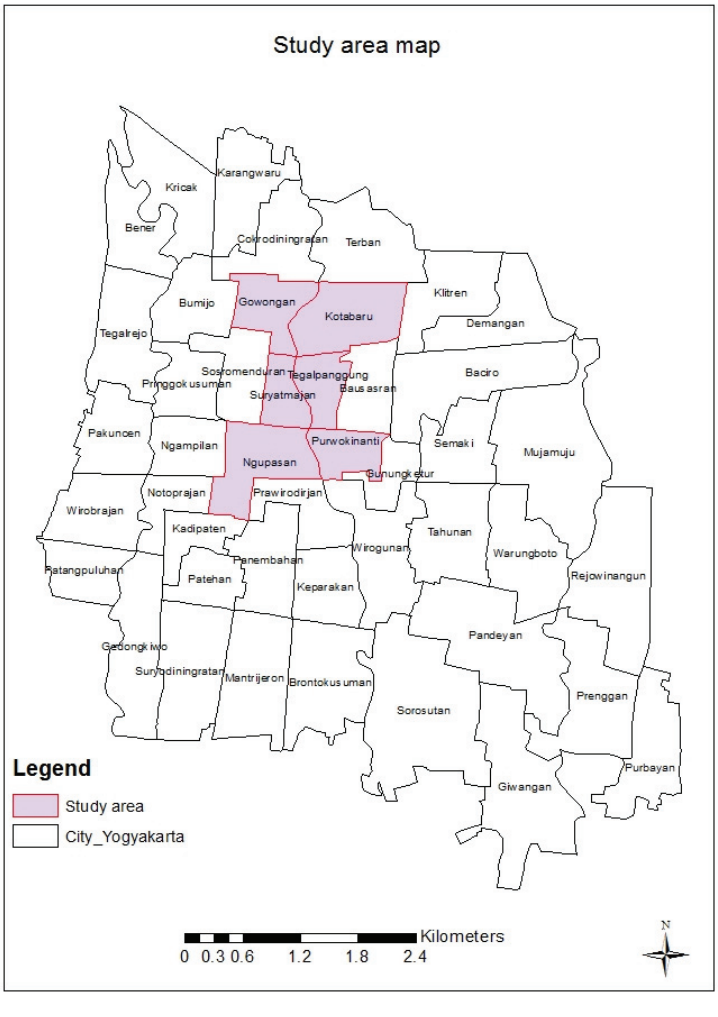

Figure 4-1 - The study area location

The names and land area of the administrative units are as shown below (see table 4-1).

No.	Districts	Land area(km2)	Sub-districts (urban villages)	Land area (Km2)
1	Mantrijeron	2.61	Gedongkiwo	0.9
			Suryodiningrata	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	Petangpuluhan	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

Table 4-1 - Administrative units

Source: (BPS statistics of Yogyakarta city 2007). Adapted from Salendu (2010).

In geographical aspect Yogyakarta lies between Merapi Mountain at the North and Indonesian Ocean at the South. It topographic orientation declines towards the South. It has a hydro climate condition which makes rain water a source of GW recharge and consists of sandy soils. Rivers flow parallel from North to South within the city (see figure 4-2). Domestic waste of houses along the rivers is flushed in the streams thus minimizing GW pollution.

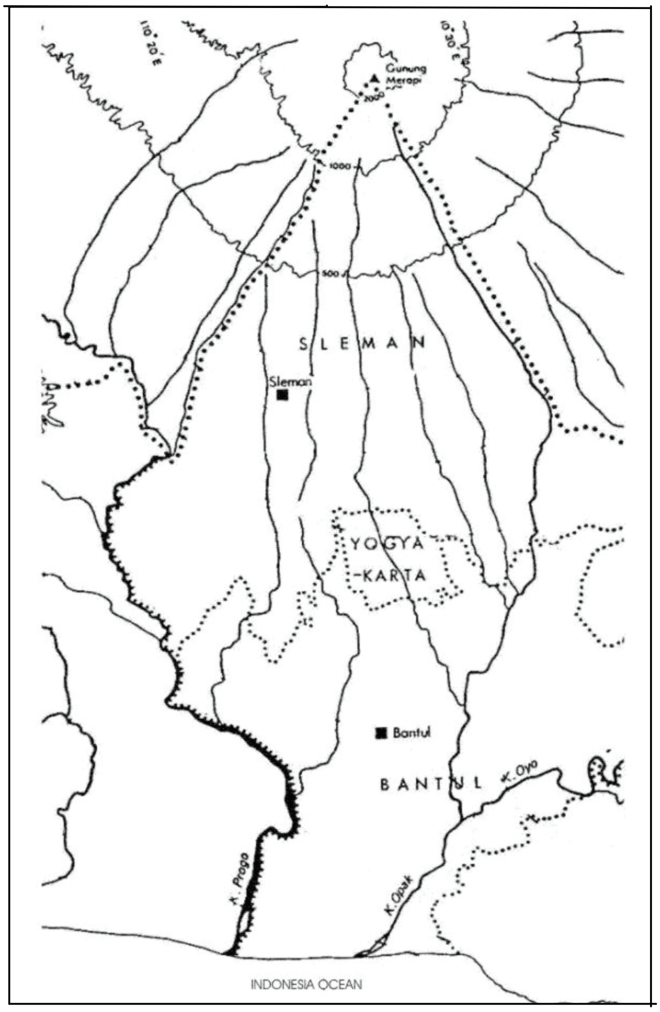

Figure 4-2 - Location map

Source: Sir MC Donald and partners (1984), cited in Azzam (2007).

4.1.1. Topography and geology

The Yogyakarta region is a plain and its elevation is about 80.0m to 136.0m above sea level and the slope of land is roughly 1% to the South. The geology of the area is on land formed by the fluvial volcano of Merapi Mountain to the North, Nanggulan formation in the West ,Sentolo, Jongrangan, Wates plain and sand dunes in South beach of Indonesian Ocean in the South, and Batur Agung formation on the East as shown in figure below(see figure 4-3).

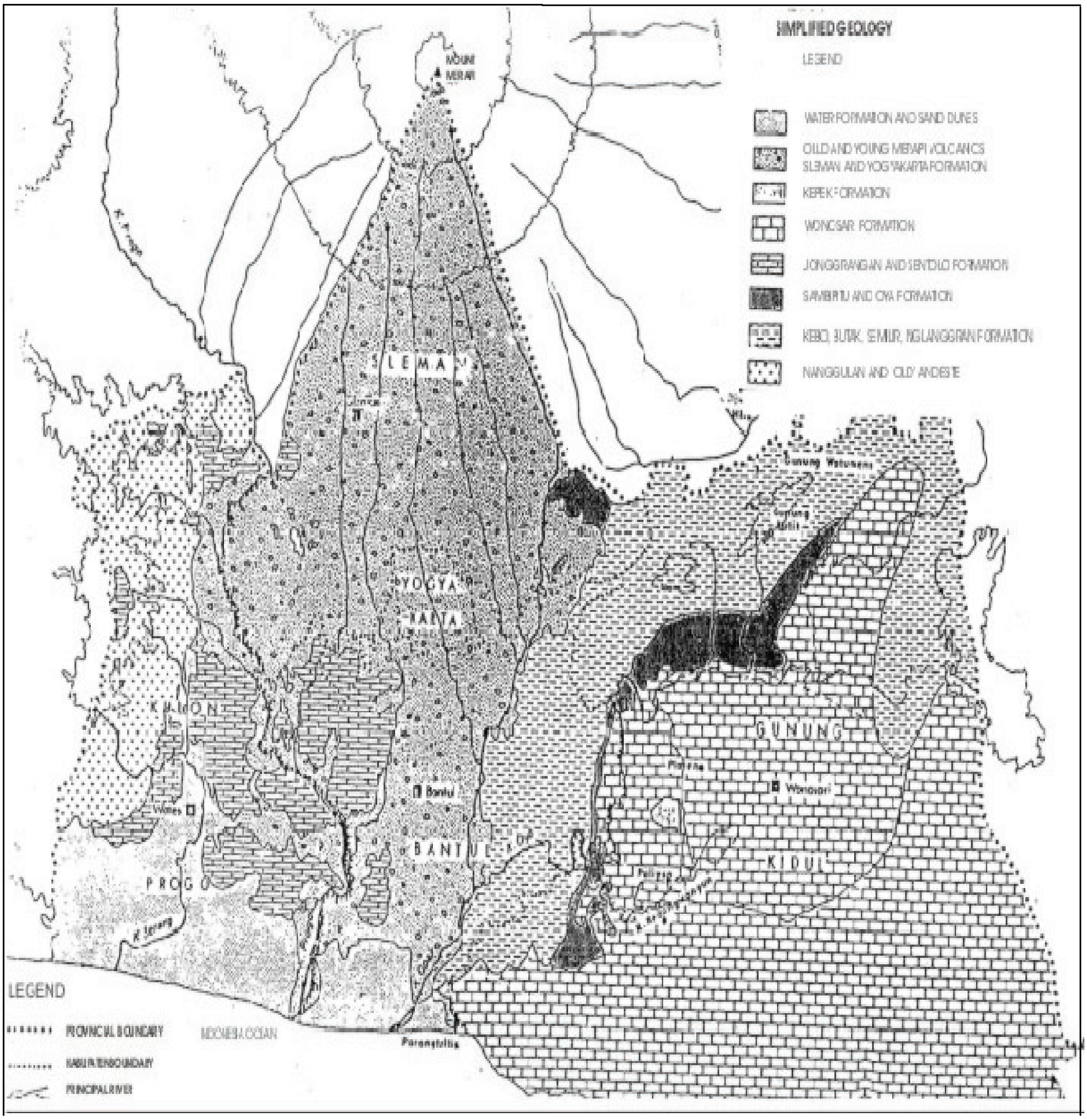

Figure 4-3 - Geological formation of Yogyakarta Province

From Sir Mc Donald & partners (1984), cited in Azzam (2007).

The city formation includes silt, clay, sand, and gravel, from Sleman region from the North and from Merapi mountain eruption (Sir Mc Donald & partners 1984 cited in Azzam 2007). The formation in Sleman is the base of formation in Yogyakarta and it consists of silt, sand, clay, gravel, volcanoclastic and big rocks. This builder materials are 20-40 m layer thick very permeable and builds Merapi aquifer which has high potential for water supply for Yogyakarta community. This aquifer spreads from North to South thus GW flow in that direction and affects the recharge process within the city. The recharge process sources are plains at the North of Yogyakarta and local area.

4.1.2. Climatic conditions

The region has two seasons, dry and wet. Dry season is in months of April- October and the wet season in month of October – April. Average monthly rainfall is grouped in regard to these two seasons. The dry seasons records an average of 20mm to 120mm and the wet season an average 150mm to 380mm. the average annual rainfall is 2,090 as shown in figure below(see figure 4-4). This affects both the surface water flow and recharge in the city of Yogyakarta.

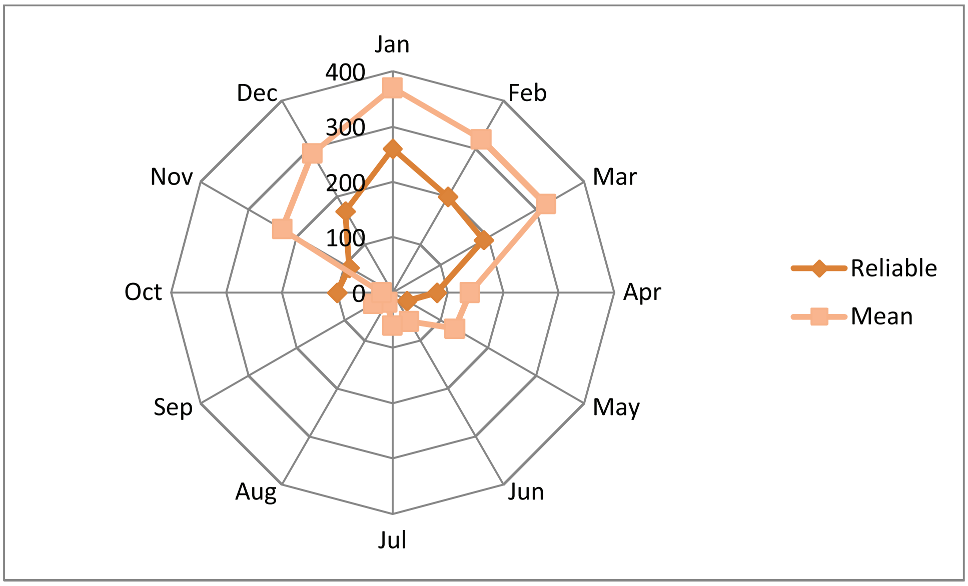

Figure 4-4 - Monthly rainfall in Yogyakarta

From Sir Mc Donald & partners (1984) cited in Azzam (2007).

Yogyakarta region has three rivers flowing from North to South parallel to one another. This are Winongo river on the West of the city, Code river in the centre thus through the city and Gajahwong River in the East of the city. Most of the water infiltrate into aquifer due to erosion from the North. The flow of the Rivers will follow the season's variation of rainfall thus high volume and sometimes floods during wet season and low volumes during dry seasons.

4.1.3. GW recharge in Yogyakarta City

Earlier on it was understood that increased level of urbanization led to decrease of GW recharge in urban areas due to impermiabilazation of catchment by built up surface. However studies by (Barrett et al., 1999) show the reverse is true. Recharge in cities is higher than peri – urban areas. Two main sources are attributed to this, one rain water, two, leakage, from waste water and main supply networks. Where waste water is not exported almost 90% of it goes to recharge (Barrett, et al., 1999) thus affecting quantity and quality of GW.

Research carried by Ministry of Environment in 2007 on GW recharge for Yogyakarta city and neighbouring regencies of Sleman and Bantul, realised that rate of recharge in the city is less than demand. But for the other regencies the demand for GW is less than recharge rates.

The research incorporated the demand of GW by sector i.e. for domestic, commercial and industrial purposes for the two regions and the city, projected from 2002 to 2014 and results captured in below tables in m^3 per year (see table 4-2). The projection is up to 2014 and the three categories considered are domestic, commercial and industrial. The implication is that by 2014 Sleman region will have a total demand of 68,059,101 million m^3. This will still be less than estimated recharge of 350 millionm^3 per year

Region	Use	2002	2005	2008	2011	2014
Sleman	Domestic	49639279	53516104	57393033	61269853	65146749
	Commercial	1522621	1581267	1632404	1677739	1718455
	Industrial	1079943	1117862	1147871	1172709	1193897
	Total	52241842	56215232	60123308	64120301	68059101

Table 4-2 - GW demand in Sleman regency

Source - Ministry of Environment Yogyakarta

Table 4.3 below is illustrating the total demand of GW as projected by year 2014 which is estimated to be 37,049,007 million m^3 for Yogyakarta region. The region total recharge per year is estimated at less than 50 million m^3.

Region	Use	2002	2005	2008	2011	2014
Yogyakarta	Domestic	3526407	30260934	30787926	31314982	31842060
	Commercial	3526407	3675375	3805269	3920425	4023849
	Industrial	1097990	1124389	1146709	1166044	1183098
	Total	34358216	35060697	35739904	36401451	37049007

Table 4-3 - GW demand in Yogyakarta city

Source - Ministry of Environment Yogyakarta

The demand in Bantul region for GW will total 45,729,207 million m^3 by 2014 (see table 4-4) as compared with a recharge level of approximately 80,000,000 million m^3 (see table 4-5).

Region	Use	2002	2005	2008	2011	2014
Bantul	Domestic	38864465	39971423	41078311	42185221	43292165
	Commercial	1039533	1086161	1126820	1162865	1195237
	Industrial	1078600	1135321	1178275	1212857	1241804
	Total	40982599	42192905	43383406	44560943	45729207

Table 4-4 - GW demand in Bantul region

Source - Ministry of Environment Yogyakarta

The last on this discussion is the total estimated recharge for the three regions as indicated (see table 4-5).

Region	GW Recharge (m3)	Total demand (m3)
Sleman	375000000	70000000
Yogyakarta City	20000000	45000000
Bantul	80000000	47000000

Table 4-5 - GW recharge

The figure below is a depiction of GW recharge and demand for the three regions as estimated in 2007 by Ministry of Environment Yogyakarta (see table 4-6).

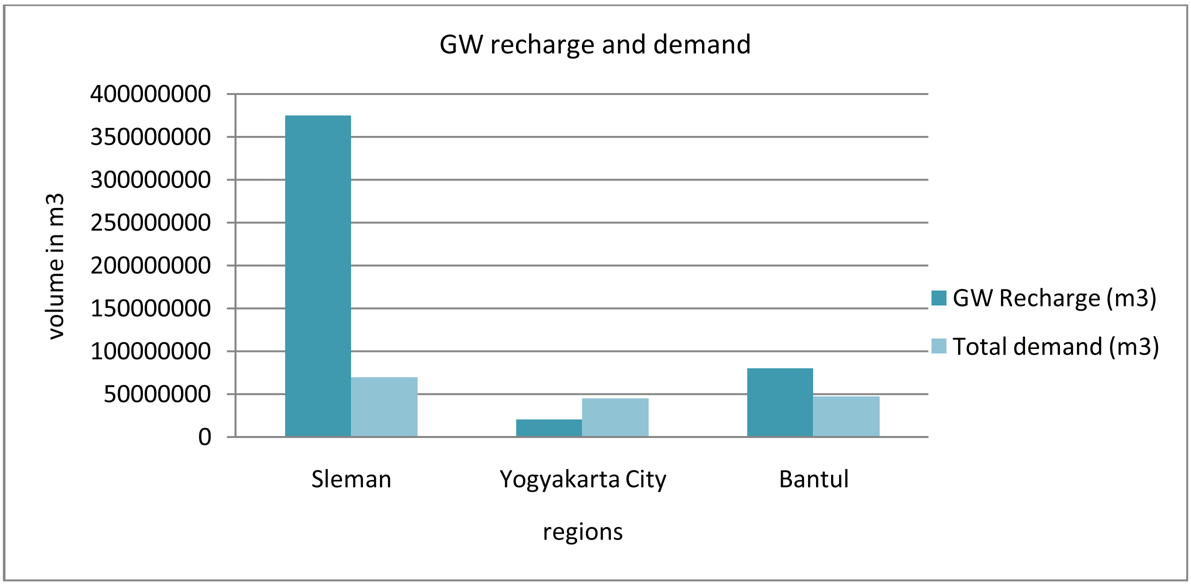

Table 4-6 - GW recharge and demand

Source is Ministry of Environment Yogyakarta (2007).

Sleman regency which is in North has high recharge levels due to high level of rainfall than the other regions. It's expected that the GW from Sleman trickles down to Yogyakarta and Bantul regions.

4.1.4. Land use

The city has an area of 32.50km². 20.95km² (64.5%) of land is used as community housing, and only 1.77 km² (5.5%) found as agriculture land, while the rest is used as follows, open space (1%) company (8%), industry (2%), others (12%), service(8%), etc. (Kamulyan, 2005). This means that almost more than 90% of the area of Yogyakarta city is used as community housing and urban activities (see figure 4-5).

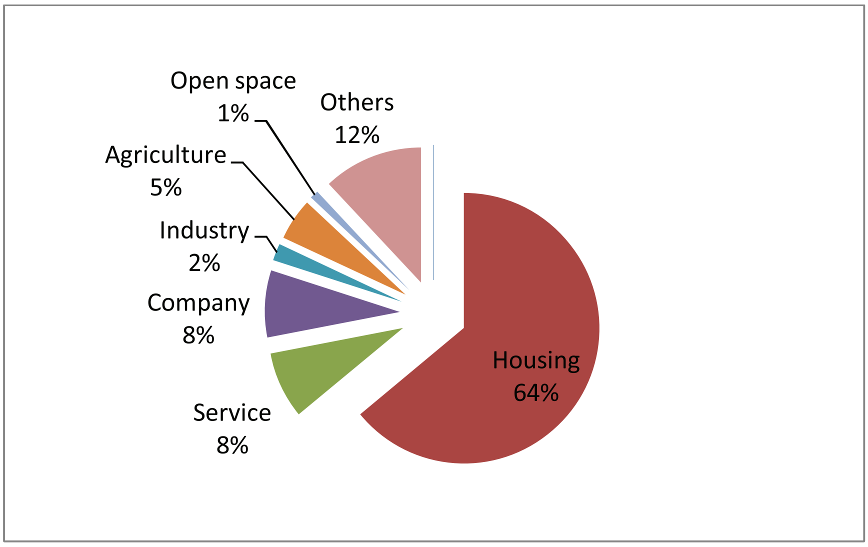

Figure 4-5 - Land use in Yogyakarta

Source: Sir MC Donald and partners (1984) cited in Azzam (2007)

4.1.5. Study area Population

The city has a population of 483,760 peoples (Kamulyan, 2005) that have average population density about 14,885peoples/km². The population by 2006 was 523,191 people (Salendu, 2010) . Population density of each district is varying from7,564 peoples/km² for Umbulharjo District located in the outer side of urban area to 27,652peoples/km^2 in the centre of urban area or in the business centre area. The annual growth rate is predicted at 1%. The figure below shows the population within the study area (see figure 4-6).

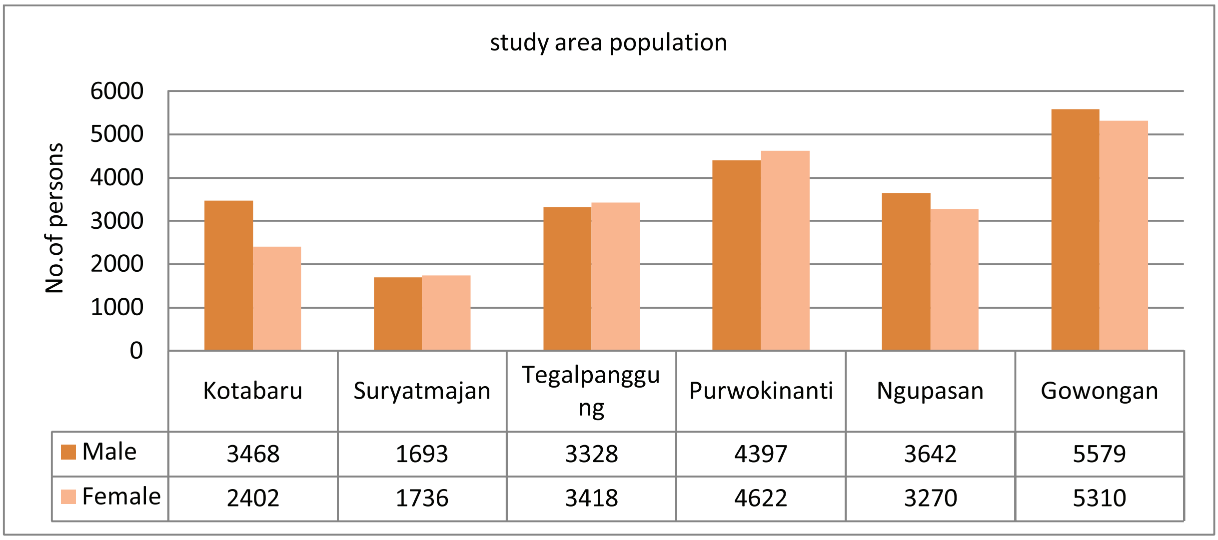

Figure 4-6 - Study area population

Source; CBS Yogyakarta

It's evident that high population is in Gowongan village within Jetis village and the lowest population is in Suryatmajan village in Danurejan District.

4.1.6. Water supply

Water is tapped from boreholes and supplied to the population from holding tanks. PDAM has 29 deep wells where 5 of them are within the study area. The company supplies up to 40% of the population where 60% relies on their own supply from shallow wells and private vendors. The company is responsible for a 40km^2 service area but its utilities have covered 32.50km^2. Out of 525,000 persons 510,000 are within the service area and only 248,000 persons are served.

The main source of water is direct river abstraction, boreholes and shallow wells. This is treated through disinfection, filtration, flocculation and sedimentation, and aeration.
The supply system is able to produce 40,780m^3/day and the length of its distribution network is 844 km with a storage capacity of 7,750m^3. The table below is a summary for types of connection and status (see table 4-7).

Type of connection	Number of connections
Domestic households	31,910
Non domestic households(industrial, commercial, institutional , other)	2,646
Connections with meters(functional)	34,556
Average length of service pipe from main to water meter	6.00m

Table 4-7 - PDAM connection

Source: PDAM Yogyakarta

The company is able to produce 17.36 million m^3 per year and out of this only 9.39 million m^3 is metered/year. From the amount unmetered 28.64% is due to meter inaccuracies. There is no bulk water sale apart from domestic sales which accounts for 9.31million m^3 and 1.77 million m^3 for non-domestic (PDAM Yogyakarta)

5. REPORTING THE POLICY FINDINGS IN RELATION TO SPATIAL VARIATION OF GW QUALITY AND LEVELS

This chapter evaluates the variation of GW levels and quality. It also looks into indicators individual policy elements linking these variations to policies. To begin with is an assessment of GW quality carried out by processing information on supply and use of GW and whereby a quantitative analysis of total coliform is assessed. The second part is on spatial analysis of GW levels by determing specific capacity of different wells. This is by using the drillers log values as input in Arc GIS and performing spatial autocorrelation and spatial interpolation. Then we assess the allocation and abstraction of GW to indicate the level of use and availability which is achieved by bringing the amount allocated per user to Arc GIS, and performing analysis to visualise different value points in the city study area. Spatial analysis is similarly applied in analysing GW quality to assess the relationship/similarity for E.coli values. The third part is assessing the success of policies by measuring a number of policy elements and later on reporting on their findings. Last and not least is a discussion on key elements of policy that can be added in the GW management policy document for Yogyakarta region.

5.1. Percentage of GW use

This analysis is to find out the percentage and number of households using GW within the city six urban villages which have a total population of 42,865 (see figure 4.6) persons. The values are from sample collected in the field. The total sample size was one hundred and fifty households with an average household size of five persons. The households are supplied by different sources of water that is, from piped water source and wells. This is captured in a graph (see figure 5.1) in whole numbers and later on percentages are computed and explained.

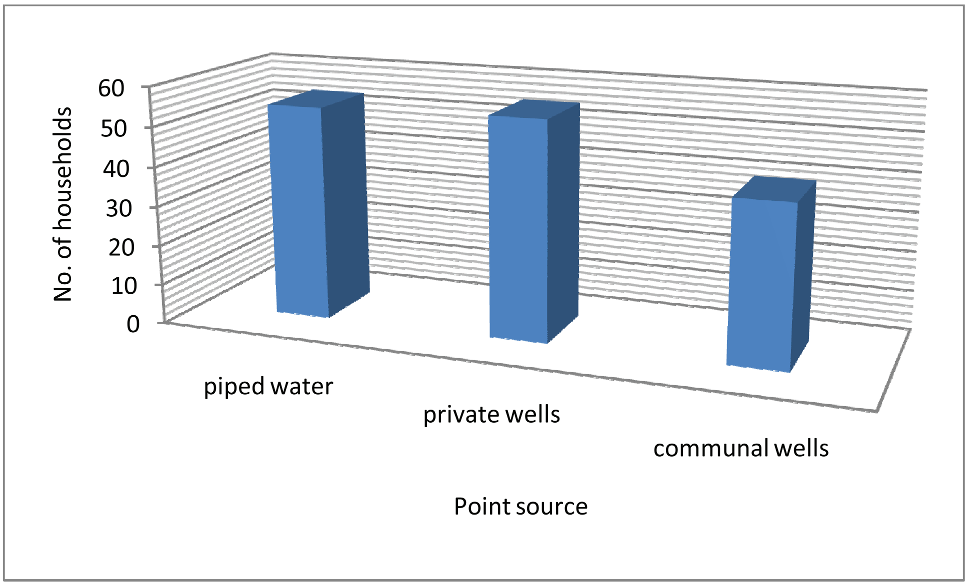

Figure 5-1 - Major source of water

GW remains the main source of water for domestic use mainly due to convenience, low cost and availability. The data show that forty households which are 27% of the residents obtain their water from communal wells, fifty five households which are 37% obtain water from private shallow wells and fifty four households which are 36% percent draw their supply from piped water. The use of GW from shallow well for domestic purposes like drinking and washing is free. This means there are no user charges and the policy is not formulated to regulate it in any way. No taxes are associated with the use of shallow wells unlike piped water that's why it's most preferred source. In addition the supplies are constant at all season as found out in the field survey. None of the respondents reported a case of dry shallow well at all. Similarly shallow wells are within for in many cases the wells are located within household compound. Thus it takes an average of five minutes to draw the water thus very reliable. Where there is sharing it's just within the vicinity on friendly terms as found out in the field.

PDAM which is the company responsible for a 40km² service area has utilities cover of 32.50km². From the city population of 525,000 persons 510,000 are within the service area and only 248,000 persons are served. (see 4.1.7). This translates to 40% within the city and it differs with 4% from the observed results though a sample for six urban villages. This can be explained by the fact that some connections do not provide water thus the owners relying on wells though included in the PDAM figure. Interviews with PDAM revealed that they rely on twenty nine boreholes to supply to their customers. These are both deep and shallow wells in addition to surface abstraction.

As evident in the analysis most GW is abstracted by shallow wells (hand dug wells, or drilled wells) for domestic use. Data collected indicated that the average depth of shallow wells is fifteen metres. The water is drawn manually or by small pumps unlike deep wells where the water is pumped by use of electricity. From observation some wellheads are not protected leaving a ready ground for contamination. The use of GW for domestic purpose is not regulated by policies and it's allowed to be extracted for this purpose at no additional costs/tariffs to cost of drilling the well and operating the pump. Thus policies give an upper hand to use of GW for domestic purposes and individuals determine the amount to abstract according to their domestic needs and family size.

5.1.1. GW demand for domestic use

This refers to gross domestic GW used by 64% of the total sampled households which is equivalent to five hundred and twenty eight persons (see table 5.1), as computed from family sizes of households interviewed. On average per day it translates to 56,060 litres derived from sample of data collected in field (See table 5.2), i.e. all the respondents estimated the amount they withdrawal per day during the household survey and this amount in litres was summed to arrive to amount used per day which is 56,060 litres. This follows that the population that relies on GW within the study area uses approximately 1.1 million m^3/year (see table 5.2) since sixty four percent of the study area population is 27,370 persons using GW (for study area population which is 42,765 persons see figure 4.6). This is the amount of GW abstracted per annum in m^3. This is derived from field survey as estimated from figures collected in field. Secondary data within Ministry of Environment Yogyakarta, quotes that the city population uses approximately 45 million m^3 of GW per year for domestic, industrial and commercial purposes.

		Quantity withdrawn a day(L)	Population
N	Valid	150	150
	Missing	0	1
Sum		56060	528

Table 5-1 - Amount of GW used per day within the study area

Domestic GW used in study area (in million m3)	GW used in city (in million m3)
1.1	45

Table 5-2 - Total GW use

These figures from the study area do not include GW for commercial purposes but it's for domestic use only with sources from private shallow and community wells. None of the households reported a case of dry well and they said there are no fluctuations on level of water in different seasons to warrant further excavation of depth. The analysis depicts a situation whereby there is no problem on availability of GW in shallow wells for domestic use within the study area.

5.1.2. Water quality according to user perception

The user perception of GW was based on colour, odour and taste of shallow well water. Survey for wells was done at household level to identify the above named physical characteristics of GW. Ninety eight percent (98%) of the respondents reported that the GW has no taste, 99% did not observe any colour and 99% said the water has no smell (see fig 5.2a, b, and c).

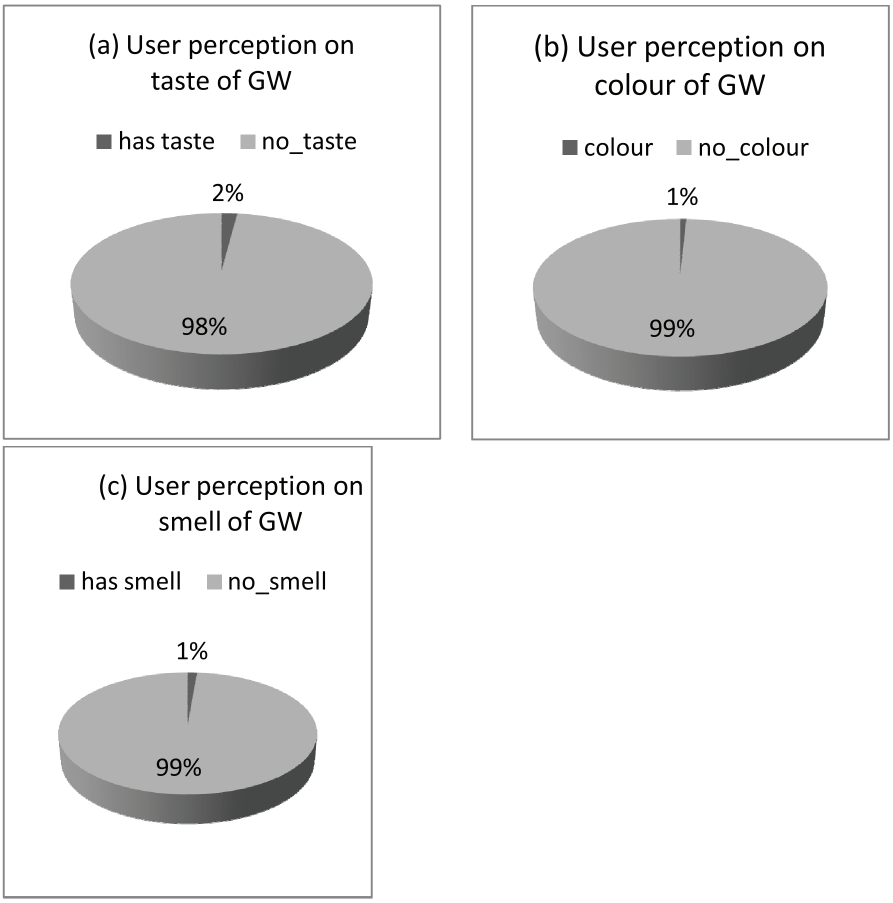

Figure 5-2 - a, b and c - Perception of GW by users on smell, colour and taste

The above results have strong similarity with results of previous work carried out on same subject in part of the study area by Salendu (2010). In her research the author found that 98.5% and 98.9% of the respondents said GW from private and communal wells has no odour respectively. She also found out that all respondents reported good taste for both private and communal wells while 98.5% and 97.8% of respondents said private and communal GW has no colour respectively. This implies perceived qualities of GW water within the area according to users are good.

5.2. Quantitative analysis for total Coliforms

5.2.1. GW quality

According to Yogyakarta policy regulations and WHO regulations (see table 3.2) GW for consumption/ domestic use should be free from coliform. With this in mind, samples were collected from groundwater wells for quantitative analysis to assess the quality of water. Total coliforms include genera that originate in feces (fecal coliforms) which is an indicator of fecal contamination more so for E.coli. A test for E.coli was done to indicate microorganisms for other pathogens that may be present in feces thus contaminating the water. Their presence provides warning of contamination by pathogens which implies that water has been contaminated by faecal waste of human or animals.
The result of the survey from GW wells within the study area is summarized in below graph (see figure 5.3).

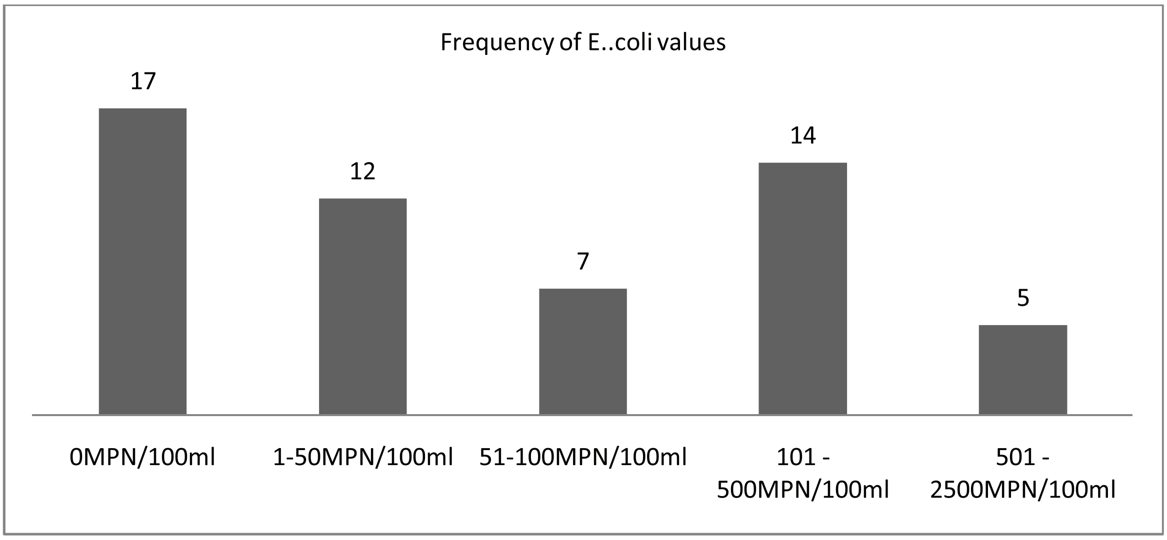

Figure 5-3 - Number of samples taken and contamination levels

The above results show that pollution concentration of seventeen wells are in class with contamination factor of 0 MPN / 100 ml which is thirty one percent (31%). The seventeen wells are not contaminated at all. Others have a contamination level of as high as 2400 factor. The degree of the contamination differs from one point (household well) to the other.

The above samples which are fifty five in number were used as input in the study area map. This was arrived at from households surveyed which were one hundred and fifty. From the total sample some households were using private wells as source of water, others piped water and others were sharing mainly from community wells. These samples for laboratory test were taken from the shallow wells only. This is for reasons that shallow wells are most likely to be contaminated by coliform due to their shallow nature and because households use this for their domestic purposes thus need to asses it suitability. There were difficulties in time and distance in the process of sample collection as discussed earlier (see chapter 3.1.2). Nevertheless the results indicate different values of contamination level at different spatial points. It is clear there are differences in degree of contamination with some wells not contaminated at all and others highly contaminated (see figure 5.4).

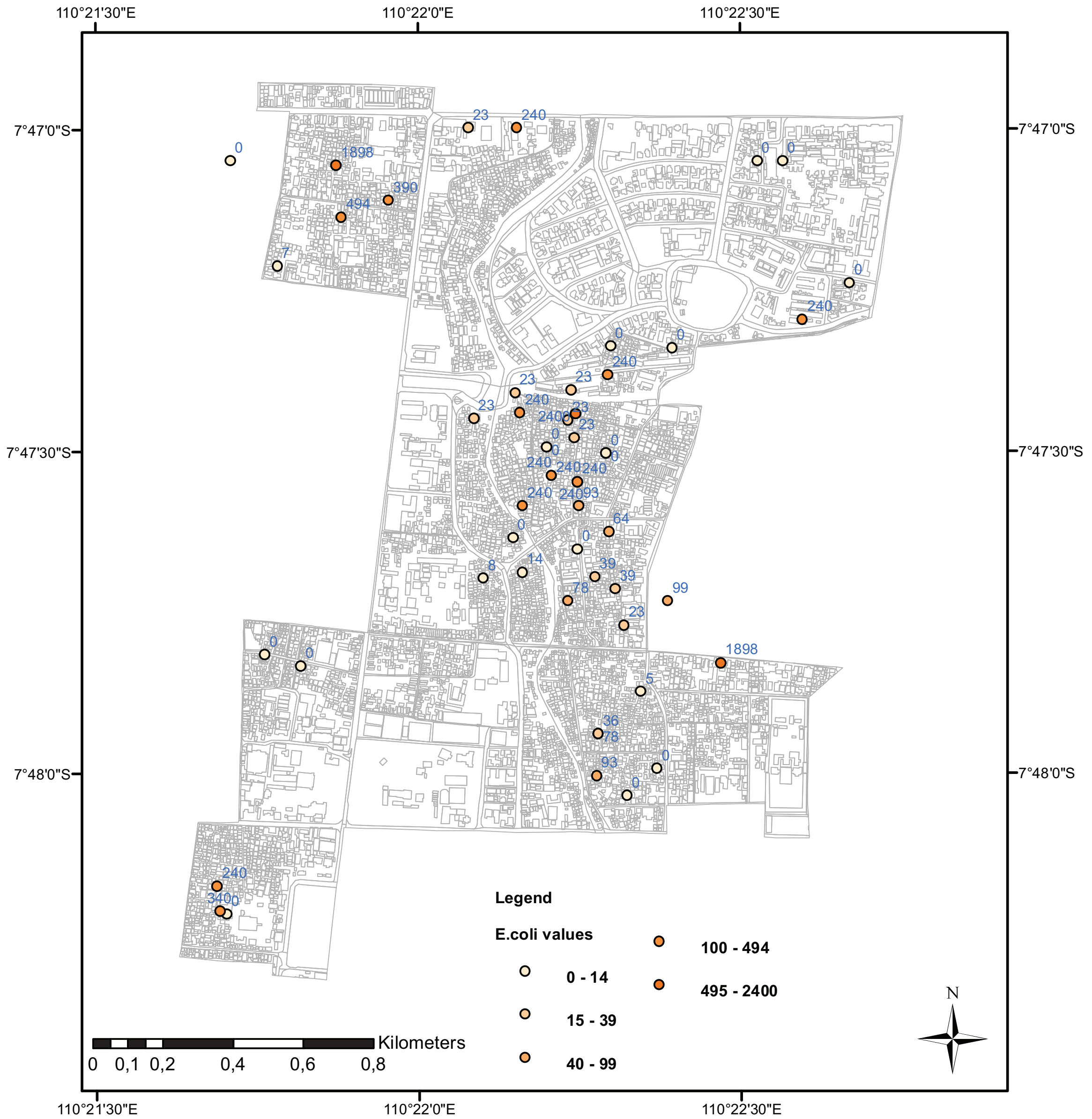

Figure 5-4 - Spatial variability of E.coli values

The results are a clear indication of GW contamination by human/animal waste. Points highly polluted are by values above 2400MPN/100ml sample. We mean above 2400MPN/100ml because that is the maximum value the laboratory could detect but it can be higher than that (for MPN see list of acronyms). The overall indication is that GW is polluted at varying levels though there exists isolated cases of non – pollution. One cannot say there is a particular area with same levels of pollution as seen on map. The fact that there is pollution of GW contravenes the policy standard and thus need for redress to ensure the water is not polluted.

If the above results are related with infections by water borne diseases within the household members, it would be expected in normal cases that the water would lead to diseases like cholera, typhoid, and dysentery. Meanwhile a household survey was conducted within the study area to assess prevalence of these diseases. Interesting results contrary to expectations were observed (see figure 5.5)

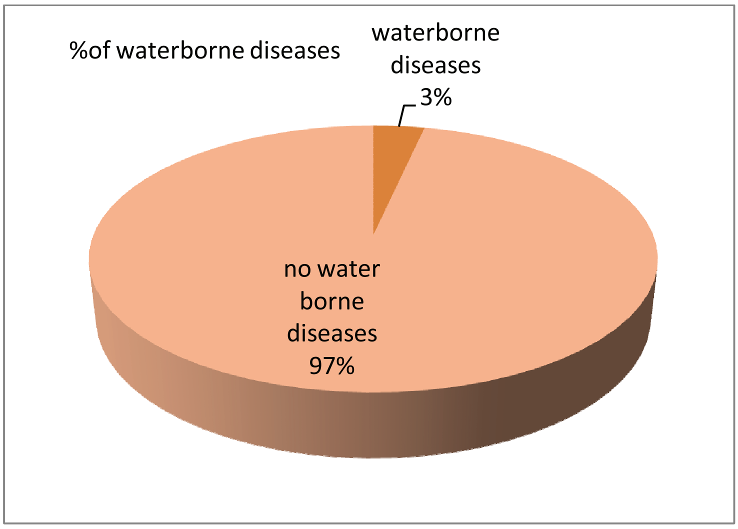

Figure 5-5 - Percentage cases of water borne diseases

The results indicates only three percent (3%) of the total sample has been affected by water related diseases. A survey on use indicates GW is key in all domestic uses including drinking as previously seen (see figure 5.1). Apparently the inhabitants are aware of the quality of the raw water and do not drink it untreated. This follows from results of periodical tests done by Public Health Ministry and consequently communicated to the population. On same note, previous survey by Salendu (2010), within a part of the study area indicated people treat water through use of water treatment chemicals and boiling. All this significantly reduces cases of water borne related diseases.

5.2.2. Spatial Autocorrelation of total coliforms spread in GW

The objective of performing spatial autocorrelation using ArcGIS 10 is to measure spatial variation of E.coli variables within the study area. The analysis will show if these values are clustered dispersed or have a random distribution as explained earlier in the literature review.

Point locations of GW wells samples were the basis of ArcGIS input using their geographic coordinates. These were linked to a table with values of E.coli prepared in SPSS for analysis using Morans I. The features relationship was conceptualized using inverse distance weighting to ensure that observations that are far apart would have a reduced impact compared to observations that were close. The distance was calculated by use of euclidian method since GW transmissivity is not confined to certain network (see figure 5.6).

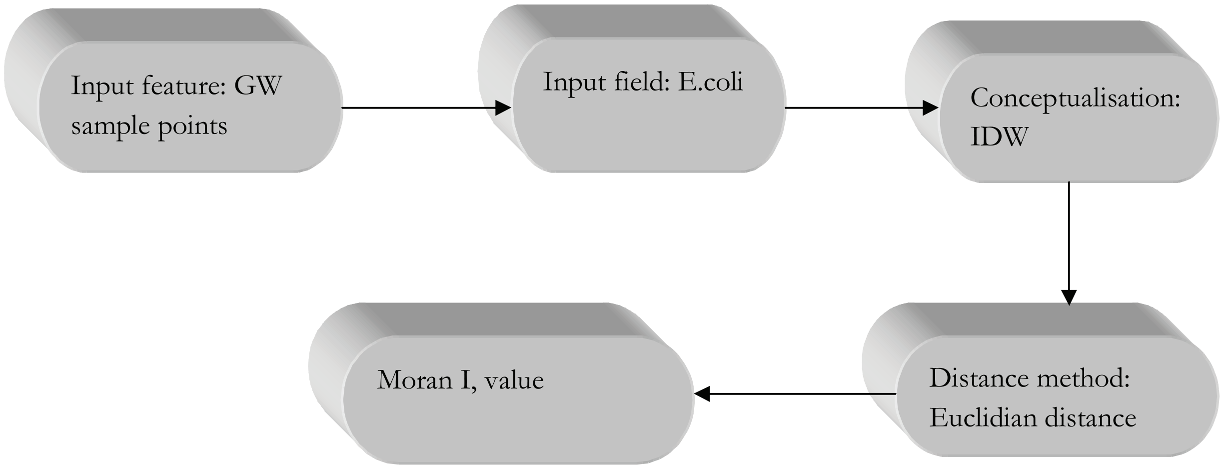

Figure 5-6 - Flow chart for spatial autocorrelation

From the analysis of all observations in the study area, a global Moran I value of 0.23 was registered. This is an indication of weak positive spatial correlation between water samples point in relation to the total coliforms observed. Morans I index was used to decide on the null hypothesis which states that "there is no spatial pattern among the features or among the values associated with the features in the study area" i.e. the expected pattern is just one of the many possible versions of complete spatial randomness.

The observed result is that the occurrence of different levels of pollution is by chance. Results could be influenced by the wide nature of the study area. That is the points are far away from one another. One explanation could be that the spatial correlation of pollution operates at shorter distances. Some of the steps taken to address pollution would be a call for publicity to enhance awareness to individuals on public health to avoid wells pollution, for instance disseminating information regarding protecting the well heads from surface runoff and ensuring wells are not sunk near onsite waste systems.

5.2.3. Spatial interpolation of total coliforms in GW

This is a procedure of estimating the value of properties at un sampled sites within the area covered by existing observations (Nigel, 1997).

Spatial interpolation is a follow up of spatial autocorrelation. The results of global Moran I of 0.23 express a weak positive relation due to reasons advanced earlier. Through visual analysis of the pollution distribution it is possible however to identify some weak clusters, which may be an indication that there is higher spatial correlation in some local clusters at shorter distance. In view of the limited number of sample points it is not realistic to determine Moran's I for these small clusters. Despite the low Moran's I a spatial interpolation has been carried out for purposes of getting a rough idea of the contamination levels in between measuring locations. To this end also, an IDW method has been applied. The aim is to estimate spatial areas with similar GW pollution values using the water sample points from the wells. The methodological approach is as shown (see figure 5.7).

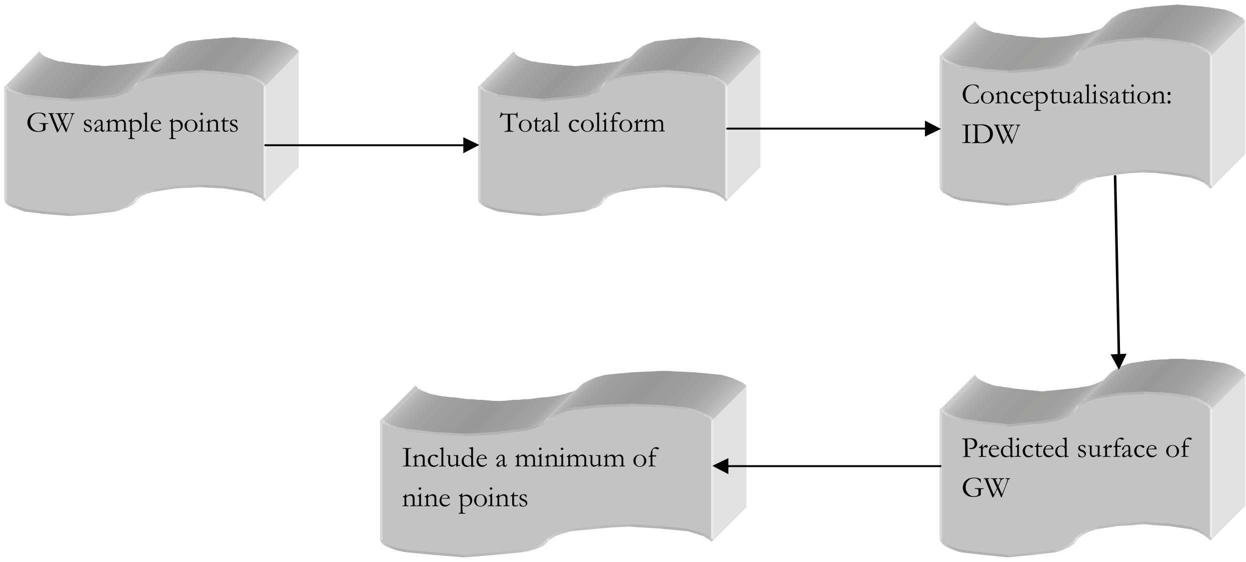

Figure 5-7 – A flow chart to show spatial interpolation process of GW

After processing in Arc GIS 10 and in regard to the above flow chart results were visualised in the study area map. Some points were slightly outside the study area though included. The values of the contamination levels per point are also labelled for ease of interpretation (see figure 5-8).

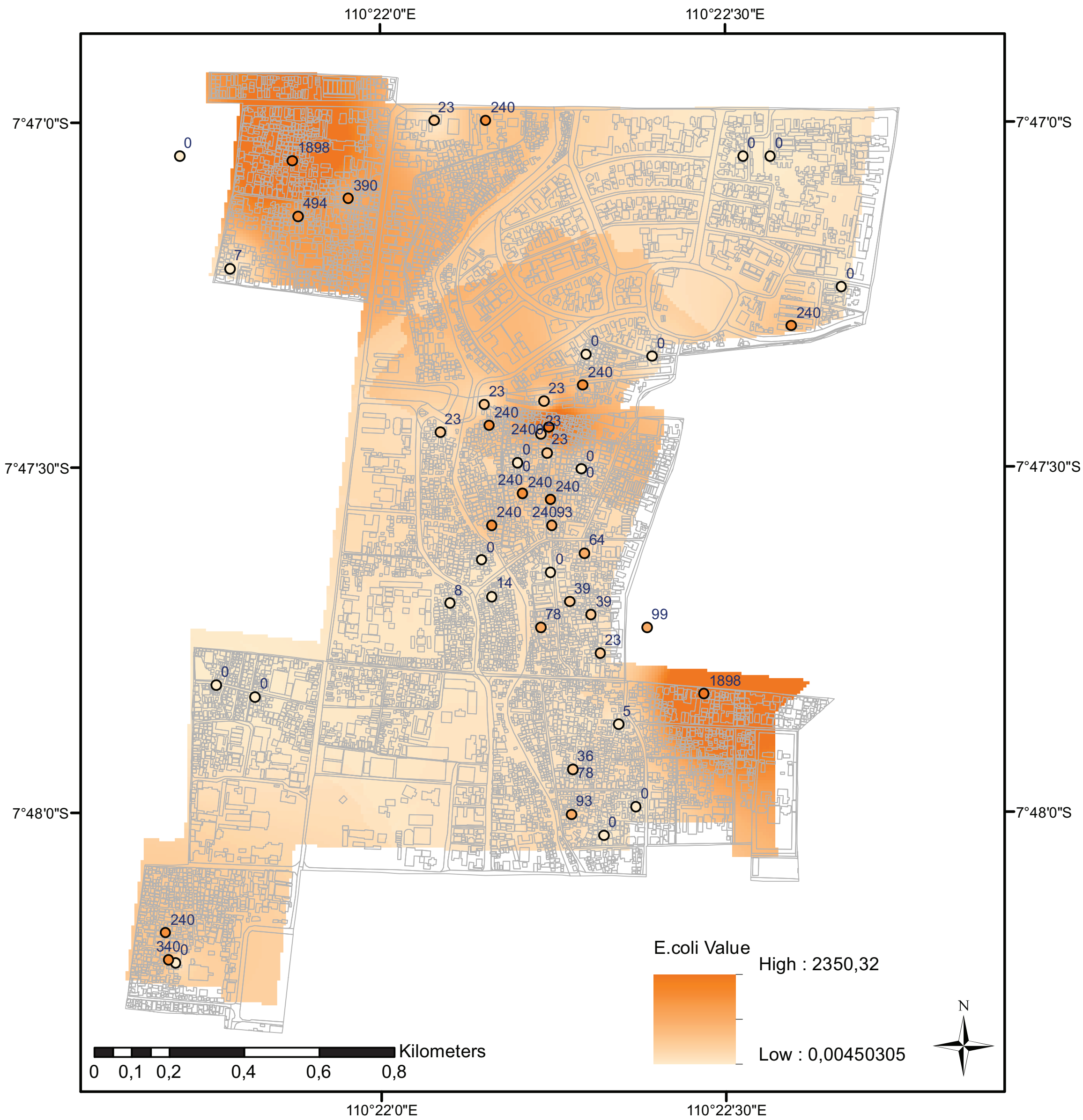

Figure 5-8 - Spatial interpolation of E.coli values

From the above results, areas with high values are evident as seen by thick colouring. It implies the level of pollution in each of these areas is relatively high as compared to the study area as whole. On the other hand areas with low contamination/pollution values are expressed by thin colouring. The proposition is that there are spatial units with fairly high contamination levels and these areas qualify for first intervention.

Apparently, we can observe through visual analysis some weak clusters especially at the middle and South tip though with relatively high values. This is a pointer that, there is high spatial correlation in local clusters at shorter distance. Since the number of points is less, it's not realistic to determine morans I for these small clusters.

On a further analysis points with high contamination values were isolated. These were points with contamination values of above 1898MPN/100ml sample. Spatial analysis was determined without these outliers to observe a better pattern of pollution distribution (see figure 5-9).

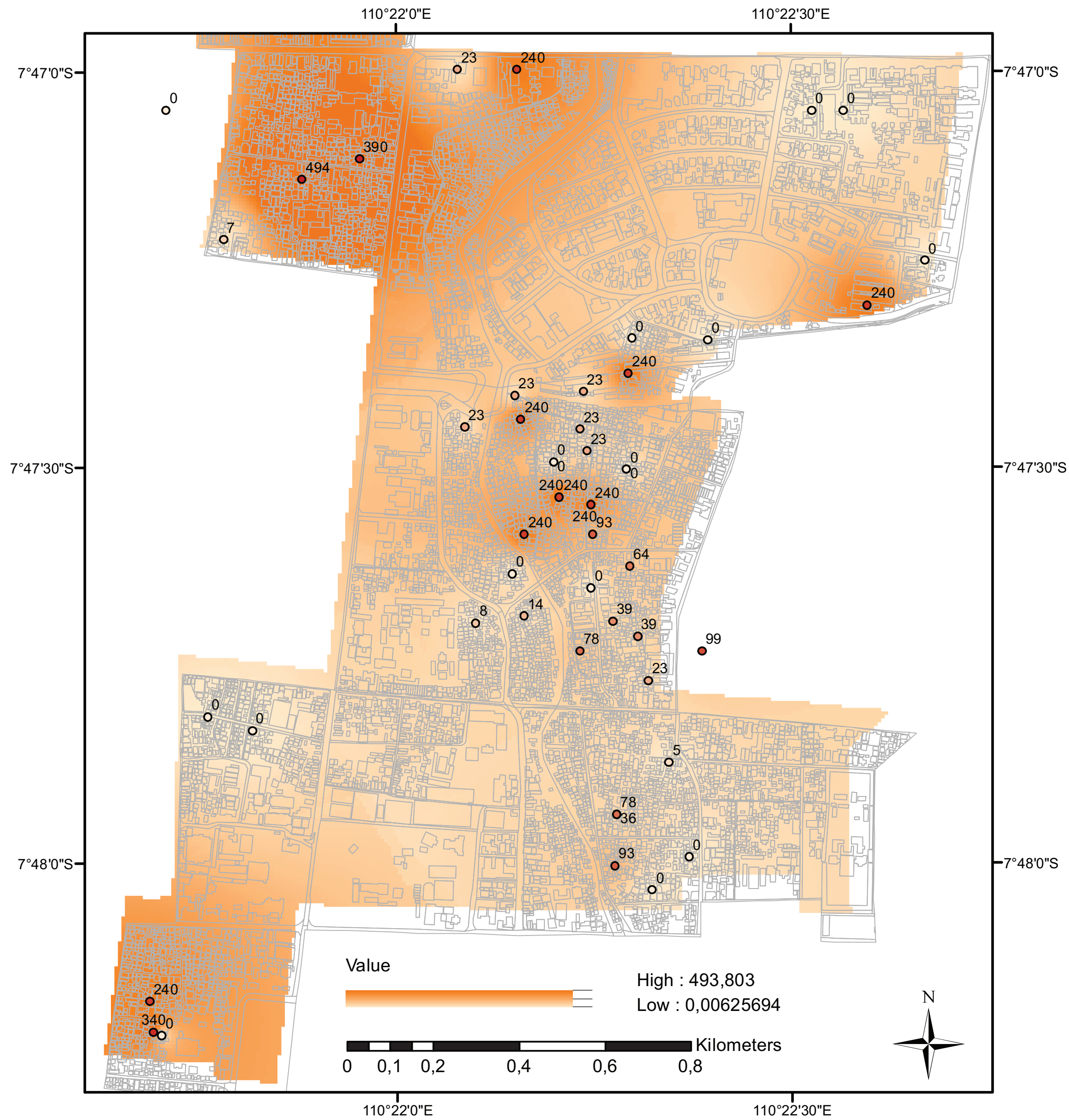

Figure 5-9 - Spatial interpolation of E.coli values without outliers

It's clearer to identify pollution distribution of earlier weaker clusters mainly at the middle and South tip. They have a relatively more thick colouring. At these earlier weak clusters (see figure 5-9) we can see higher spatial correlation of the observations when the high values of MPN have been removed. This indicates a high spatial correlation of pollution at shorter distances noting that outliers were isolated and were mainly at the edges and the middle of the study area. All the values of contamination are reflected in the figure unlike the first one where only high values are reflected with a thick colouring. We can see GW is predicted to be contaminated within the whole study area though raging from high to low contamination values.

It's better to target the whole study area for intervention.

The public health agency can target these areas with measures to stem out pollution. The measures may include relocation of shallow wells or sharing water from non - polluted wells (see 5.2.4 for the influence of sanitation system). This will probably be long term measures including and not limited to proper planning standards and public health activities. It will also involve participation of city managers to construct a reliable sewerage system and connect all the households.

5.2.4. Predicting occurrence of coliforms in GW

The expected probable causes for presence of total coliforms in GW are investigated through analysis of distance of shallow wells to septic tanks and depth of the shallow wells since they are major contaminants (Pang et al., 2004). This were singled out as likely sources of contaminant but does not imply excluding other possible explanations. A relationship between these variables was assessed using scatter plot mainly to asses outliers on SPSS (see figure 5- 10).

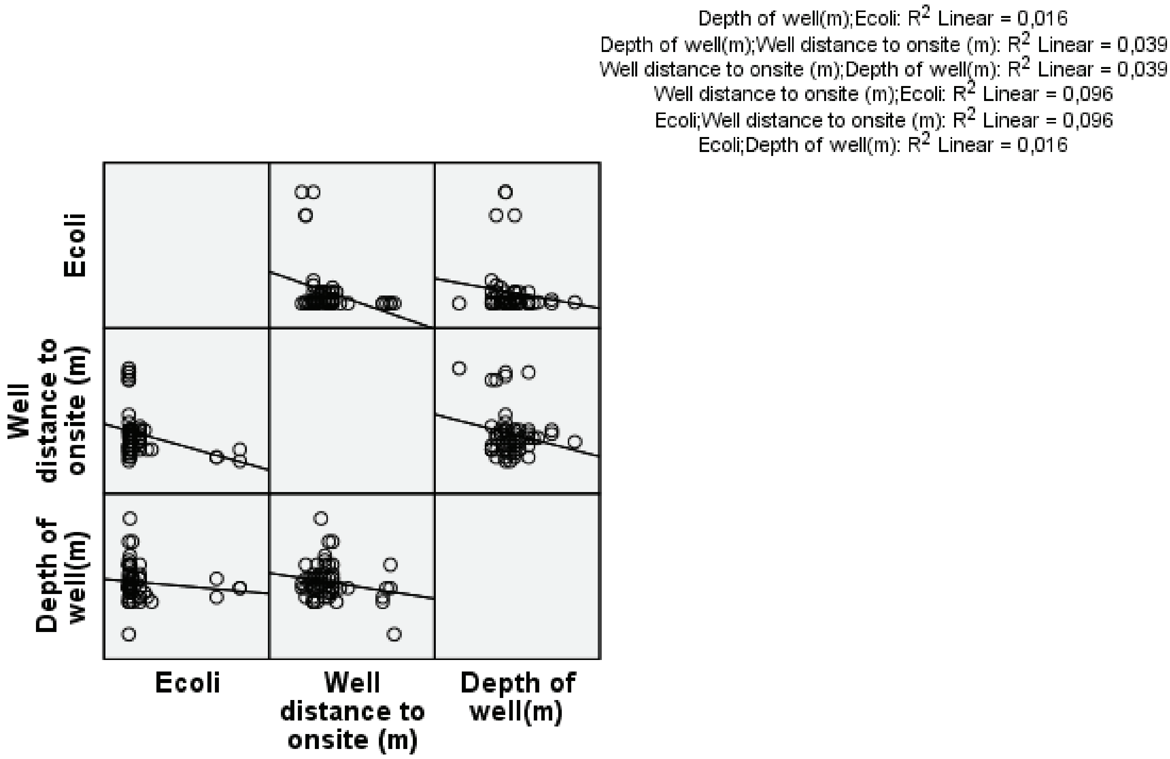

Figure 5-10 - Relationship between variables

From the observed results majority of points are within the neighbourhood of other points. The fit line is added and there is same trend in all the data whereby E.coli values are associated with well distance to onsite systems and depth of well. This can be verified by values of R^2 linear which indicate a relatively strong association between the variables, however the trends of diminishing E.coli levels with increasing distances to sanitation and increasing depth of wells is visible.

The correlation analysis was performed to see if the variables were related. The dependent variable was E.coli while the independent variables were depth of well and distance to septic tanks. The relationship of variables was expected to either be positive, negative or not related at all. A bivariate correlation was undertaken using Pearson's correlation. A two tailed test was taken since it was not possible to predict the nature of association of the variables. A matrix of the correlation of the three elements was produced using SPSS (see figure 5-11).

Correlations

		Ecoli	Well distance to onsite (m)	Depth of well(m)
Ecoli	Pearson Correlation	1	-,310*	-,126
	Sig. (2-tailed)		,021	,360
	N	55	55	55
Well distance to onsite (m)	Pearson Correlation	-,310*	1	-,198
	Sig. (2-tailed)	,021		,147
	N	55	55	55
Depth of well(m)	Pearson Correlation	-,126	-,198	1
	Sig. (2-tailed)	,360	,147	
	N	55	55	55

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

Figure 5-11 - Results of Pearson's correlation

Contamination of GW in shallow wells by E.coli is negatively related to well distance to onsite sewer system by a Pearson correlation coefficient of -.310 and the significance value is .021. The implication of this significance value is that there is a realistic relationship between contamination levels and well distance to septic tanks. In this case it means then the null hypothesis that there is no relationship is wrong.

Another thing we can read from the output is the relationship between depth of well and level of contamination. What we can see is that there is a weak inverse relationship suggested by *r* value -.126 thus an increase in depth of well imply reduction of E coli value in shallow wells GW even if with a small margin. All in all there is need to factor other causes of contamination apart from the ones assessed.

Other sources of contaminating GW in shallow wells with E.coli could be surface runoff from storm drains, activities within surrounding environment and level/condition of well protection. It's also important to assess the contamination levels at different seasons to see if seasonal variability is a factor.

5.3. Spatial variations for GW levels

The policy document requires the GW managers to undertake GW levels analysis to enhance making informed decisions on abstraction and conservation. The recharge levels for the city have been estimated (see table 4-6) but this does not point to variation in GW levels for different aquifers. The purpose of this sub chapter is to demonstrate that, indeed spatial variations of GW levels exist within the study area and its neighbourhood. Secondly is to make a proof we can use spatial analysis tools to estimate spatial units with high GW levels and use this to realise areas for potential wells. Likewise (see 2.1.5 for more in aim of SC) it can be used to develop a proper well maintenance schedule as well as estimate transmissivity of aquifers tapped by the well perforations. In this research, the former is achieved through quantitave analysis and mapping of specific capacities of eight wells within and slightly outside the study area (due to data challenges), a process further outlined in immediate sub chapter.

5.3.1. Quantifying and visualising specific capacity

The quantitative analysis of GW levels involved calculation of the specific capacity. The initial idea was to obtain parameters on deep wells which are yield in m^3/hr and drawdown in metres together with their geographic coordinates. Specific capacity obtained from parameters recorded at test pumping is the maximum amount of water that deep well can produce per m^3/m/hr. It's in very unlikely cases to get a higher value of specific capacity than initial one. This is because of physical, biological and chemical contamination which occurs to the well once in use. This has been described further in chapter 2 (see2.1.5). Specific capacity helps identify potential wells, aquifer problems, to develop a proper well maintenance schedule and to estimate transmissivity of aquifer tapped by the well perforations (Johnson, 2005). In this case the aim is to estimate GW levels used to identify potential wells for purpose of meangiful GW abstraction. The second aim is to illustrate how you can use spatial analysis tool to asses SC and use the values to help estimate a ceiling of amount of GW abstracted.

The data obtained in the field were ten points of deep wells drilled from year 2000. Two of them did not have a value for drawdown and one of them was very far outside the study area but it was included and thus only eight points were mapped. Three of these eight points were inside the study area and five were outside the study area and all are included in the analysis to demonstrate the applicability of the process with at least handful points. After calculation and mapping of specific capacity the wells inside the study area had values of 5.393258, 5.625, and 2.457545 m^3/m/hr. These points are on the West part of the city (see figure 5-12). The other four points outside the study area had values of 3.921569, 30.508475, 2.748092, 4.422604 and 10.40624 m^3/m/hr. These have two points with highest amount of water located at the same part of the city that is on South Eastern (see figure 5-12).

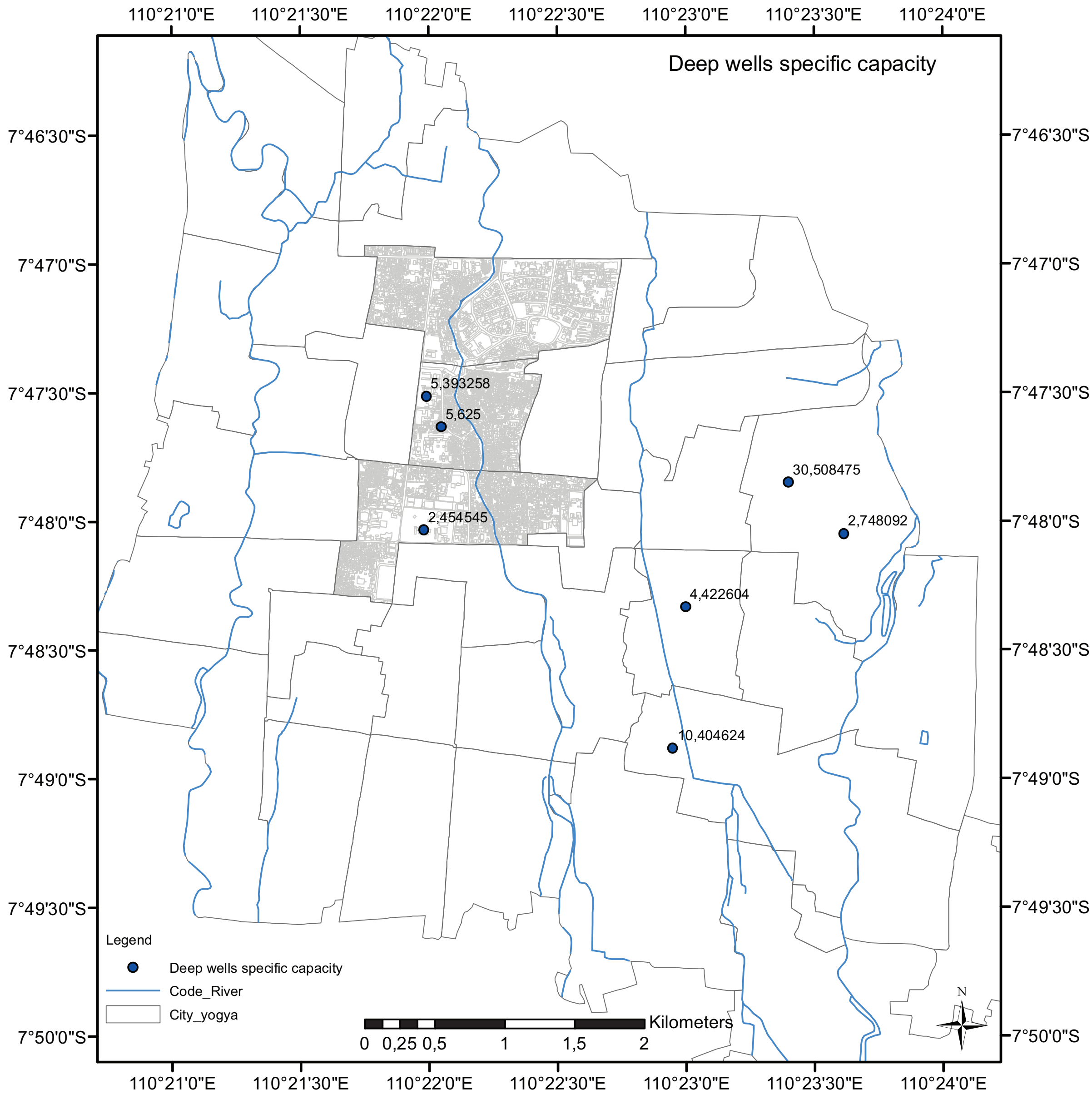

Figure 5-12 - Spatial variations of GW levels

It's clear that the South East side of the city has high potential of GW (see figure 5-12) with two wells having a specific capacity value above ten $m^3/m/hr$ and, this fact is explored further in this analysis. Note that the study area is just a portion of the entire city (as seen in figure 5-12). In order to explain the occurrence of probable pattern results of Morans I are processed, and two is the results of spatial interpolation, three is analysis of drainage pattern and four is through the description of geology of the area in reference to map 4.2 and map 4.3 which are in chapter four.

5.3.2. Spatial autocorrelation of GW levels

The procedure of spatial autocorrelation has been described earlier (see sub chapter 2.2 in chapter two and figure 5.5 in this chapter). In this case we want to identify the strength and type of SC which indicates GW level potential and patterns using Global Morans I index. Thus specific capacities are the input parameter which has been computed from yield/drawdown in $m^3/m/hr$. After the analysis in Arc GIS 10 the resultant value of Morans I is 0.24 which suggests a weak positive relation. The main challenge was data size been too small (only eight points) and a note was that the inputs number might affect the results. The solution is to increase the inputs points prior to running the analysis. Again for the purpose of analysis spatial interpolation was carried on.

5.3.3. Spatial interpolation of specific capacities

Spatial interpolation process has been discussed also (see sub chapter 2.2 in chapter two and figure 5.6 in this chapter). The purpose of performing this analysis in Arc GIS 10 using IDW is to predict values of GW levels within the study area and its neighbourhood. The process includes bringing the values of specific capacity in Arc GIS and interpolating them. The values were not picked from the entire wide study area. The resultant prediction (see map 5.4) is in line with observed GW levels variation (specific capacity values) as seen in figure 5-11.

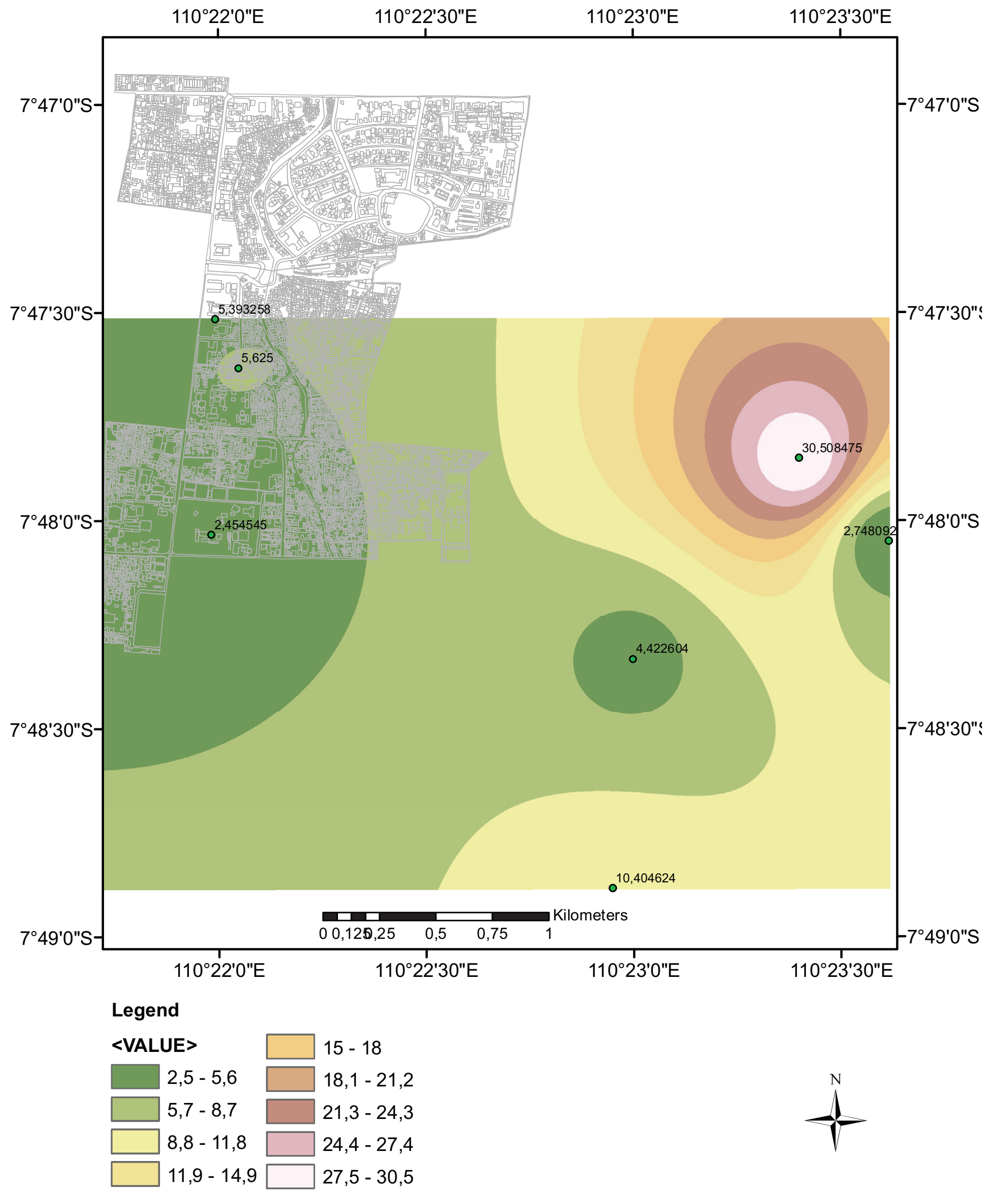

Figure 5-13 - Spatial interpolation of specific capacities

What we can see is the area of potential well(s). That is along the conduit predicted to contain large/high levels of GW and it runs along South East part of the city (see figure 5-12). Along this there are two wells which have the highest specific capacity of 30.508475 and 10.404624 $m^3/m/hr$. On the West (see figure 5-

12) part of the city there is less GW as it is demonstrated by the lower predicted values. With this observation we conclude there is likely hood (since the points were not adequate for affirmative conclusion) of more GW in South East part of the city than the West part and it follows a defined pattern. Likewise this is an area with high potential for drilling new well(s).

Factors to explain this pattern is the formation of the areas geology. As discussed in chapter 4.1.1 "The formation in Sleman is the base of formation in Yogyakarta and it consists of silt, sand, clay, gravel, volcanoclastic and big rocks. This builder materials are 20-40 m layer thick very permeable and builds Merapi aquifer which has high potential for water supply for Yogyakarta community. This aquifer spreads from North to South thus GW flow in that direction and affects the recharge process within the city".

It implies the rock along this conduit is more permeable and stores much of water. Also the flow of GW from mountain i.e. North to South is more towards the East as seen on the figure 4.2 and 4.3 in chapter four. Additionally there is change of rock formation at the bottom South East where one different rock formation is next to a different rock formation. This creates a joint running from North to South Eastern side. This is a conduit of GW seepage due to the space in between knowing well water will tend to seep along that joint. It can also be seen that different rock formation have varying amounts of GW implying each has its own level/capacity of permeability.

Another important factor is the drainage of the area whereby we see the land slopes from North to South East. This is also the direction of flow of the rivers i.e. from the Merapi mountainous area towards the city and in this case we have three rivers flowing past the city on this direction. This implies there is tendency of GW to flow from the highlands and settling at lowlands thus increasing recharge at these low areas.

Significance of this to planning is ability to allocate amount to be abstracted to users as required by the policies. This will protect overexploitation of aquifers and GW amount will be allocated according to it availability in the aquifer. It will also point to potential areas of abstraction to new investors and also assist in protection of aquifers threatened by overuse.

5.3.4. Assessing relation of drawdown with specific capacity

According to Johnson (2005), he states that higher transmissivity levels of GW are associated with more prolific aquifer and consequently low value of drawdown. Draw down in metres is recorded at initial pumping test after well construction and is the difference between water rest level and water pump level. To assess this relation the computed values of specific capacity and drawdowns are used to perform Pearson's correlation analysis. Since we are able to predict this relationship through observation in scatter matrix that SC increases with a decrease in drawdown (see figure 5-14), we use a one tailed test (see figure 5-15) to perform Pearson's correlation analysis.

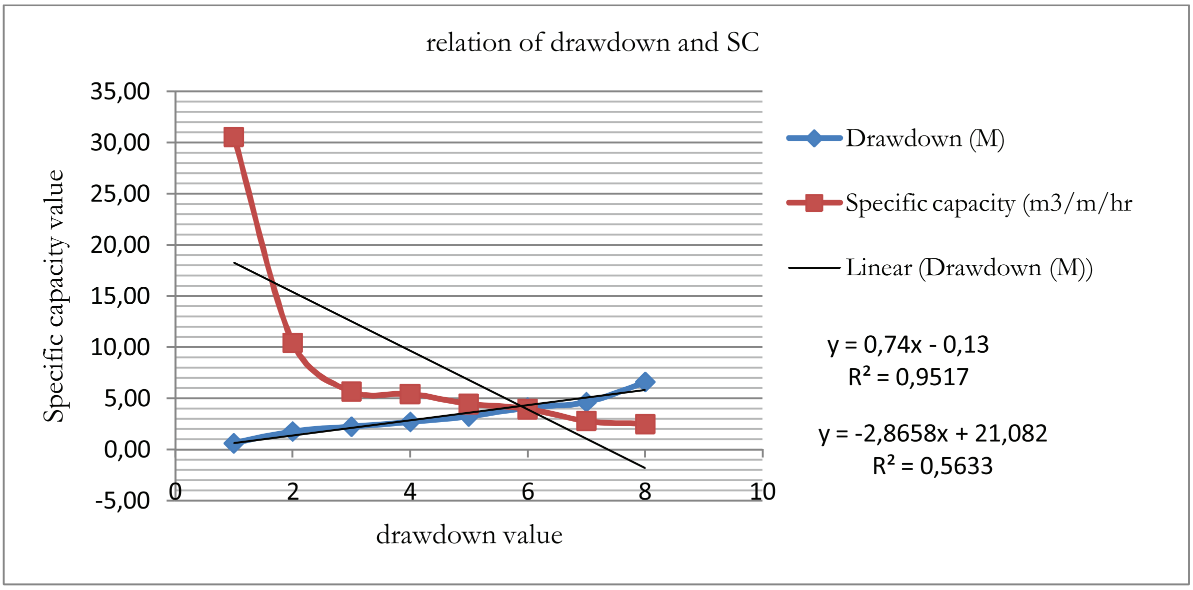

Figure 5-14 - Scatter matrix for drawdown and specific capacity

From the results of scatter matrix we realise low levels of drawdown are associated with high levels of specific capacity. This implies strong relation as seen by values of R^2 which translates to high GW levels and more prolific aquifer. This concept is clarified the more by results of Pearson correlation coefficient (see figure 5-15).

		Drawdown (M)	Specific capacity (m3/m/hr
Drawdown (M)	Pearson Correlation	1	-,723*
	Sig. (1-tailed)		,021
	N	8	8
Specific capacity (m3/m/hr	Pearson Correlation	-,723*	1
	Sig. (1-tailed)	,021	
	N	8	8

*. Correlation is significant at the 0.05 level (1-tailed).

Figure 5-15 - Results for relationship of GW levels variables

We see that drawdown is negatively related to specific capacity with a Pearson's correlation coefficient of r = -.723 and a significance value of .021. An increase in drawdown causes a decrease in specific capacity. Thus the null hypothesis that there was no relationship between these variables is rejected, and we adopt the confidence that there is a strong relationship between these variables.

5.3.5. Policy indicator - total registered GW wells for commercial activities

The aim of the GW policy for Yogyakarta city is to instil management of GW abstracted for commercial purposes through several regulations elements. Earlier on it has been explained that water abstracted for domestic use is not regulated by the policies and that all commercial wells should be registered for purpose of monitoring and regulation as discussed in the literature review. The total registered wells for commercial activities (wells for domestic use are not registered) within Yogyakarta city is five hundred and five (see figure 5 - 16). These wells are for the entire city region which has fourteen Districts. This is far above the study area but specific attention is focused on districts in which the study area is located.

Notably, the districts in which the study area is located have a total of seventeen urban villages. Out of this are the six urban villages which form the study area. The total area of the seventeen urban villages is 14.18km² and the study area villages have a total area of 3.55 km². Thus the study area is 25% of the total entire four Districts. The five Districts have one hundred and sixty two registered wells which is 32% of the total registered wells in the fourteen districts (see figure 5-16).

Though it's not possible to quantify the exact number of registered wells from this data for it's not disaggregated as we would expect it's clear that deep wells are registered by the responsible Government agency. Interview with the Ministry of Environment staff of Yogyakarta confirmed registration is a continuing process and is helpful in purpose of monthly revenue collection for GW use.

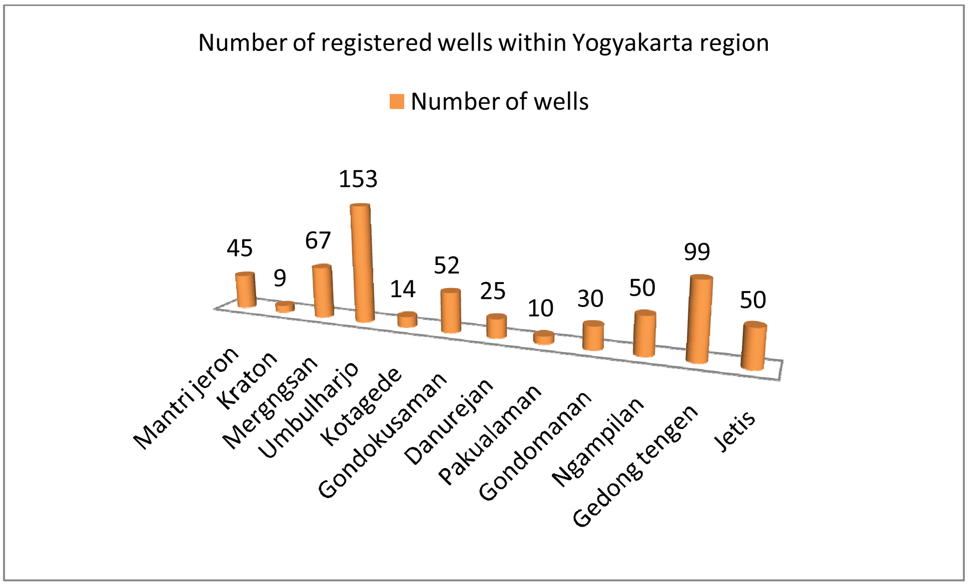

Figure 5-16 - Total number of registered wells per District

Source Ministry of Environment, Yogyakarta.

From the above figure Umbulharjo District has the highest number of the total registered wells which is 25% followed by Gedongtengen District which has 16%. The bottom three is Kraton, Pakualaman and Kotagede which have an average of 2% each. The five Districts that contain the study area urban villages amongst other villages are Jetis which have fifty registered wells(10%), Danurejan which have twenty five registered wells(5%), Gondokusaman which have fifty two wells(10), Pakualaman which have ten registered wells(2%), and Gondomanan which has thirty registered wells(6%). Policies do not detail out the number of deep wells that should be registered within an area but has a detailed and elaborative licencing procedures. Application to construct new wells is initiated by the user according to his need and thus, market forces of demand and supply creates the need for a new well. This is a loop hole that needs address.

5.3.6. Policy indicator - total registered monthly withdrawals from GW wells

In conformity with the policies the Ministry of Environment Yogyakarta has allocated each commercial user amount of water to abstract per month. This is monitored through use of water meters where users are penalised for above normal abstractions. The amount of GW abstracted in metre³ per month as noted in Ministry of Environment department in Yogyakarta city (see figure 5 -17) is for the entire city which as discussed earlier has fourteen Districts. The total registered abstraction is 52,027 m³ per month (figure 5-17 show total abstracted) in the city for commercial activities. The five Districts which contain the study area (see figure 4.6) have a total of 21260m^3 per month as registered amount abstracted which is forty percent (40%) of total registered abstraction within the city.

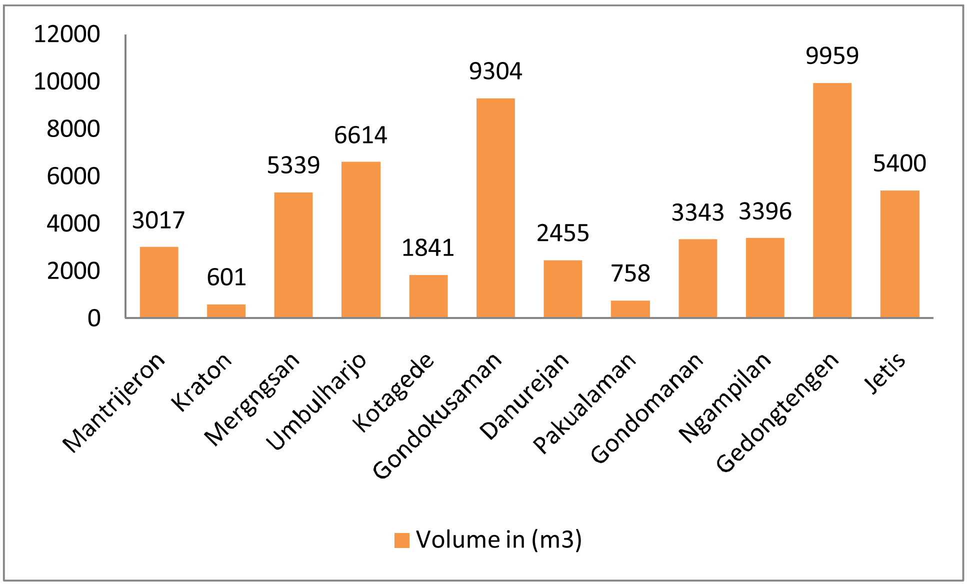

Figure 5-17 - Total registered GW abstracted per District

From the above results Gedongtengen has high abstraction levels of 19% followed by Gondokusuman 18%, and third is Umbulharjo district with 13%. The last three are Pakualaman, Kraton, and Kotagede with 1%, 1% and 4% respectively.

It can be seen that there is attempt to confirm to the policy by quantifying amount of GW abstracted to monitor trends of GW levels. Though this data is again not at disaggregated level as we would expect, it indicate efforts towards registering abstractions. Again it cannot quantify specifically the amount abstracted, registered, within the study area but it's evident that the process is carried out as intended by the law.

5.3.7. Visualising GW allocation for commercial purposes within the study area

The study area i.e. the six urban villages has an estimated number of fifty boreholes used for commercial activities. Their total allocated registered volume (see figure 5.18) allowed to be extracted per month is five hundred and seventy seven thousand m^3 (577,000m^3/month). This is higher than the total registered abstractions of the five Districts which contain the six urban villages forming the study area which is 21,260 m^3/month. Note that the comparison here is between six urban villages and the five Districts containing them due to aggregate nature of data. This means the amount allocated is far higher than the amount abstracted.

This could be so due to data mismatch or it may be true that the amount allocated is high than amount abstracted, though at different spatial scale, and would point to low demand of GW within the study area and the city.

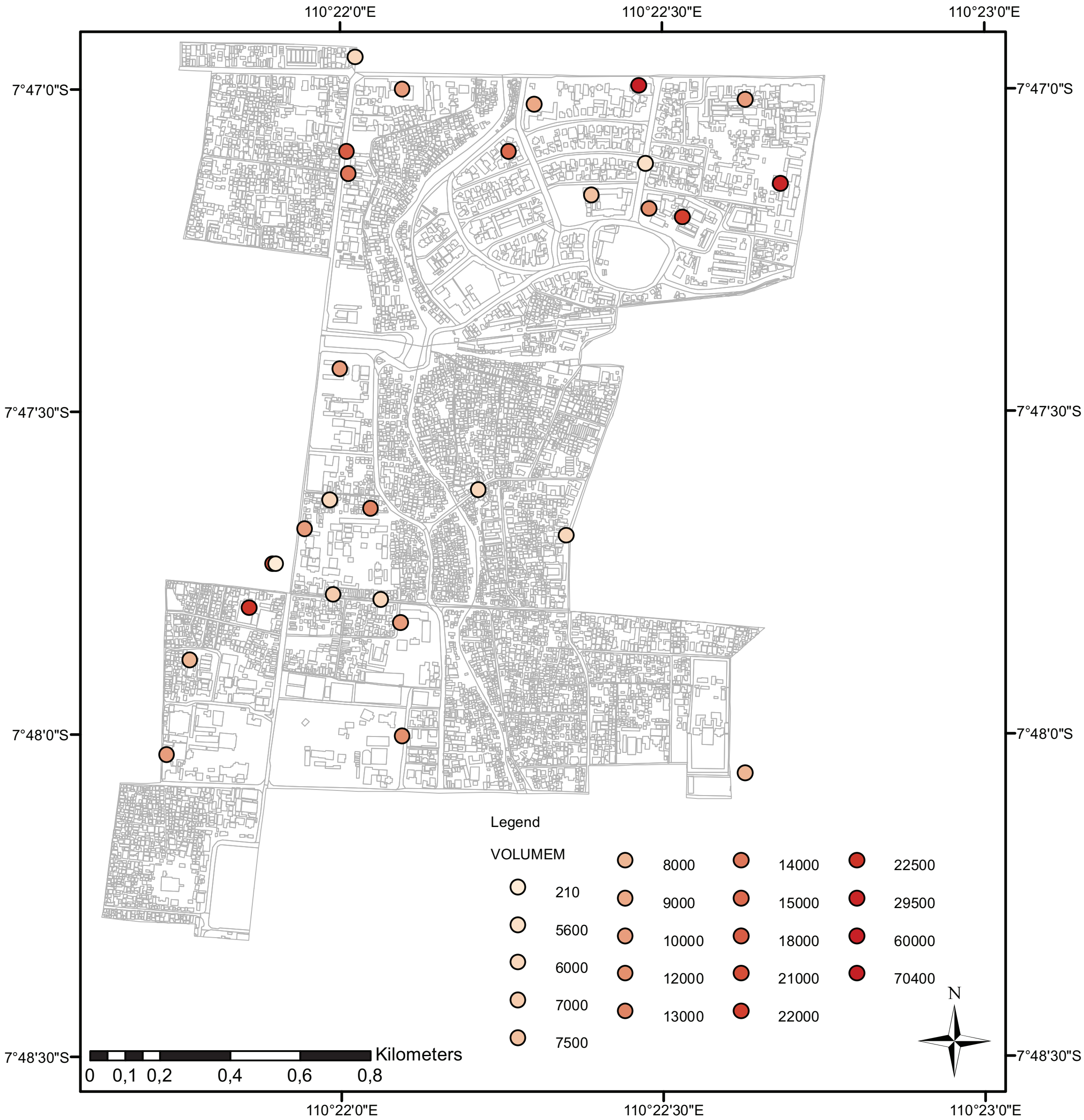

Figure 5-18 - Boreholes points and amount allocated per month

Some of the points are missing due to data problems where their coordinates were missing or not well referenced. However it can be seen that allocation of amount to be abstracted is at varying degrees. This is more influenced by ability to pay since the higher the amount allocated the more you pay. It's also determined by scale of business with small businesses opting for less allocation and large scale business goes for high allocation. Still some small businesses rely on shallow wells which have far less cost. Hardly is there a cohesive policy element to determine how much water should be allocated per well in a specific place. This is left to market forces, maybe a piece of local competent authority legislation and probably arbitrary allocations.

Efforts have been made to define a ceiling of maximum abstractions and allocations whereby the user is not allowed to abstract more than 70% of total water in that well per year. The challenge is there is little evidence to show this is the case, and whether there is constant evaluation of the ceiling in regard to SC change as it would be required in appropriate management way.

5.3.8. Policy indicator: Percentage of wells with registered abstractions within the study area

The following discussion is on survey outcome of several policy elements that are quantified to assess the success level of policies implementation. In total they are five but in addition is total amount abstracted, total registered wells and total amount allocated which are also included as measures of policy performance and are discussed earlier in 5.3.1, 5.3.2 and 5.3.3 respectively. The others are as evaluated below.

One of the key requirements by the Government of Indonesia is that all wells for commercial activities must be registered on amount abstracted as outlined in the Act (see table 3.4 and table 6.1 for policy statement). Additionally all firms involved in construction of wells must possess operating licences too. In the field it was hard to establish how many wells abstractions are registered and licenced but it's expected the total registered abstractions by Ministry of Environment are all licenced because they are known. After we conducted the survey the field assistants were able to survey and report on thirty seven wells due to vast study area and the fact that they had to search for the actual well points. This was done irrespective of whether the well was in the Ministry of Environment register or not but the few deep community wells (a number of community wells are shallow wells) were not included. The aim was to find out the percentage of wells with registered abstractions (see figure5.19).

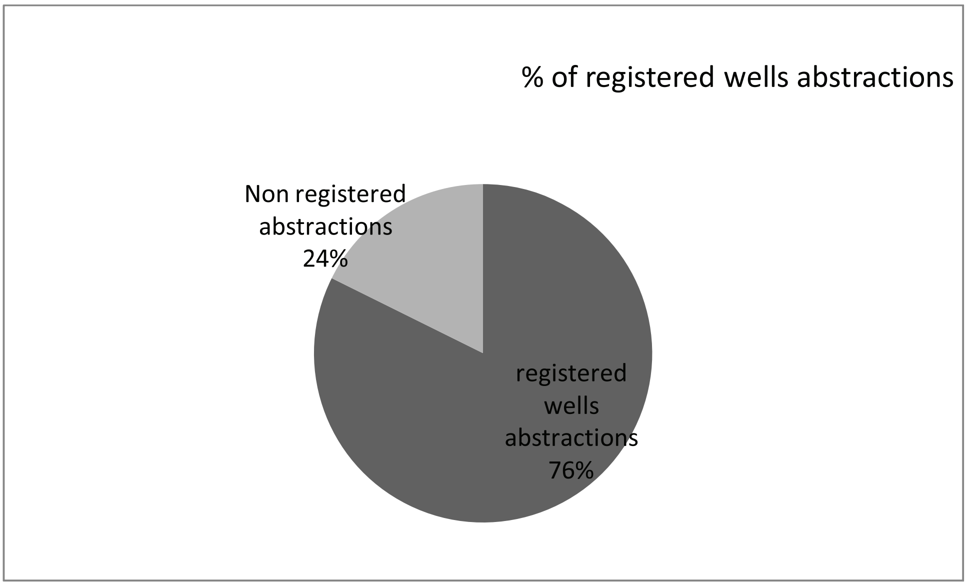

Figure 5-19 - Percentage of GW registered wells within the study area

From the above figures seventy six percent of the wells found with registered abstraction while twenty four are not. The authority expects policy implementation to be a hundred percent success. The reasons behind disparities in success of this and other policy elements will be expounded on later in chapter six, but briefly this is an indication of discordant and need for correction measures. To solve this there need a thorough assessment with cooperation of the community to bring all deep wells to book. Additionally this reveals a need for thorough targeting of all wells through a count.

5.3.9. Policy indicator: Percentage of permit holders metering abstractions

The aim of measuring the percentage of permit holders metering abstractions was to find the number of permit holder's metering abstractions within the study area to see if all users have meters as required by the policies(see table 3.4 and table 6.1 for policy statement). A field survey within the study area to identify how many deep commercial wells meter abstractions was carried out. This was to assess policy compliance as intended by the regulations. It's expected and intended that this is a cost generating element and at the same time is one way of prudent management since it boosts sustainable use. The user will consider cost factor and thus try to limit the amount of GW abstracted as much he can. From the results of the survey commercial GW users found to have installed water meters were sixty nine percent and those who have not installed water meters were thirty one percent (see figure 5.20).

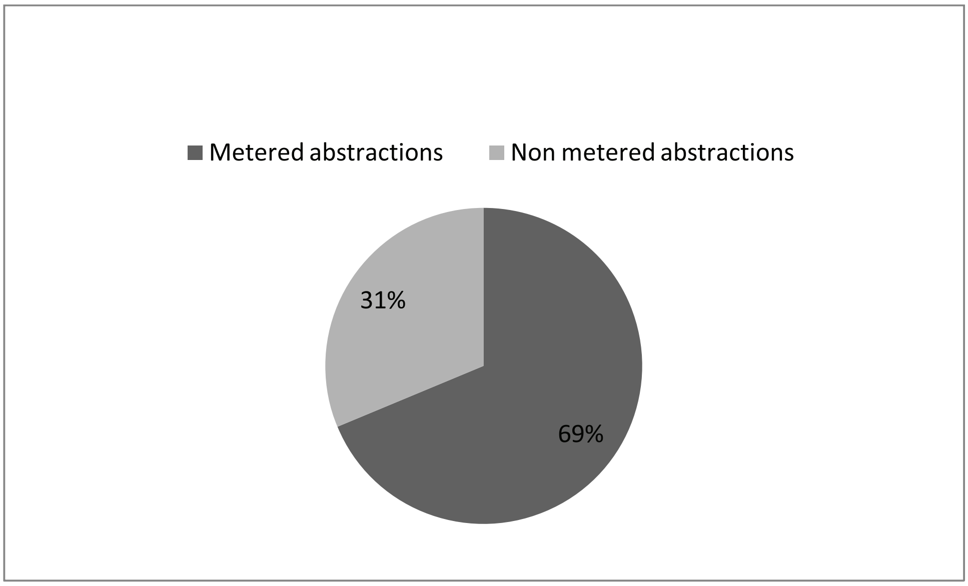

Figure 5-20 - Percentage of permit holders metering abstractions

The values are different from that of commercial GW users having registered abstraction wells. These values are an indication of laxity in implementation of the policies by the competent authority which can be explained by several factors as it will emerge in chapter six. All in all probable explanatory cause would be staff size and motivation for officers mandated with policy implementation. A small working force might not be able to regulate construction of wells for the entire area and less motivated work force can compromise. It's very paramount to involve the community especially to police illegal construction of wells since this happen in their back yard. A hotline can be established for this purpose of reporting any suspicious activity connected with GW.

5.3.10. Policy Indicator: Number of reported abstraction points with and without licence

This element is used to identify if the points metering abstraction matches with licenced points and if they are as stipulated in the policies (see table 3.4 and 6.1 for policy statement). Licences are issued before construction of the well by the office of the Mayor in collaboration with Governors office and relevant line ministries. The licence is mainly issued for five years but in some cases it can be issued for more years but up to fifteen years. Analysis of field data show licenced points within the study area are eighty two percent and unlicensed points are eighteen percent (see figure 5.21)

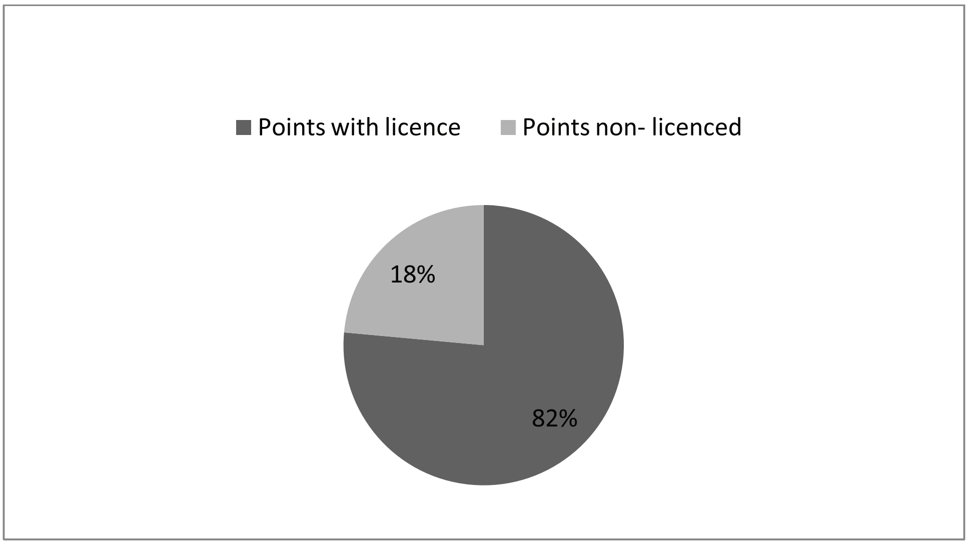

Figure 5-21 - Number of reported abstraction points with and without licence

From the analysis of the field data all the three figures differ and have unique percentages from one another and thus a single reason cannot be used to explain the dissimilarity. One thing in common they point to is need for meticulous implementation of different pieces of policies. Coordinated efforts by the various departments can easily provide remedies to these varying levels of policy elements success. It's also worth noting these pieces of legislation are key in revenue collection from GW and thus they are more and often addressed as well as continuous implementation by the competent authorities. They are also a measure of staff performance and thus implemented in a more serious manner.

Besides these there are other policy issues like management of GW data that are not prioritised much. This can be due to complexity associated with their operationalisation like need for up-to-date technical skills and sometimes high budget. Last is a note on the data required to assess revenue collected. This was not available due to institutional secrecy, wrong documentation and storage or for other institutional reasons.

5.3.11. Policy Indicator: Number of recharge wells within buildings

It has been found out that the level of demand outstrip GW recharge in the Yogyakarta region (see figure 4.2). This can reduce the GW levels to less alarming quantities and not attractive for long term supply of GW. To manage the same it's mandatory for every new building in the city to provide room for artificial GW recharge well. From interview held with owners of different buildings within the study area it emerged that recharge wells as intended in the law are hardly constructed.

This policy element is a recent declaration and it's after many years of city development. Thus a large percentage of city space is built up and no recent constructions have been carried out on a large scale. This could have provided a room for recharge wells construction. Nevertheless if this policy is well implemented a significant number of property owners can likely adhere to the regulation thus increasing the rate of GW recharge in the study area and city as whole. The best forum to address implementation of this would be through approval of building plans by ensuring that the recharge well is included in the building plans before commencing construction.

5.3.12. Policy Indicator: Number of monitoring wells within the study area

Another policy requirement is construction of monitoring wells to be used in measuring/monitoring changes in GW table. This shows either an increase or a decrease of GW at varying seasons and assists in making decisions as pertaining the construction of new wells. The recommended standard is one monitoring well per 1km^2. The study area has one monitoring well in the compound of Environmental ministry. Its total area is approximately 2.13km^2 (see table 4.1 for study area size) and thus there is a shortage of one monitoring well.

This implies need to sink one more monitoring well. The shortage could be associated to financing and lack of land rights within the study area. As such actual monitoring of water table in the area is not evaluated at the whole of the study area. In absence of monitoring wells a reliable indicator is number of dry wells whether deep or shallow. This is coupled with increasing depth of deep wells which can also be associated with other indicators.

Within the area there was no reported case of dry wells whether deep or shallow or a significant increase in depth. In fact no one in the survey indicated having to drill deeper to abstract the GW.

5.4. Key policy elements missing in the document

At this juncture we have realised the results of some policy elements used to manage GW within the study area. We have also realised the pattern of GW levels and quality variation by analysis of different pieces of data. The following discussion is on identifying key pieces of policy not included in the document and explaining their importance and contribution they can make to GW management within the Yogyakarta region. Also for a reminder the study area does not have policy document or elements to manage GW from shallow wells.

5.4.1. Setting maximum admissible drawdown

First and foremost there is no maximum admissible drawdown defined in the policy document. Drawdown is used to indicate GW levels and is recorded at initial pumping test. It's recommended that pumping test should be undertaken semi-annually to estimate level of well performance. This means keeping a record of drawdown twice a year. It's also recommended that if drawdown fall by twenty five percent that well should be cleaned.

As discussed in 2.1.4 'drawdowns is related to aquifer whereas aquifer is an underground formation that holds a large amount of water. There is a very slow movement of water through aquifers such that over pumping from wells can cause a long term cone shaped depression in the GW level called drawdown (University of Wisconsin, 2010).
The impacts of large drawdowns (long term drops in GW levels) are decline in water levels for wells, streams and wetlands (or they dry up completely). Additionally it led to increase of arsenic, radium and salinity in drinking water due to wells been drilled deeper (University of Wisconsin, 2010). The entire drying up or reduced flows of this water sources can critically affect habitats for many birds fish and mammals".

It's prudent to stop further abstraction if drawdown falls below a particular level. For instance if the initial drawdown was 2m and then after few years it falls below 6m which is 100% may be it is in order to start conservation measures and stop further abstraction. This guideline is missing in the document and is very crucial.

5.4.2. Setting a ceiling on amount of GW that can be abstracted and density of wells

Results of specific capacity should guide the managers on capping the amount that can be abstracted per well. This implies allocating number of pumping hours in a day and amount that can be abstracted in a period between one pumping tests to the other. This should go hand in hand with semi – annual evaluation of specific capacity. Likewise studies should be carried to find the 'carrying capacity' per 1km^2 to avoid over construction of wells. This in result leads to over abstraction and misuse of GW resource.

Though users are allocated amount they can abstract it's mainly based on their requests depending on the nature of use, it's also based on the amount they are able to pay but they are not allowed to abstract more than seventy percent. the challenge is with this ceiling of seventy percent is that it's not evaluated annually or semi-annually depending on realised decline in GW levels.

5.4.3. Establishing density of monitoring wells per area

Monitoring wells are used for purposes of monitoring the quality and quantity of GW (Gonz, Lez, & Sankaran, 1997). According to (Gonz, et al., 1997) the purpose of monitoring wells is to collect geologic, hydrologic(depth of the water table, aquifer characteristics, e.t.c) and chemical data on soil and water and also provides a room for long term monitoring capabilities. These wells can be drilled by the state, landlords or tenants and their depth must go beyond mean seasonal high and low water table.

In this discussion it's important to advice the study area managers to identify the suitable number of monitoring wells within a particular radius. For instance the ratio can be one monitoring well per one km^2.policy within the area have not defined this relation though it states the need for monitoring well. This has also been complied with to a fifty percent level and they need to further develop it.

5.4.4. Formulating policy document to manage shallow wells

Time and again this piece has been mentioned as not given any attention within the existing policy document. At the beginning of chapter five it was demonstrated that alot of residents rely on GW from shallow wells for their day to day need. In spite of this policy document has no clauses on management and regulation of the same. There is need to develop articles on this issue to ensure safety of the users and sustainable use of the resource.

5.4.5. Control data from well drillers

The current policy document requires deep well construction work to be undertaken only by licenced drillers. Likewise, qualifications for registration to undertake construction is submitted to meeting set criteria. This has been implemented as it was realised in process of interviews in the field. However this element need to be strengthened further by ensuring that the well drillers submit all the necessary data of any construction work they undertake to government agency. As it is now this concern is not a requirement and if implemented it will aid data management and monitoring of related well activities.

6. DISCUSSION OF THE FINDINGS

The main purpose of this chapter is discussion of the findings realized in chapter five. The discussion begins with integrating policies and results of quality and quantity variability by developing a table that identifies various GW policies. This is followed by a discussion on analysis of GW pollution by E.coli and likely contaminant sources. Then an explanation is given on results of GW levels spatial variation, allocation and abstraction to inform in policy decisions. Lastly the quantitative indicators derived from policy elements are discussed one by one and reasons advanced as to why there is varying degree in their success.

6.1. Preliminary

Significant economic consequences can be realized from GW protection policies by commercial users and communities (Abdalla, 1994). Various benefits are obtained from GW protection as outlined by the author. The first is damage avoided by GW contamination on human health effects which causes high morbidity or mortality rates. The second is fear and anxiety in the community caused by contamination of community wells. The third is ecological damage and loss of recreational use and the last is the loss of source of drinking supply.

Various articles have focused on the study of GW as a source of drinking water, however, knowledge on protection policies to boost economic value of GW is limited (Abdalla, 1994). A laxity in policies can contribute to problems like over abstraction, over allocation, contamination, low revenue generation, and uncertainty over GW ownership which encourages misuse.

In many countries the state is responsible for drafting legislations. Some of the legislations are not measurable and that poses the question why have them. Similarly, existing studies model quality and quantity of GW with less examining how the two relates to policies. This work is providing knowledge of evaluating the performance of policies towards overall management of GW resource and making recommendations on policies.

Additionally this research has concentrated on measuring policy performance since this evaluates the effectiveness in satisfying the objectives of GW management, conservation and sustainable use. This was assessed through linking two elements which are GW quality and GW levels to policy performance, though it's a difficult course to discuss the two main elements i.e. variation in quality and quantity to policies without isolating any one of them.

Analysis in chapter five however has tried to integrate this, and this chapter develops a greater link to the two. Issues emerging relating to policy are disparities in their degree of success. The element assessed can be classified in to two, those group of policy related with revenue collection like GW licencing and thus revenue generating and management elements, and those which need a high budget and scientific skills to implement thus cost incurring elements for instance requirement to have GW monitoring wells.

6.2. GW quality results

6.2.1. Consequence of E.coli in GW

A fast check on quality indicates contamination of the GW by total coliforms at varying values in each location. From the sample tested thirty one percent of the wells are not contaminated while the rest are contaminated. The E.coli is an indicator of possible presence of water borne disease causing microorganisms which are a cause of concern to human health. Policies dictate that for water to be potable it must be free of E.coli at all times. This implies raw GW from sixty nine percent of wells within the study area is contaminated and not appropriate for drinking without treatment. The expected standards as outlined by WHO and study area policy (see table 3-6) states drinking water whether from GW or piped water should not be contaminated at all. It should be 0MPN/100ml sample. With this it's clear there need intervention measures to address the deviation.

Results of scatter matrix indicate a relationship between well depth, distance to septic tanks and E.coli levels. This is further enforced by observation of Pearson's correlation coefficient of *r* -.310 between E.coli and well distance to septic tank thus accounting for about 31% of the total coliforms. These results were significant at .021. The Pearson's correlation coefficient of *r* value for E.coli and depth of wells was -.126 thus explaining 12% of total coliforms and results were not significant. This calls for analysis of other probable causes of pollution like well protection, surface runoff, and seasonal variability.

The 0.23 value of Morans I indicates spatial correlation is positive between GW sample points in relation to the total coliform observed. With this value of Morans I it implies the relationship is relatively strong. It also indicates that the observations are relatively correlated and thus their occurrence has no defined pattern as we thought would have been the case but by chance/ random. In the figure 5-8, three spatial clusters of total coliforms in GW are identified by Morans I. These clusters have thick colouring unlike the other points which have low correlation and indicated by thin colours.

We also see other high values but having low correlation. If spatial analysis could have been performed at local level there would have been strong correlation for this observation. But due to the little number of input points it's not viable to take such an analysis. From this result of visual observation and from further analysis with no outliers, we realise that the vast study area has an effect on output of spatial autocorrelation and interpolation on strength of correlation, and that the test works well at small distances.

Argument by Seattle & King County (2010), gives reasons for contamination of shallow wells. The author argues that since shallow wells penetrate aquifers that are near the ground surface, it's possible for them to be polluted by leachate, sewers, chemicals or onsite sanitation systems. Additionally surface water runoff and rainfall such as acidic rainfall can deposit pollutants in shallow aquifers or directly in the well (Seattle & KingCounty, 2010).

Likewise, the author cites characteristics of a poorly protected well which are, being located within 100ft of pollution sources, not sloped against flow of surface water runoff, poorly sealed, and pumping equipments and well head not protected. On the other hand properly protected wells is not within 100ft from contamination source and well protected from direct pollution amongst other things (Seattle & KingCounty, 2010).

Likewise, Salendu (2010) states that, contamination of shallow well water within some part of the study area i.e. along the river is due to short distance between the GW points from onsite sanitation systems like septic tanks and the shallow depth of wells. This coupled by the fact that residents do not clean their wells can be a serious concern to Ministry of public health.

More so, there are possible risks associated with contamination of water by E.coli bacteria which include diarrhoea sickness. People can recover fully from this though they remain weak but some people can develop a form of kidney failure called Haemolytic Uremic syndrome (HUS) which can consequently led to serious kidney damage and even death especially in young children and the elderly (Clark, 2011).

On the other hand perception of people on quality has a bias since it gives the quality a thumb up which is not the case. The inaccurate judgment could be as a result of adaptive use of GW or since there is a tendency of wide belief that GW is naturally clean all people think so (bandwagon effect). This makes it important to create awareness on possible risks associated with GW use to change the perception that it's pure in all cases as expected.

6.2.2. Spatial variation of GW levels

The objective of having GW levels analysis was to identify areas of potential well i.e. predict spatial units with high and low levels of GW to be used by management in decision making. According to Johnson (2005), specific capacity (SC) can be used to identify potential well. The author notes SC can also be used to estimate the transmissivity of the aquifer(s) tapped by the well perforations. Johnson notes transmissivity is the rate water is transmitted through the aquifer and the higher it is the more prolific is the aquifer and less the drawdown recorded.

From the data the following values of drawdown were computed and recorded (see table 6-1)

Drawdown (M)	**Specific capacity (m3/m/hr**
0.59	30.508475
1.73	10.40624
2.2	5.625
2.67	5.393258
3.2	4.422604
4.07	3.921569
4.59	2.748092
6.55	2.457545

Table 6-1 - Values of drawdown and specific capacity

What we can see is that an increase in drawdown value is causing a decrease in specific capacity and this justifies the literature of Johnson (2005) that less drawdown is associated with more prolific aquifers.

The 0.24 value of Moran I indicate that levels of GW assessed are correlated with specific capacity though the relationship is relatively strong. This weak relationship can be explained by the vast study area in relation to only eight samples used as input. It's expected a stronger relation would have been the output if more than thirty points of specific capacity were used. Pearson's correlation coefficient of *r* was -.723 and was significant 0.05 level. This was a one tailed test and from it we can learn that there is a strong relationship between drawdown and SC. Results of scatter matrix indicate a strong relation between drawdown and SC as seen by results of R^2 linear.

Spatial units predicted to have high levels of GW have less drawdown and thus high capacity. The spatial area is seen as a long conduit along South East of the city (see figure 5-12) and is indicated by a pale white colouring. The rest of spatial areas have almost similar GW levels and are indicated by green colouring (see figure 5-12).

The significance of the results is that there is spatial variability of GW levels and spatial analysis is one method of assessing them. Through this process, spatial units of high GW levels can be identified and the city managers can use this output for conservation, allocation and regulation of GW abstraction within an area. They can also allocate new wells along areas of high GW levels.

6.2.3. Analysing results of GW abstraction and allocation.

From the earlier results of GW amount allocated within the study area, the indications are that they are high than amount abstracted by the users. This could be caused by, one, low demand of GW for commercial use by the fact that the city has no major industries to warrant high demand. Two is that since a lot of water is abstracted for domestic use satisfaction of the supply is met at domestic level. This means institutions would rather depend on shallow wells than deep wells. It's also expensive to construct a deep well as compared to a shallow well.

Likewise, it is possible that the amount allocated is always high than required due to lack of proper asses of demand or, the wells do not produce the expected yield so that the volume cannot be achieved. The last explanatory factor could be, there is failure to register accurately the amount abstracted for commercial use. The policy goal is to have all specific volume allocation registered in publicly accessible water register which is not the case. They must be enforceable too and based on knowledge of GW levels.

There is general indication that there is no over abstraction as evidenced by continuous performance of wells, high allocation than demand, and no case of dry well was reported. On the other hand there lacks set criteria of determining allocations. This implies allocation is based on ability to pay but not on the analysis of GW levels.

6.2.4. Analysing results of policy indicators

Various indicators used to measure the policies have varying degrees of success. The indicators that were used are percentage of registered wells abstraction, factor of E.coli in sampled water, GW user perception on colour, odour and taste, volume abstracted per year, and percentage of abstraction points with and without licence. Others include percentage number of recharge wells in the study area, total volume allocated in million m^3, percentage of permit holders metering abstractions, discussion on data needed for GW management and percentage of permit holders paying user fee per month.

A reason as to why the above indicators were chosen is ability to quantify the outcome of their operationalisation in numbers/percentage. Their outcome also reflects on performance of competent authority in GW management. Additionally it would be possible to gather data since they are issues of day to day concern and reflects on the level of GW use. The last reason is ability to assess within the given field time.

The table below summarises the results of several indicators and points out the policy elements associated to that indicator (see table 6.1). Later on these Indicators are discussed one by one as read from 6.2.4.

Policy Act	Result
Overall policy objective - to register all commercial wells as seen in these articles. Article 1 part 7 "GW management is an effort to plan, implement, monitor, evaluate implementation of GW conservation, efficient use of GW and control the destructive forces of GW", part 15 right to use water from GW is right to obtain and use GW and part 17 permit to use GW is a licence to obtain rights to use water from GW utilization. Indicator***: percentage of registered abstraction wells***	The percentage of registered abstraction wells is seventy six percent as seen in 5.19
Overall policy objective; protect GW contamination as described by this articles. Article 36 "monitoring of GW aims is to determine changes in the quantity, quality and or GW	From the total sample tested 31% was not contaminated by

environments. monitoring include (a) measure and record the position of GW (b) examine the physical, chemical contents, biological or radioactive material in GW Article 45 – Managing GW quality include (i) preventing GW contamination (ii) addressing GW contamination (iii) restoring GW quality that has been contaminated. Indicator used (i): ***factor of E.coli in sampled wells.*** Indicator (ii): ***GW user perception on colour, odour and taste***.	E.coli. The rest had contamination values raging from 17MPN/100ml to 2400MPN/100ml. 99% of GW users reported no colour and 98% said the GW has no taste and odour.
Overall policy objective; control abstraction levels – indicator: ***volume abstracted per year***	The levels abstracted are less than allocated though this comparison is drawn from analysis at different level of spatial units. Volume abstracted is at district level while volume allocated is for study area only.
Overall objective – GW licencing. Article 54 - use of GW is intended to meet basic needs day to day agricultural people and not business activities. For agricultural it's only when surface water is inadequate. For business permit has to be given by Mayor/Governor to individuals, cooperate business, government or social organizations. Indicator: ***percentage of reported abstraction points with and without licence***	The percentage of reported abstraction points with licence is eighty two percent and eighteen percent of the commercial wells have no licence.
Overall policy objective – to boost GW recharge. Article 43 part one aim to increase capacity of GW recharge by amount of surface water through artificial recharge Article 61 to prevent/cope with saltwater intrusion and reduce declining of GW, buildings should have recharge wells. Indicator: ***percentage number of recharge wells in the study area***.	There is hardly any recharge wells within the buildings.
Overall policy objective – to control amount allocated per user. This is supported by Article 60 which states the minister has authority to set the allocation of GW. Indicator – ***total volume allocated in million m3***	-Total volume allocated is 255, 125m3 per year.

Article 77 part (b) each permit holder must install water meter at each production well (c) pay management fee Indicator – ***percentage of permit holders metering abstractions***	Percentage of permit holders metering abstractions is sixty nine (see figure 5-20).
Overall policy objective – GW data management. Article 1 part8 "inventory of GW is an activity for obtaining data and information on GW" Article 21 part 3 inventory of GW include mapping investigation, research exploration and evaluation of data. Article 80 and 81 is about management of data through data collection, storage, processing, renewal and publication and dissemination of data and information. GW information is referred to as part of network information managed in central management data at the national, provincial, and district/city levels. It includes conservation, utilization, monitoring Indicator – ***discussion on data needed for GW management***	Much of data needed was missing and there was mismatch on some of available one like number of deep wells in the study area. Therefore this policy objective could not be validated.
Overall objective – Cost recovery. Article 84 mention the source of fund for GW management part of it to be user fee from the GW permit holder implying all permit holders must pay fee. Indicator – ***Percentage of permit holders paying user fee per month***	Data not available.

Table 6-2 - GW policy results

6.2.5. Discussing results of other policy indicators

As it was noticed earlier in the discussion the study area population relies heavily on GW source (64%) compared to PDAM (36%) see figure 5.1. For this reason there has to be prudent management for GW resource. Management should guide conservation, efficient use, damage control and proper information compiling. In success cases management develops plans where GW has been developed or plans for areas with potential to be developed. They also outline local management rules on how GW will be shared in time of shortage. In case a minimum limit of abstraction has been achieved the area is declared a protection area.

To begin with the seventy six percent of the registered abstractions wells implies that out of thirty seven interviews conducted twenty eight of the wells were found registered with the Ministry of Environment. The information did not involve public water supply wells like from PDAM and community wells. This was in order to concentrate on commercial deep wells since shallow wells are not regulated by policy and thus they cannot measure policy performance. The success is attributed to revenues generated by implementing this piece and related ones like meter installation. On the other hand one has to meet all necessary approvals from the governor and the mayor and identify a licenced driller to be allowed to construct a well. It's challenging that this data cannot be accessed online and thus a major challenge to the office.

From the total sampled wells it was found that not all of them were licenced as expected. Thirty wells had licences and seven of the wells were not licenced. The policy aim is to manage access to the GW aquifer and it states that any person who constructs groundwater borehole must obtain licence before construction. This also minimises over extraction by limiting users. Apparently, it's an offence to operate a borehole without a licence. The offence attracts both fine and a jail term. One can only be licenced if he has adequate prove to engage a licenced driller to drill and construct the borehole. In this case a site plan is required. In addition the user is supposed to pay necessary fees to the government agencies to obtain the licence which has stipulated conditions. The licence is given for a period of five years but in some cases it can be issued for fifteen years. After this period expires the licence is supposed to be renewed otherwise it becomes illegal to use GW.

Before drilling the conditions are read by both the driller and user to understand them well. If in the process of operating the borehole, you fail to adhere to the conditions, your licence can be cancelled and fined. Some of these conditions involve amount allocated to abstract per month and the use for example commercial or irrigation purposes. Amount allocated is sometimes in hours allowed to pump per day. The margin of success indicates illegal boreholes within the area either due to long time construction before policies were repealed, inept administration, expired licences or vested interests.

All reasons and purposes requiring GW licence must be metered. Installing water meters is a policy for Indonesia Government at large. The aim is to improve management of the GW resources in a fair equitable and sustainable manner. To avoid meter alterations the department of Environment is mandated with fixing the meter at users cost but the meter is their property. Meters are used to monitor amount use and for calculating monthly charges including penalties in cases of overuse. Sixty nine percent of wells are metered within the study area and this undermines revenue generation as well as encouraging unsustainable use. Laxity in policy implementation could explain the failure or vested interests.

6.2.6. Reasons towards varying degrees of policy implementation success

Various reasons explain why the policies evaluation indicates a different success rate. A major challenging issue is coordination of management of GW by different departments in Ministry of public works, Environment, Water, office of the Mayor, and Governor. These offices are mandated by the law to regulate and monitor use of GW. The fact that this cannot be achieved at one Ministry creates unnecessary bureaucracy which needs address. The below diagram is a flow of the various departments involved in GW wells approval and management within Yogyakarta city (see figure 6.1).

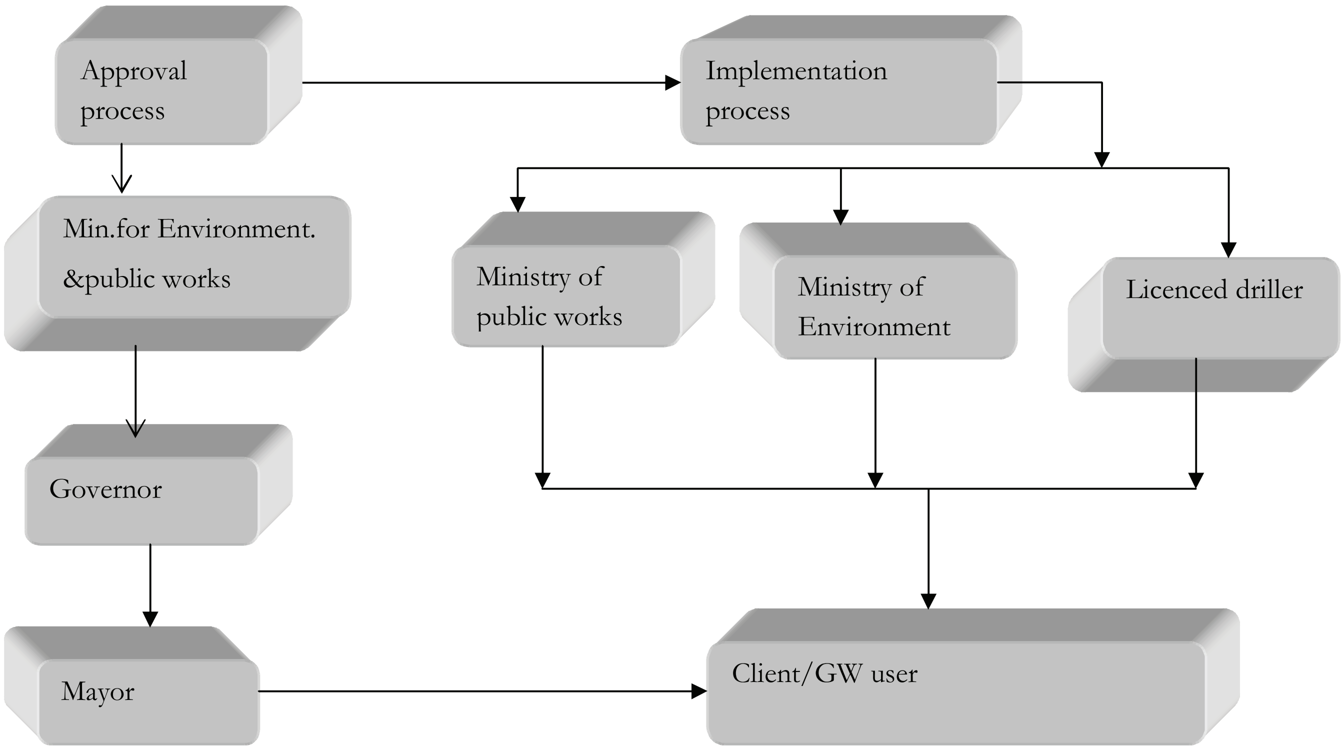

Figure 6-1 - Flow chart of boreholes approval process

Source is own creation as surveyed in field.

The process is disjointed as evidenced in process of data collection. The departments are challenged by documenting GW management data as required by the act ("Article 80 and 81 is about management of data through data collection, storage, processing, renewal and publication and dissemination of data and information. GW information is referred to as part of network information managed in central management data at the national, provincial, and district/city levels. It includes conservation, utilization, monitoring").

With this it becomes difficult to monitor various activities like payment of taxes and user fee, renewal or cancellation of licences, GW levels, and GW quality to expected standards. Where some departments have this data it's not the same, each department has different values. For instance experts at provincial level has mapped eighty wells but Environment department has the number far less than that within the study area i.e. fifty wells.

There is need to establish a centralized department aimed at data collection and processing like the case with Asmara regency. All the parameters for GW quality and quantity are well documented and shared online. It's easier to implement all monitoring strategies mainly licencing and installation of meters when you have up-to-date, detailed information. Additionally allocation of GW amount to be extracted and licensing new wells get based on fact but not arbitrary. With good data system the department can adequately monitor the depth of water table, salinity of GW, GW contamination and water levels to enhance conservation and protection measures. This can go hand in hand with appropriate implementation of planning standards in the city built up environment to prevent GW contamination.

Another cause of low performance could be failure to include the community in GW management. The University of Gadjah Mada, Engineering department is trying to work with GW well users especially those along the river in quality assessment and conservation trends. Likewise line ministry need to consider participation of the community in monitoring process. This can assist reduce the pollution levels. It can also create awareness on importance of GW and the need to adopt artificial recharge methods to boost the ever dwindling recharge levels. Participation of community can also be enhanced in distribution of GW allocation and create an understanding to limitations of GW resources at local level. This ensures a common agenda for GW management.

Though no reduction in water quantity was reported from data obtained in household survey or any dry wells the demand is rising more than the supply and need for prudent utilization is all time high. The latter is seen by the community resistance of PDAM or any other commercial client to sink boreholes. Recent activities compound this resistance. An effort to sink a borehole in neighbouring regency was disastrous. The well became source of mud flow destroying properties and taking toll on lives (Yogyakarta Daily Newspaper August 2010).
Much still the companies don't have land rights to access new ground within the city for borehole drilling and thus they need to involve the community. The option is to pump water from Sleman regency thus raising operational and supply costs. This consequently pushes the prices of piped water subjecting populations to GW. Sleman region transmit much GW to Yogyakarta but this will change if abstraction increases in Sleman regency.

From interview the departments are less staffed especially on technical department necessary to model the condition of GW in the area. The employees are more into clerical work and normal surveillance which poses a challenge in GW levels monitoring. This is because GW monitoring should be an on-going process and policy directives issued in response to changes observed now and then. There are no constant activities undertaken to monitor GW quality and levels. Quality monitoring is left to individuals and at times Ministry of health. There seem to be general unresponsiveness in management issues that need a budget and expertise and need for a keen review on this. This has caused a serious data shortage thus compromising management of GW and policies evaluation. It's not possible to explain how much water is available for allocation and extraction at different aquifers. This is detrimental to long term use and can result to negative environmental implications.

6.2.7. Impacts of policies operationalisation

Several issues have been cited been results of proper policy operationalisation. A more concrete situation is discussed in this sub-chapter to relate each element analysed with possible effects. It's clear that there is mismatch between policy operationalisation and policy in document. A major problem is GW pollution due to unmonitored planning standards within the study area. This leads to additional costs and in isolated cases increases vulnerability to ill health.

Second lack of GW monitoring data on water levels impacts on allocation of entitlements where by its not clear to identify aquifers that need to be conserved and ones that can be developed for abstraction. This causes haphazard drilling of wells and can cause shortage of GW in future. It's also possible to overexploit a particular aquifer without giving it room for recharge.

Failures in management by competent authorities compromise on cost recovery and allocation of sufficient budget to construct monitoring wells crucial for water table monitoring. The necessary data is also not available and thus it's not possible to monitor quality of GW or condition of vulnerable aquifers. There is need for building capacity in these offices to empower on overall management of the resources.

Another side effect is lack of community participation and thus knowledge of GW resources management at local level is comprised. In recent case this is causing conflict between commercial and domestic users. Furthermore the authority can benefit by increasing rates of water metering and licencing since the community is able to identify old and new cases easily. Where there is constant transfer of staff the community will be able to direct new staff on management related issues.

Policies are meant to protect GW in length and when they fail the resources are exposed to over use and destruction of marine and ecosystem environment. Though this is not the situation in the study area, due to high recharge levels and the fact that the economy is not supported by industries, it can happen in future. The latter are major uses of water as it's the case in Jakarta and causes stress in GW availability.

7. CONCLUSION AND RECOMMENDATIONS

This last chapter is specific to conclusions of GW quality, GW levels and their link to policies. Various points are summed up to form opinion from findings of data obtained in Yogyakarta city. This has enhanced formulation of recommendations and way forward towards improving policy performance level.

7.1. Introduction

The entire thesis evolved around assessing the success of GW policies in Yogyakarta city. This is achieved through analyzing spatial variability of GW quality and quantity alongside policy documents. Major revelations include dominant role of GW for both domestic and commercial purpose, contamination and varying degrees of policies success. It also noted that much of piped water supplied by PDAM is derived from boreholes though some located outside the study area. It has also been demonstrated, the levels of GW allocation is high than abstraction which is good for GW availability and supply which might be true or a case of unaccounted reasons to prove otherwise. Towards analysis of GW levels it's realised that spatial analysis can be used to assess spatial units of abundant GW. This is crucial for management of GW allocation and withdrawals and determining conservation areas.

The thesis has adopted statistical and spatial analysis processes to derive conclusions and recommendations as well as literature review been incorporated at all levels of analysis to make far reaching decisions. Statistical analysis is applied to run Pearson's *r* for several variables relating to GW spatial variations on SPSS. Recommendations and areas for further research are more so stated as it will be seen in this chapter.

7.2. Overall policies performance.

The analysis and discussions undertaken in this work points to some major observations, that policies elements have varying mark of successes. For instance effort to increase artificial recharge or establish monitoring wells are a less success (less than ten percent) compared to such as licencing policy. The varying performance level is attributed majorly to fragmented/improper coordinating between the different departments, vested interests and less monitoring data. Other reasons are low level of integrating community in management of GW, failure of planning standards, absence of communication strategy to inform GW users of the state of resource, low level expertise and less capacity to undertake overall GW management practices among other reasons.

These issues can mislead in decision making. Other issues of concern are on allocation of new wells, community participation , GW contamination, GW allocation decisions, risk to aquifer overexploitation, risk to sustainable use and uncoordinated management and thus unable to evaluate actual benefits and losses from the resource.

7.3. Precise conclusion

The purpose of this sub chapter is to expound on the earlier made remarks (see 7.2) which caps the conclusion of this research. The conclusions arrived at are,

1. Policies elements quantified in this analysis have varying degrees of success. These elements can be classified into two. One is cost recovery elements and two is cost incurring elements. Cost recovery elements are the ones contributing to revenue generation and are generally designed to manage abstraction of GW. Cost incurring elements are ones that need a budget to implement and, in general are meant to protect the GW resource use. It has been found that the cost recovery elements are more successful than the cost incurring elements. This is because one

criteria of assessing staff performance is on how much revenue they collect from these GW resources. This is not a good evaluation criterion because it encourages over allocation. The other group of policy elements are less successful due to high budget associated with implementation which normally is not available or not prioritised.

2. A more significant idea is that there is no policy drafted and agreed upon to legislate the management of shallow wells which are a major source of water supply in the area. If this could be licenced and registered it would greatly contribute to cost recovery. The revenues generated could be used to implement overall GW policy. There are other aspects policies for shallow well can focus on for instance prohibiting its use by any form of business enterprise and restricting use to domestic purposes only.

3. Contamination of GW resources is rampant within the study area to a high factor of 2400MP/100ml. Reasons as to this high level contamination are low planning standards considering that shallow wells are drilled in shallow aquifers. Thus it's possible to contaminate these wells by leaks from onsite sewer systems and rainfall surface runoff in case of poor construction.

4. GW monitoring which includes assessing the GW levels to identify aquifers for abstraction and protection has not been carried out within the study area. For this reason GW allocation and licencing is not based on tangible scientific evidence but ability to pay and obtain a licence from competent authority.

5. There lacks a reliable data management system which is critical for making decisions. The available data is not similar within the relevant offices and much data is unavailable. Records keeping and sharing is also a problem. This goes hand in hand with need to evaluate available technical skills and systems to improve on data management and sharing.

6. Communication strategy or participation of the community towards management of GW resources remains a big challenge within the study area. The community need to be involved in management of the resources at local levels and also information should be shared between GW users, community and the technical persons. This will increase accounting of the resource and mutual understanding on management and conservation measures.

7. It's noted that policies are well written and intended but the laxity is in operationalising them. With this in mind the recommendations in this work aim at identifying action points to reactivate implementation but not much to writing new pieces apart from shallow well policies and other few ones.

8. The process of coordinating monitoring and implementation of decisions is carried out by different four Ministries as well as data keeping. This leads to a mix of responsibilities. The resource management need to be assigned to one office who report to one overall manager.

9. Several elements of policy can be added in the document. These elements include setting maximum admissible drawdown, setting a ceiling on amount of GW that can be abstracted,

establishing density of monitoring wells, and requirement for well drillers to submit data of all construction work carried out.

7.4. Study area recommendations

GW has been demonstrated as a major source of water. However contamination can reduce its usefulness as a reliable source of domestic water. To solve this Government need to invest in sewer systems as an element of GW protection policy and have houses connected. This can be addressed through municipalities by encouraging water supply systems and sewer systems. The system will significantly reduce levels of GW pollution. In the meantime the population is urged to continually treat the commodity before use or acquire other potable sources of water.

To tackle the inefficiency in data collection and analysis functions such as GW monitoring, studies on recharge, preparation of zoning plans and site plans with production levels for different aquifers and GW testing should be privatised, to assess the levels of GW for efficient management of allocation, licencing and abstraction. An added advantage in this case is the work will be done by qualified professionals who can give appropriate advice to guide proper use of GW. Policies should be ratified to allocate a wider financial base to carry out this process.

Develop a policy that will involve the community in local resource management. It will involve assessment of opportunities for development of GW education programs.
This can be through providing educational programmes to the community and involving them in determining GW allocation for it will help monitor pumping hours. A hotline can be identified for reporting any case of GW abuse that needs action.

Formulate strategies for GW information sharing between the experts and users. This necessary to help the administrator to constantly review and update data on chemical or biological contamination, GW levels, changes in water table, and change in depth of wells which will inform on timely intervention measures.

Budget provision of adequate funding for GW system research in high priority areas can be entrenched in GW policies. This can be achieved by redirecting revenue generated to GW studies and much more. Successful management can only be achieved by a substantial budget allocation year in year out and fully cost recovery.

On the other hand it should be a policy that well drillers must provide information on every new well they construct. Requirements for drillers to provide well construction data for all wells drilled will aid data collection and ensuring compliance to implementation of policies elements.

Management and licencing of highly yielding aquifers to ensure the government reap maximum benefits is very essential. In this case GW abstraction should be prioritised as a commodity able to generate much revenue which can boost social development.

The administration to undertake institutional reforms to streamline GW management functions by allocating them to centralised management unit. The idea is to see elimination of conflicts of responsibilities and improve managerial responsibility. This will streamline data storage and GW regulation.

There is need to build capacity for policy implementation and GW monitoring. This is possible when there is goodwill from legislators and will be achieved through training monitoring and constant evaluation probably twice in a year.

Policy to regulate, monitor and manage shallow wells should be formulated and adopted since abundant quantities are withdrawn at this level.

Last is to define standards for maximum admissible drawdown, setting a ceiling on amount of GW that can be abstracted, and establishing density of monitoring wells.

7.5. Limitation of the research

Various challenges were experienced in the process of this research which varies from language difficulties both spoken and in text, time limitation, red tape, data secrecy, and other technical issues. A highlight of these and other issues describes these problems in depth.

1. Of all difficulties there was unwillingness by the staff members to avail requested data may be due to unavailability or institutional secrecy. This greatly reduced the number of indicators that could be discussed and analysed. Additionally it was a blow to GW level analysis. It was also noted that private drillers do not submit their information on new constructions and this impact negatively on data consolidation necessary for GW management.
2. The topic is such a wide one and to study the three issues that is policy, GW quality and GW quantity would require a lot of data and far much time in the field.
3. It was not possible to take enough samples from the wide study area due to complex sensitivity procedure that had to be observed within a short time.
4. The mismatch in data available lead to conflicting information which can affect the quality of research.

7.6. Further research

An area for further research would be to access more policy indicators and write new policy elements as recommended to strengthen the existing ones. New policies for shallow wells as put in recommendations can be researched on to assess their possible impact in management of GW.

Further research can be done to the whole city to quantify GW levels through analysis of specific capacity. This will require more than thirty points from deep wells. This can go hand in hand with modelling of GW levels and quality at an advanced level.

Research can be done for GW quality at different timelines to asses impact of seasonal variation to GW contamination by E.coli and GW levels. This can factor in other possible source of contamination which can be researched on.

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7.7. Appendix

Appendix 1 – Household questionnaire

Date………………………………………………
Surveyor…………………………………………...
Question number…………………………………..
Village name………………………………………..
Household number…………………………………
GPS points-
X – Coordinate……………………………………..
Y – Coordinate……………………………………..

Household data

1. Details of respondent:

Position in the family: husband ☐ wife ☐ other - specify

2. Number of persons in household:

Ground water provision

1. Which water supply source does the household rely on? (It can be more than one answer)

Source	Tick the source
Provider (PDAM)	
Rain water	
Ground water	
Communal ground water	
Buying from vendors	
Surface water (river)	
Other sources (specify)	

2. If **ground water** indicate uses and amount used in liters per day

Uses	Tick the right one or combination	Liters (>10,15,20,25…..100)
Drinking and cooking		
Washing		
Gardening		
Other activities		

3. If **groundwater** for drinking, cooking, and washing indicate quality

Odor	Taste	Colour

Smell/no smell	Have taste(chlorine)/ no taste	Colour/colourless
specify	Specify	specify

4. Have you or any of your household members ever suffered from any of these diseases?

Diarrhea ☐
Cholera ☐
Typhoid ☐
Others

5. If yes when was the last time you got the disease?

E.g. 1mth ago ……………………………………….

Deep well data

6. If you are using a private deep well how is the supply situation per day in dry and wet seasons? (If shallow well skip to question number eleven)

situation	**Explanation in wet season**	**Explanation in dry season**
Continuous flow daily(no problem)		
Water available in morning and evening hours only.		
Water available in morning hours only		
Other situation		

Nb. If the private individual deep wells are regulated by policies like industrial deep wells fill in the questionnaire for institutions too.

7. If communal deep well state the situation per day in dry and wet seasons

situation	**Explanation in wet season**	**Explanation in dry season**
Continuous flow daily(no problem)		
Water available in morning and evening hours only.		
Water available in morning hours only		

Other situation		

8. How often do you rehabilitate the well?

- -I do not rehabilitate ☐
- -more than twice per year ☐
- -once in a year ☐
- -after two years ☐
- -others

9. Which year did you had the well dug?

10. What is the depth of the well and how has it changed over time?

-Initial depth…………..

-Change with time……………

GPS POINTS for private deep wells

	Coordinate pick by GPS for well	
Points	**X - Coordinate**	**Y - Coordinate**
HH. No………………………………..		

GPS POINTS for communal deep wells

	Coordinate pick by GPS	
Points	**X – Coordinate**	**Y - Coordinate**
HH. No……………………………………		

Shallow well data

11. If you are using a private shallow well how is the supply situation per day in dry and wet seasons?

situation	**Explanation in wet season**	**Explanation in dry season**
Continuous flow daily(no problem)		
Water available in morning and evening hours only.		
Water available in morning hours only		

Other situation		

12. If communal shallow well state the situation per day in dry and wet seasons

situation	**Explanation in wet season**	**Explanation in dry season**
Continuous flow daily(no problem)		
Water available in morning and evening hours only.		
Water available in morning hours only		
Other situation		

13. What is the depth of the well and how has it changed over time?

- Initial depth…………………

-Incremental depth over years………………..

For both types of well

14. What is the distance of the well from the on-site sanitation?

15. What is the distance of the well from the building?

16. Has the level of water been decreasing every year?

Appendix 2
Target group 2
The target group for this questionnaire is companies and organization relying on groundwater from deep wells.

Area name

Name of company or organization

From which year has the institution used GW /which year was the well dug?

GPS coordinates for the well – X…………………………………………………….
Y……………………………………………………….

1. Do you have recorded data on initial specific capacity of the well? Yes/ NO
1b.If yes what is the value of
(i) Estimated yield ……..
(II) Initial drawdown ……..
2. Have you carried out any other analysis on specific capacity yes/No (if much analysis detail all time period)
2b.If yes when?
2c.What was the value of
(i) Estimated yield

(ii) Drawdown
3. What is the cost of pumping per hour?
4. is there GW regulation (limit) on amount of use through quota allocation by responsible authority? YES/NO
5. Has there been change in amount of GW quota allocations. Yes/ no
6. What was the initial depth of the well?
7. By what margin has the depth changed over years?

Depth in 2000…………………………………… Depth in 2006……………………………………

Depth in 2001……………………………………………. Depth in 2007…………………………………….

Depth in 2002……………………………………………. Depth in 2008……………………………………

Depth in 2003……………………………………………. Depth in 2009……………………………………

Depth in 2004……………………………………………. Depth in 2010……………………………………

Depth in 2005………………………………
8. Does the institution/organization have a well maintenance schedule? Yes/no
9. How many times have you rehabilitated the well since its inception up to now?
10. What was the cost of each rehabilitation process in rupees?

Part b indicators for compliance to policies & water act

1. Is your well licenced? Yes/no (if no give reasons)

2. When were you issued a licence for abstraction?

3. Is there a limit of amount you are supposed to abstract per year? Yes /no

4. If yes what is your allocation in m^3 per year?

5. How much GW do you use per year or per month or per day? (Change the year to month or day where necessary)

6. Have you installed a water meter to measure water used from the well per day yes/NO?

6a. is your well abstractions currently registered?

6b.If No get reasons as to why s/he has not installed one or registered

7. At what period of the year do you get GW bill? monthly or sometimes?

7b.On average how much water user fee do you pay per month/per year?

8 is the flow constant throughout the year? Yes / no

9. Have you constructed a recharge well as required yes or no

Appendix 3

Interview schedule for competent authority, (water institutions, local authority) managing and exploring GW.

Part A

Area name…………………………….

1. What is the average cost of pumping GW per month/year?
2. Is there a ceiling on amount of GW one can pump in a month Yes/NO

2a. if yes what is the maximum level allowed to be pumped per month?

2b.To what % is (how many persons) compliance for amount pumped per month (provide yearly data if possible)?

2c.What are the penalties for non – compliance?

2d. has there been change in amount of GW quota allocation for major installations. Yes/ no

2e.Outline the change in the last ten years in m^3

Change in 2000……………………………………………… Change in 2006……………………………………

Change in 2001……………………………………………… Change in 2007……………………………………

Change in 2002……………………………………………… Change in 2008……………………………………

Change in 2003……………………………………………… Change in 2009……………………………………

Change in 2004……………………………………………… Change in 2010……………………………………

Change in 2005………………………………

3. Is there change in groundwater well(s) depth? Yes/no

3b. if yes describe the change in GW well levels for the last ten years in meters

Change in 2000……………………………………………… Change in 2006……………………………………

Change in 2001……………………………………………… Change in 2007……………………………………

Change in 2002……………………………………………… Change in 2008……………………………………

Change in 2003……………………………………………… Change in 2009……………………………………

Change in 2004……………………………………………… Change in 2010……………………………………

Change in 2005………………………………

4. What is the total number of dry wells reported for the last ten years?

Total no. of dry wells in 2000……………………… Total no. of dry wells in 2006………………………

Total no. of dry wells in 2001…………………… Total no. of dry wells in 2007………………………

Total no. of dry wells in 2002…………………. Total no. of dry wells in 2008……………………….

Total no. of dry wells 2003…………………….. Total no. of dry wells in 2009…………………….

Total no. of dry wells in 2004……………….. Total no. of dry wells in 2010…………………..

Total no. of dry wells in 2005…………………………….

5. What is the trend in water table change for the last ten years meters?

Water table Change in 2000…………………… Water table Change in 2006……………………..

Water table Change in 2001…………………… Water table Change in 2007……………………..

Water table Change in 2002………………… Water table Change in 2008………………………..

Water table Change in 2003 ………………….. Water table Change in 2009…………………….

Water table Change in 2004……………….. Water table Change in 2010……………………

Water table Change in 2005…………………………

6. Has there been analysis on trend of water quality for the last ten years? Yes/ no

6b. If yes what kind of analysis chemical /biological?

Part b indicators for compliance to policies & water act

1. What is the number of permit holders for GW use for the last ten years?

No. of permits in 2000…………………… No. of permits in 2006……………………..

No. of permits in 2001…………………… No. of permits in 2007……………………..

No. of permits in 2002………………… No. of permits in 2008………………………..

No. of permits in 2003 ………………….. No. of permits in 2009…………………….

No. of permits in 2004……………….. No. of permits in 2010……………………

No. of permits in 2005…………………………

2. What is the number of total registered annual withdrawals (in million m^3) for the last ten years?

Total registered withdrawals in 2000……………… Total registered withdrawals in 2006……

Total registered withdrawals in 2001……………… Total registered withdrawals in 200……….

Total registered withdrawals in 20………. Total registered withdrawals in 2008………

Total registered withdrawals in 2003 …………. Total registered withdrawals in 200………..

Total registered withdrawals in 2004…….. Total registered withdrawals in 2010……...

Total registered withdrawals in 2005………………

3. What is the number of reported abstraction points with licence in the last ten years?

No. of licenced points in 2000…………………… No. of licenced points in 2006………………………

No. of licenced points in 2001…………………… No. of licenced points in 2007………………….

No. of licenced points in 2002…………………. No. of licenced points in 2008………………………

No. of licenced points in 2003 ………………….. No. of licenced points in 2009……………………

No. of licenced points in 2004………………... No. of licenced points in 2010…………………….

No. of licenced points in 2005…………………………

4. What is the number of reported abstraction points without licence in the last ten years?

No. of unlicensed points in 2000…………………… No. of unlicensed points in 2006………………………

No. of unlicensed points in 2001…………………… No. of unlicensed points in 2007…………….

No. of unlicensed points in 2002…………. No. of unlicensed points in 2008………………

No. of unlicensed points in 2003 ………………….. No. of unlicensed points in 2009……………

No. of unlicensed points in 2004………………... No. of unlicensed points in 2010…………….

No. of unlicensed points in 2005…………………

5. Is there disparities in fees on amount billed and collected yes/ No?

5b. if yes what is the difference for the last ten years in Rupees?

Difference in 2000…………………… Difference in 2006………………………

Difference in 2001…………………… Difference in 2007……………………….

Difference in 2002………………… Difference in 2008…………………………

Difference in 2003 ………………….. Difference in 2009………………………

Difference in 2004………………… Difference in 2010…………………….

Difference in 2005…………………………

6. What is the % of permit holders metering abstractions in the last ten years?

% 2000…………………… % 2006………………………

% 2001…………………… % 2007……………………….

% 2002………………….. % 2008…………………………

% 2003 ………………….. % 2009………………………

% 2004………………… % 2010…………………….

% 2005…………………………

7. How many wells are currently registered by your department?

NB. Collect other secondary data on specific capacity parameters i.e. yield, water rest level and pumped water level (drawdowns) for boreholes together with their GPS points.

Thank you!