Semarang, and its underground problems: Spatiotemporal hydrochemical assessment of shallow groundwater in Semarang, Indonesia

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November 2020

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This thesis is submitted in partial fulfilment of the requirements for the academic degree of
Master of Science in Water Science and Engineering
UNESCO-IHE Institute for Water Education, Delft, the Netherlands
Master of Science in Environmental Engineering
Instituto Superior Técnico, Universidade de Lisboa, Portugal
Master of Science in Hydro Science and Engineering
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IHE Delft, The Netherlands

November 2020

Acknowledgements

While I alone am responsible for this thesis, it is not alone that I have reached its completion. I would like to start thanking my supervisors, Dr Tibor Stigter, and Dr Michelle Kooy for their guidance through each stage of the process. Dr Stigter for his help with the interpretation of the hydrogeochemical data, and Dr Kooy for trusting her funds into my research.

I would also like to acknowledge Dr Thomas Triadi Putranto and his assistants for their support, help and guidance during my fieldwork in Semarang. A campaign that was not of ease, and with the joint forces and knowledge resulted in great success.

I would also like to extend my thanks to the technicians of the Kemanterian Energi Dan Sumber Daya Mineral laboratory of the Bandan Geologi department for their help in offering me the resources in running the laboratory analysis for my dug well samples.

I wish to thank my dear friends and parents for their support and encouragement throughout my study, without them I would not have reached this far. These times were defining for the last phase of my research.

Finally, to my grateful thanks to my master colleagues, which altogether went through challenges and ensure that none was left behind. We started a journey being individuals from our respective countries in 2017 and now after two years have shaped and become global citizens.

Resumo

Para garantir água potável e saneamento para todos até 2030 (UN-SDG6), os países têm que investir em infraestruturas adequadas, melhorar as condições de higiene e garantir um saneamento adequado. Semarang é uma cidade em vias de desenvolvimento localizada na ilha de Java, Indonésia, e que enfrenta inúmeros desafios ambientais, principalmente relacionados com a qualidade dos recursos de água subterrânea. Esta investigação estuda o aquífero superficial de Semarang que tem vindo a apresentar sinais do impacto do rápido desenvolvimento da cidade com o objetivo de caracterizar a qualidade da água subterrânea combinando métodos de análise hidrogeoquímica e estatística multivariada das amostras de água subterrânea recolhidas em 2017 e 2019 com um levantamento sobre os usos e práticas da água dos proprietários dos poços onde foram recolhidas as amostras. Os resultados confirmam dois tipos de poluição, uma de origem difusa (intrusão salina) encontra-se nas áreas industriais devido às práticas insustentáveis de captação de água subterrânea; e, outra de origem pontual (nitrato, nitrito e E. Coli) relacionado com a falta de rede adequada de saneamento. Esta investigação verificou ainda que a água subterrânea captada a partir de poços escavados privados muitas vezes não está em boas condições para consumo humano, concluindo que a qualidade da água subterrânea influencia os usos e práticas dos proprietários de poços escavados na baixada de Semarang, uma vez que estes acabam por não usar a água subterrânea como fonte de água potável e em alternativa recorrem a origens de água potável, como a água engarrafada ou a água tratada da torneira.

Palavras Chave: água subterrânea, intrusão salina, poluição difusa, Semarang, Indonésia

Abstract

To ensure clean water and sanitation for all by 2030 (UN-SDG6) countries need to invest in adequate infrastructure, encourage hygiene, and good sanitation facilities. Semarang is a developing city located in Central Java, Indonesia, which is experiencing all kinds of environmental challenges mostly of which relate to water. This research focuses on the unconfined aquifer of Semarang lowlands, since it is suspected to be impacted by the current rapid development of the city. This development is leading to an increase of anthropogenic activities, and these are suspected to have an impact to the unconfined aquifer. This research assesses the current state of the unconfined aquifer, via a hydrogeochemical and multivariate statistics analysis of the collected groundwater samples from Semarang lowlands in 2017 and 2019, and a survey on water uses and practices of the same dug well samples. This analysis results to identify two kinds of pollution: diffuse and point-source pollution. The first one is found in the vicinities of industrial areas, and is characterised by seawater intrusion. The latter is found in the form of nitrate and nitrite in some of the 30 dug wells, including E. coli is found in all 30 dug well samples, ranging from 1 to 5 MPN/L.

Seawater intrusion is reflected in the water-type composition of dug wells, and there are two water types characterising Semarang lowlands: Ca-Na-HCO3 (with varying concentrations of Ca, Na) and HCO3, (with a low concentration of Cl). The first group is mainly found near the higher planes. The second water type is characterised as Na-Cl-HCO3 (with a low concentration of Ca and higher mineralization). This second group is only found in the vicinities or inside industrial areas of Semarang lowlands. Both years were brackish, but varying in percentage, fresh-brackish with a 13.3% in 2019 and 3.3% in 2017. The previous findings are supported by the statistical analysis with a positive correlations in the Pearson analysis between sea-water components, such as Cl vs SO4 ($r = 0.59$ in 2019 and $r = 0.63$ in 2017). At the same time a positive relationship between magnesium and chloride is observed in 2017; where Mg has higher concentrations due to seawater mixing and possibly cation exchange ($r = 0.4$ in 2019 and $r = 0.93$ in 2017). PCA results not only evidence but support the previous findings on the hydrochemical variables which play a major role, and therefore are influential, to the groundwater quality of the area.

Point source pollution is also evidenced in statistical analysis, where in the PCA results of 2019 show a correlation between nitrite and ammonium, but this is different for 2017 results. However, these compounds remain highlighted in PC4 and PC5. The location of the contaminated samples from nitrate and nitrite are located in the neighbouring areas of industrial zones, being clearly evidenced by the 2019 dug wells. In this research it is discussed the presence and origins of these nitrogen-compounds; by the industrial wastewater, and/or sanitary infrastructure of Semarang lowlands. Throughout the discussion it is put to debate the relatable causes of these existing pollutions, since it is suspected that seawater intrusion links to the unsustainable groundwater abstraction practices by industries of the area, and point-source pollution relates to the poor sanitation infrastructures of the city. Furthermore, this research concludes that the groundwater accessible from private dug wells is often not of good condition for human consumption. This research understands that the quality of groundwater has an influence on the uses and practices of the dug well owners of Semarang lowlands. By discarding the end user habit of using groundwater as a drinking source, and move to potable water sources such as bottled water, or treated water from the tap.

Keywords: água subterrânea, seawater intrusion, diffuse pollution, Semarang, Indonesia

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‘There is plenty of water in the universe without life, but nowhere is there life without water ‘-Sylvia Earle

Chapter 1 Introduction

This section presents a brief introduction to the water situation of Semarang City up to date. Highlighting the current problems which the city is experiencing, specifically groundwater issues.

1.1 Background

The UN Environment publication on ‘Progress of Ambient Water Quality’ in 2018, observed that the achievement of Sustainable Development Goal (SDG) 6 related to ensuring availability and sustainable management of water and sanitation for all, is globally falling behind (SDG, 2011). This issue was further discussed in the High-Level Political Forum (HLPF) in 2018, and one of the important indicators to review SDG 6 was indicator 6.3.2: ‘proportion of bodies of water with good ambient water quality’. To ensure clean water and sanitation for all by 2030, countries need to invest in adequate infrastructure, encourage hygiene, and good sanitation facilities (UNDP, 2019). The global population is at a constant growth from 3 billion in 1960 to 7.5 billion in 2018 (World Bank, 2018). Migratory movements follow this increase in population regionally and internationally towards coastal cities (Khumaedi and Purnomo Putro, 2017). Coastal areas exhibit a higher rate of population growth and urbanization but simultaneously correspond to areas of high vulnerability of the current climate change patterns (Neumann, *et al.*, 2015; Nganyi, Akrofi, Farmer, UNEP-GPA, WMO, and UNEP-WCMC, 2012). This population growth is increasing the pressure on resources and commodities of coastal ecosystems (Syvistski, 2008).

Coastal ecosystems naturally possess a saltwater – freshwater balanced interface where the land meets the sea. This balance can be easily disturbed by the local geomorphology, paleo-waters and weather events, tides, extreme-rainfall, or floods, and cause seepages of saltwater into the aquifer (Imam Wahyudi, *et al.*, 2017; Rahmawati, *et al.*, 2013). Furthermore, these areas are often found under pressing anthropogenic pressures, which also distort the natural fluctuations of the named interface, which cause an increment of saline intrusion into coastal aquifers. This leads to a decrease of groundwater quality for users of this source.

Groundwater, once known to be the ‘invisible’ water source, has been moved over the last decade to make headlines by the economic and population growth worldwide (Kemper, 2004). This source is subject to vulnerability, which is enhanced by the increased stress on fresh water by the populations' growth and withdrawal of this source (Datta and Singh, 2014; Khumaedi and Purnomo Putro, 2017). This is putting at risk one of the most important renewable and natural resources, groundwater (Datta and Singh, 2014). Leading to the salinization of surface waters and shallow fresh groundwater bodies, making the water unfit for irrigation, drinking water supply or industrial purposes (DeLouw *et al.*, 2011; Worland, *et al.*, 2015). Where the supply of freshwater is not adequate, the forced consumption of saline water can impact on human health by promoting the development of renal failure, kidney disease, hypertension and gastrointestinal irritation (He and MacGregor, 2009).

Groundwater quality is often altered by more than a single pollutant. This is of major concern in water management for most of the world’s developing areas (Boy-Roura, 2013; Sadler *et al.*, 2016). Aside from the degradation of water quality of aquifers by seawater intrusion, and other chemical pollutants such as nitrates responsible for the contamination of groundwater. Nitrates and nitrites are often to be by-products from agricultural and wastewater practices (Andrade and Stigter, 2009; Foster, 1987; Stigter, 2008; Templeton *et al.*, 2015). The degradation of quality of aquifers is largely blamed to the ongoing farming activities since the mid20th century, and other sources which introduce large quantities of nutrients, such as nitrates (Burg and Heaton, 1998; Buzek *et al.*, 1998; Dietrich and Hebert, 1997; Focazio *et al.*, 1998; Foster, 1987; OECD, 2008; Stigter *et al.*, 2006). The other contributors are the discharge from leaking sewers, septic tanks, spreading of sewage sludge and atmospheric deposition (Mtoni *et al.*, 2013; Templeton *et al.*, 2015; Stigter *et al*, 2008; Wakida and Lerner, 2005).The artificially added nutrient-load by these activities is often found to be harmful for human health, the *WHO* since 2008 in their studies that the ingestion of nitrate even below their guidelines (50mg/L) has a high risk of contracting certain cancers, adverse pregnancy outcomes, diabetes and thyroid disorders (Boy-Roura, 2013; Ward and Brender, 2011; WHO, 51 2008; Ward *et al.*, 2005). Other studies have expressed their concern for human health exposed to the small quantities of nitrates and nitrites, since research has mainly focussed on the extensive study for nitrite concentrations above guidelines levels (Philips, *et al.*, 2002).

Furthermore, the scientific community has been growing more concern towards the environmental problems which stem from the increasing number of nitrates as these nutrients are very difficult to remove from surface fresh- and salt- waters that cause the acceleration of algae growth leading to the eutrophication of environments (EC, 1991; Stigter *et al*., 2006).

1.2 Case study

This research is based on a case study in the Indonesian city of Semarang, and focuses on two different kinds of groundwater pollution: saline intrusion and wastewater pollution. This city comprises all kinds of environmental issues, turning it into one of the six world's resilient cities (Water as Leverage, 2017). Semarang is a coastal city in the North of the Indonesian Island of Java (Abidin, *et al.*, 2013), *figure 1.2-1*. This city is increasing in its urban area, with an expanding population of 1.55 million people last recorded in 2010 (Bandan Pusat Statistik, 2010). This development is increasing the anthropogenic activities in the area, and they seem to have a strong influence on the natural conditioning of Semarang, altering the water quantity but also the quality. Semarang is a naturally land subsiding area because of the young alluvium present in its most northern geological formation closer to the ocean. This naturally occurring event makes Semarang an area of high risk, where climate changes only reinforce the vulnerability of the city with events such as; sea level rise, degradation of water quality, floods, and land subsidence (Abidin, *et al.*, 2013; Foster and Chilton, 2003; Imam Wahyudi, *et al.*, 2017; Jago-on *et al*., 2009; Kagabu *et al*., 2012; Yamano *et al*., 2009).

Source: http://www.geographia.com

Figure 1.2-1*Marfai and King (2008)* illustrating the location of Semarang in Indonesia.

In Semarang province its Local Water Board is Perusahaan Daerah Air Minum (PDAM). PDAM is in charge to supply water to all municipality, at the same time as ensuring its availability to all inhabitants. According to *Ditjen Cipta Karya,* the standard of fresh water in Semarang as a metropolitan city is around 150L/person/day, which makes a total approximate of 87.3 million m^3/year. However, PDAM is known to only be able to 50% of the water needs of the city (Putranto, Hidajat, and Susanto, 2017). Implying the unavailability of PDAM to satisfy the water needs for the whole city. Therefore, with this study this research aims to fill in the scientific-gap of knowledge of the groundwater quality of Semarang, at the same time as contributing to the position of the city in versus SDG6. There is an urgency to carry out such research. Because of the extreme need for good quality and quantity of water in this Semarang lowlands, this thesis focuses on the groundwater quality and quantity. As this area is not only the most populated area of Semarang, but also known to be the most affected and most vulnerable to PDAM shortages (Putranto, Hidajat and Susanto, 2017).

1.3 Water sources

PDAM has two types of sources in Semarang area, from these it supplies to two different areas of the city; highlands and lowlands. The first source is located in the highlands area of Ugaran and outside Semarang city, and the second source is supplied from the river Kaligaran, located in the lowlands of the City of Semarang, *Figure 1.3-1*. Being the first source fresh from the mountains, and the second source from the midlands of the basin and of lesser quality and quantity (Hadipuro and Indriyanti, 2009). In the lowlands this thesis finds two different groundwater users with different water demands and different accesses to the aquifers, being the local communities and industries (Putranto and Rüde, 2011).

Semarang has three main lithologies, namely, volcanic rock, sedimentary rock and alluvial deposits. These deposits consolidate two different aquifer systems in the city. These two systems have been documented by several authors, *figure 1.3-2* (Arifin and Mulyana, 1990; Arifin and Wahyudin, 2000; Mulyana and Wahid, 1994; Said, 1974; Sihwanto *et al*., 1988; Spitz and Moreno, 1996). These aquifers not only range in depths, but also in their accessibility for the groundwater user. The access to the confined aquifer or to the deeper parts of the unconfined aquifer is restricted by the government with a permit. The local government defines as deep any well deeper than 80 meters. Post approval and construction of the well, there is a taxation monthly plan set according to the water consumption. The rights of this permit are reserved to the provincial Government, BKKBN Central Java Province. Differently to deep wells, dug wells or wells less than 80 meters do not require a permit for their construction or use. The residents from the lowlands often own a dug well to complement its water needs. These wells are not monitored as the deep wells, and their groundwater consumption is not monitored, instead is an estimate being of $30m^3$ per month (Putranto, 2013). The inhabitants of the lowlands seem to have limited access to deep groundwater, and their only access to groundwater is through their dug wells, which access to the shallow parts of the unconfined aquifer.

The only abstraction of groundwater in Semarang being registered is from the deep wells. But in practice it seems to be a quite different; numbers show boreholes that extract groundwater in aquifers has rapidly increased from around 400 wells since the 1980s to more than 1,600 wells in the 2000s in Semarang lowlands, and the volume of groundwater extraction has also risen from 10 to 60 million m^3 (Putranto, Hidajat, and Susanto, 2017). Thus, it is suspected the presence of unsustainable practices of groundwater abstraction by industries more than in communities. This study defines unsustainable groundwater abstraction practices in this study, as the unmeasured and unmonitored abstraction of groundwater in an unstudied aquifer system.

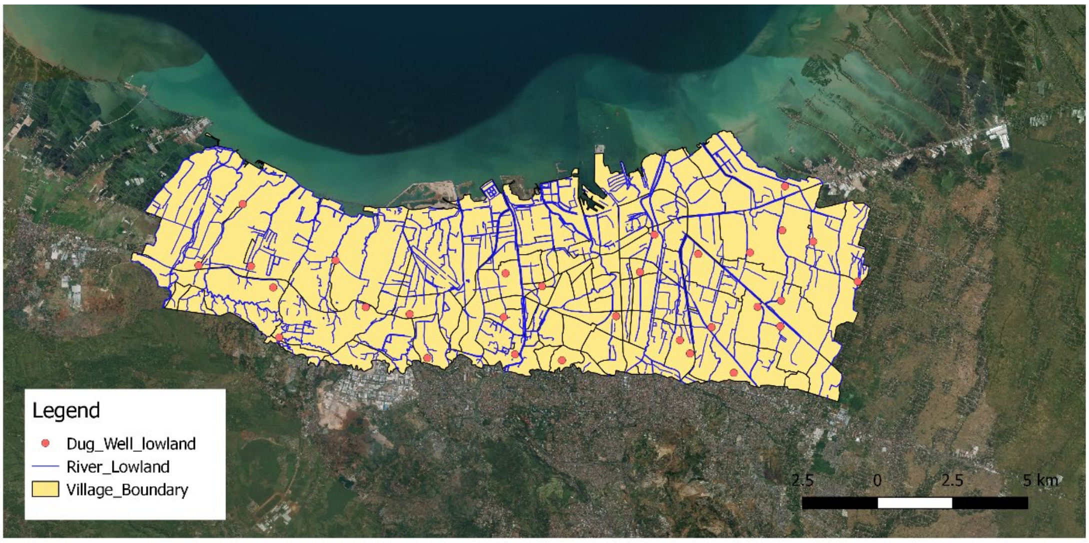


Figure 1.3-1 Map of the study area of this master thesis, the lowlands in Semarang City.

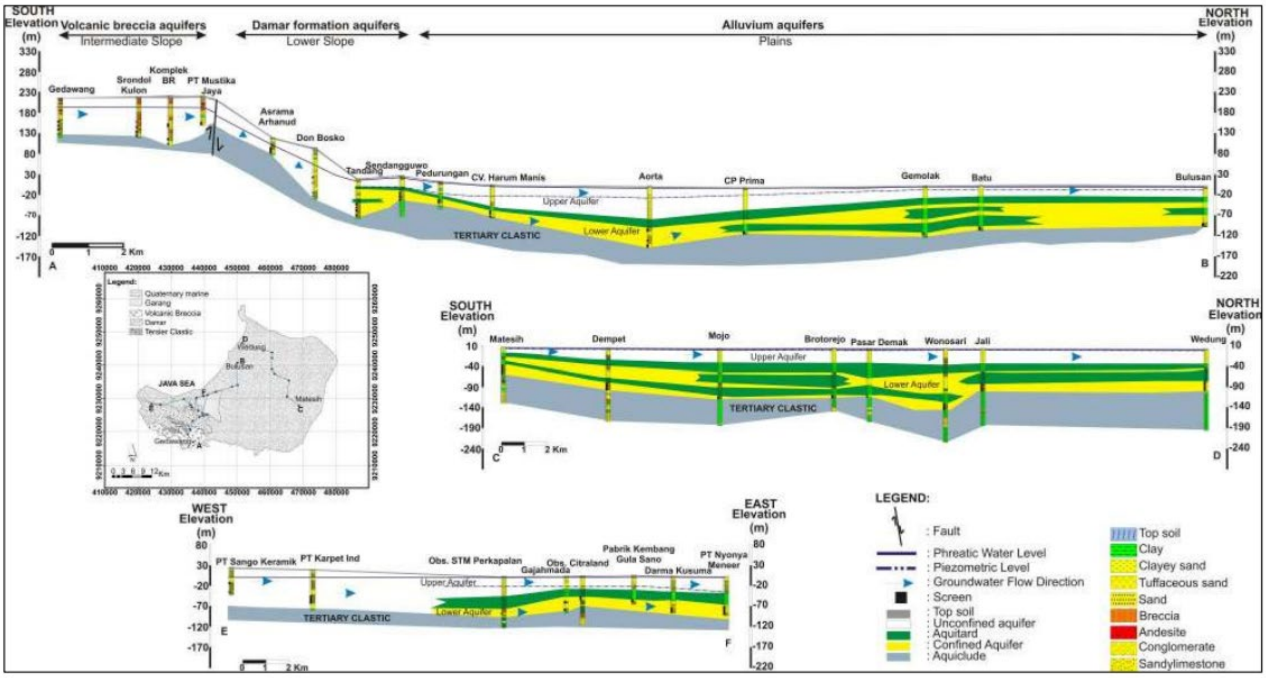


Figure 1.3-2 *Putranto and Rüde (2011)* illustrating a cross section of the lithology composing Semarang and Demak's area.

1.4 Wastewater and sanitation systems

In developing countries the disposal of sanitary waste is a growing concern (Sadler *et al.*, 2016). *Templeton et al.,* (2015) states that the most common forms of onsite sanitation facilities of developing countries are pit latrines. These latrines are used as the isolative mean of human waste, despite not being complete as often its conditions lead to nitrification of the contained waste. Other sanitation infrastructures such as soak pits and septic tanks are also known to be nitrification catalysers of nitrogen-containing waste, which leads to the formation of nitrate and nitrite (EPA, 2005; Harman *et al.*, 1996). The World Bank recorded in Indonesia on 2012 that only 54% of the Indonesian population had access to acceptable disposal facilities, which could be private or shared (Sudarno, 2016; Templeton *et al.*, 2015). Despite of the facilities of being classified as satisfactory on hygienic terms, the risk of contamination of water wells is not erased (Sadler *et al.*, 2016; Templeton *et al.*, 2015). In this case study in Semarang dug wells are often used for potable purposes, such as washing, cooking or drinking by several households or by individual (Sadler *et al.*, 2016; Sudarno, 2016). This reflects on the importance of sanitation schemes aimed at implementing sanitation to bring in the equation the aftermath of nitrate levels in the local groundwater (Templeton *et al.*, 2015). Therefore, this research aims to study for the first time in Semarang lowlands the impact of poor sanitary infrastructures to the quality of shallow groundwater. At the same time as picturing the perception of the owners of these dug wells in respect of their groundwater quality.

1.5 Study concept

Coastal ecosystems are known as dynamic, and have various processes affecting their aquifer. Consequently, a good monitoring network is necessary to track the origins of the groundwater salinization in coastal aquifers. In order to predict the consequences, a new monitoring plan of the groundwater is required in Semarang. As in this city as in many other developing countries it suffers from a lack of data. This study aims to visualize for the first time hydro-geochemical changes of the shallow aquifer over the last decade. At the same time as, understanding who is being impacted by the carried over-abstraction of aquifers. It is also expected to generate more monitoring data of Semarang, and to detect other sources of pollution, in order to make the city more resilient towards the threat to climate change.

Lack of data enhances consequences of climate change, as predictions are rather difficult to be made to be able to design protection plans for the city. Climate change is not only in the equation of negative impacts of the city, but also the aforementioned sanitation infrastructures seem to play a role in the groundwater quality of Semarang. In order to understand the real root causes of the afore mentioned groundwater problems in Semarang, UNESCO-IHE Delft joint with Indonesian research partners; Amrta Insitute for Water Literacy, University of Diponegoro (UNDIP), and University of Gadhah Madah (UGM) through the project GroundUp.

This project aims to integrate and translate scientific technicalities of the groundwater in Semarang City to all involved stakeholders. At the same time as to generate new knowledge on the social structures and relations which shape the existing problem in the city of Semarang. Finally, to support platforms for civic innovation in groundwater governance for Semarang and other Indonesian cities. The GroundUp project plans to accomplish this via long-term innovative transformations, at the same time as keeping in sight the short-term urban planning of the developing city of Semarang. At the same time as aligning itself with the sustainable Development Goal 6: Clean Water and Sanitation for all people. This master thesis aims to add one of the turns of the GroundUp project, by providing evidence on the current groundwater quality and quantity of Semarang lowlands. By marking the start of such complex system to combat the groundwater crisis of Semarang and other Indonesian cities. By doing so it is hoped to contribute to the evaluation of the progress of Semarang City into working towards SDG 6.

1.6 Problem Statement

Semarang is a city that is experiencing all kinds of environmental challenges and difficulties, which most of them relate to water. These difficulties are linked to the sociopolitical processes of the city within the water management plans. This is leading to a poor water supply and a poor water quality. Thus, IHE - Delft with other partners organized the project of “GroundUp”, where Semarang is one of the 6 resilient cities. This Master thesis will be contributing to the bigger project by covering further knowledge regarding the groundwater quality and processes of Semarang.

1.6.1 Existing gaps

This study focuses on covering two types of pollution often cited in previous literature to be present in Semarang lowlands: saline intrusion and wastewaters (Putranto, *et al.*, 2017; Putranto and Rüde, 2015; Purnama and Marfai, 2012; Ujianti *et al.*, 2018). The saline intrusion is always referred to be enhanced by over-abstraction of groundwater from industries, however the hydrogeochemical picture where the industrial impact is measured though statistics has never been studied in depth before, often subject to funding conditions (Irawan, *et al.*, 2018). Some works cite that the salinity content in groundwater increased from 1995 - 2008 conditions (Irawan *et al.*, 2018; Putranto and Rüde 2016; Purnama and Marfai, 2012; Rahmawati and Marfai 2013). There are information gaps in literature regarding what are the processes being involved and affecting the groundwater processes of the city, especially in the highly affected lowlands areas. Even if has been previously documented that there is a natural saline intrusion due to the ongoing land subsidence of the lowlands area of Semarang, other processes might be contributing to this event. Therefore, there is a need on understanding this finer-scale of the cause for variability of groundwater quality in the shallow aquifer.

Furthermore, this research suspects that there will be other influences on the shallow aquifer’s groundwater quality in Semarang lowlands, which has never been documented before; the Escherichia coli (E. coli), and nitrogen compounds. At the same time, in the area there is a grand documentation on the geological and hydrogeochemical conditions of the city, but there have not been many long-term studies to track the fluctuations of the hydrochemistry of the area, nor the study of anthropogenic impacts to the shallow aquifer.

1.6.1 Thesis objectives

This project not only aims to inform to the water management practices of Semarang’s groundwater quality state, it also aims to understand the perspectives of Semarang lowlands inhabitants on groundwater. The goal of this study is to create a technical and social picture of the lowlands area of Semarang, so regional policy makers can consider the update of their pipeline network, and develop a new monitoring program for the shallow aquifer groundwater quality. By doing this, this research aims to ensure a sustainable future for the unconfined aquifer and all inhabitants of Semarang lowlands.

Therefore, this thesis aims to determine the responsible for the groundwater pollution by looking at the water uses of the residents of the sampling area. This will be done via interviews to the households whom own groundwater dug wells in Semarang lowlands. This should give a deeper understanding on the water uses, water sources, and their policy in respect to groundwater permits. Thus, in order to check on the suspicion of the presence of unsustainable practices of groundwater abstraction by communities and industries this study designed 4 research questions that should bring this research closer to resolving this suspicion, *chapter 1.7*. The impacts of this suspected over abstraction of this resource will become evident at the ground level, as shallow aquifers are polluted with saline intrusion. Further consequences to the aquifers are then feared, if these unregulated activities continue for a longer term.

1.7 Research questions

The overall research objective of this study is to understand the underlying hydrogeochemical processes that cause the spatial variability of salinity at the lowlands areas in Semarang City, Indonesia. At the same time as, identifying other groundwater quality problems yet to be documented in the area. Specific research objectives can be defined as:

a. **RQ 1:** "What is the general hydrochemical evolution of the upper aquifer of Semarang Lowlands, in time and space?"
b. **RQ 2:** "What is influencing the salinity of the unconfined aquifer of Semarang lowlands, and does it vary in time and space?"
c. **RQ 3:** "What are the other influences altering the groundwater quality in time and space?"
d. **RQ 4:** "Does the groundwater quality define the water uses and practices of the dug well owners' inhabitants of Semarang lowlands?"

1.8 Expected impacts

The key audience at this research stage consists of local politicians, policy makers, donors and water supply professionals. Local politicians and policy makers could make use of this research for the design of urban development of the city, and update the infrastructure of sanitation practices to get a step closer to SDG 6. Water supply companies (PDAM), can establish competition in the market by providing different services that would not only improve the quality but quantity of Semarang water supply. Once technical guidelines and optimal governance arrangements have been established, the upscaling process can take off. At that stage the target audience comprises the communities, NGO’s and entrepreneurs. This could design an outreach campaign to the inhabitants and industries of the city to increase their knowledge in impacts and causes of actions to Semarang’s water. If these actions are accomplished Semarang could become a role model for other Indonesian cities.

Chapter 2 Literature review

This chapter is aimed to provide some background information regarding the various concepts within this thesis. This is done so the reader gains some background knowledge on Semarang City and Semarang lowlands. The information presented is from various research articles and books from hydrology-related fields, and will be introducing each concept starting from water quality and hydrochemistry, moving onto seawater intrusion, then to the types of contamination, and finalising with the statistical tools used in this thesis.

2.1 Why study water quality?

Water quality plays an important role for all living beings. Including groundwater quality, which has become an important water source because of the quick growth of population, industrialization, unplanned urbanization, flow pollution from upland to lowland, and abuse of fertilizers and pesticides in agriculture (Joarder *et al.*, 2008). Groundwater is considered to be one of the least polluted comparted to other inland water resources, but research remarks that groundwater is not absolutely free from pollution. Although it is likely to be free from suspended solids (Jothivenjatachalam *et al.*, 2010). The biggest problem with groundwater starts when the source becomes polluted, as it is difficult to restore to its original state. This highlights the current concern and need for the conservation and management of groundwater quality. There is no straight forward cause for the understanding of the deterioration of water quality, as it depends on various water quality parameters (Gajendran and Thamarai, 2008; Jothivenjatachalam *et al.*, 2010). Within a water quality there are strong correlations amongst these various parameters, with a combined effect of their interrelatedness shows the kind of water quality. The groundwater quality not only depends on natural geologic conditioning of the area but also on human activities, such as amongst other industries, and urbanization (Jothivenjatachalam *et al.*, 2010). Since this study is based in Semarang, a city experiencing on top of their natural land subsiding conditioning, a rapid urbanization, quick increase in industry and population growth, is easily understood that this research will find anthropogenic pressures in the groundwater quality. Therefore, this thesis will be making use of hydrogeochemical and statistical techniques to understand the groundwater processes and origins of the lowland study area. This analysis on some physico-chemical parameters will be also compared to WHO and

SNI drinking water standards to understand the origin of the pollution if found (Dash *et al.,* 2006).

2.2 **Principle of Electronegativity (%)**

In this study aims at comparing a previous sampling campaign from 2017 to the new 2019 campaign. The 2017 campaign was sampled following the groundwater sampling methodology of the Indonesian National Standard (SNI). This standard has strong differences to the International Atomic Energy Agency (IAEA) groundwater sampling method. Therefore, SNI methods need to be compared to IAEA to observe how different the results of SNI are to IEAE. To do so this, in the 2019 campaign both methods were used and their results will be tested using the Electronegativity principle (EN %). This principal says that water is not able to carry a net electrical charge, being positive or negative, but must always be electrically neutral. Since most dissolved species carry a charge, electronegativity demands that the sum of equivalents of positively charges species matches the sum of equivalents of negatively charged species (Appelo and Psotma, 1995). This principle follows *equation 2.2-1.*

$$E.N(\%) = \frac{\sum cations + \sum anions}{\sum cations - \sum anions}\ x\ 100$$

Equation 2.2-1 Electronegativity principle equation.

2.3 **Hydrochemical facies**

Groundwater chemistry is controlled by various mechanisms, from rock-water interactions, mixing processes, cation-anion exchange to evaporation. An example of these mechanisms are the adsorption and desorption processes, consequence of clay minerals and organic matter presence. Differently, dissolution and precipitation processes can occur in case of carbonate minerals presence in the aquifer matrix (Appelo, 1994; Appelo and Willemsen, 1987; Raidla *et al.*, 2019). The controlling groundwater mechanisms give rise to the large variety of water types, which appoint certain hydro-chemical facies. Hydro-chemical facies are groups of groundwater types with similar compositions and with a unique origin or pattern of evolution (Freeze and Cherry, 1979). The composition of groundwater is highly variant, not only fluctuates with the different environmental conditioning of geology, climate or land use. This variance it is also found within the same aquifer. One of the most important works on hydro-chemistry is Stuyfzand (1989). This author has provided the main baseline for hydro-geochemical research with his studies on the evolution of groundwater chemistry along flow lines (Raidla *et al.*, 2019). Stating that groundwater flows from recharge to discharge areas, and while it is travelling these flowlines it develops from an acid to basic pH, and changes from oxic to anoxic conditions.

The most commonly physicochemical parameters studied in groundwater quality research are:

- Physical: temperature, pH, electrical conductivity (EC)
- Major cations: Na^+, Mg^{2+}, Ca^{2+} and K^+
- Major anions: Cl^-, HCO_3^-, SO_4^{2-} and NO_3^-

These are often used to assign water types, to group hydrochemical facies and understand the processes controlling the groundwater chemistry of an area (Appelo and Postma, 2005). In order to understand the water quality of this study, it is of high importance to identify its parameters. Those which generally define water quality are physical, chemical, and biological indicators such as pH, electrical conductivity (EC), total dissolved solids (referred in this research as TDS), hardness, turbidity and contaminant concentrations based on guidelines provided by agencies such as the World Health Organization WHO (2006) and the Bureau of Indonesian Standards (BSN) (Mahapatra *et al.*,2012). The chemical concentration analysed in this study are detailed in *table 2.3-1.* The water capacity to convey the electrical current is measured though the Electrical Conductivity, from now on referred in this thesis as EC. The pH acts as indicator of the strength of the water to react with the alkaline or acidic material in the groundwater samples. *Hem* (1985) states that the pH is controlled by the equilibrium of bicarbonate (HCO_3^-) and carbon dioxide (CO_2). TDS content can be classified by *Todd* and *Mays* (1980) classification into different categories, being illustrated in *table 2.3-2*. The carbonate concentration in fresh waters is dependent of dissolved carbon dioxide, temperature, pH, cations-anions and other dissolved salts. The effects of carbonate equilibrium hold the bicarbonate concentration within a moderate range: most surface waters contain 200mg/L, which is found to be higher in groundwater. Chloride is one of the most conservative ions found in nature, and it is often used to track seawater intrusion. This ion when found in groundwater it may proceed from various sources, such as weathering, domestic effluents, seawater intrusion or leaching of sedimentary rocks and soil (Appelo and Postma, 2005). Bear (1999) stated that the high content of Cl is an indication that intrusion of seawater or connate water has taken place. Calcium and magnesium are the most abundant elements in surface and groundwater, at the same time as being directly related to the hardness of water. These ions mainly exist in the forms of bicarbonate and with a smaller presence of sulphate and chloride. In most natural waters' sodium is often found as the dominant cation.

	2017	2019		2017	2019
Elevation	x	x	**K^+**	x	x
Water Table		x	**Na^+**	x	x
Temp. ***Field***		x	**NH_4^+**	x	x
EC ***Lab.***	x	x	**HCO_3^-** ***Field.***		x
EC ***Field***		x	**HCO_3^-** ***Lab.***	x	x
pH ***Lab.***	x	x	**Cl^-**	x	x
pH ***Field.***		x	**$SO_4^{=}$**	x	x
Ca^{2+}	x	x	**NO_2^-**	x	x
Mg^{2+}	x	x	**NO_3^-**	x	x
Fe^{2+}	x	x	**TDS**	x	x
Mn^{2+}	x	x			

Table 2.3-1 Concentrations analysed for sampling campaigns of 2017 and 2019.

CATEGORY	TDS (mg/L)
Freshwater	0 – 1000
Brackish water	1000 – 10,000
Saline water	10,000 – 100,000
(Seawater)	(35,000)
Brine water	> 100,000

Table 2.3-2 Division in main types on the basis of chloride concentration.

Groundwater chemistry is known to be a heterogeneous source, this heterogeneity is evidenced by the wide range of possible compositions (Freeze and Cherry, 1979). These combinations can be determined by looking at specific physicochemical parameters, such as TDS. *Freeze* and *Cherry* (1979) research categorises groundwater by TDS content; fresh, brackish, saline or brine, *table 2.3-2*. Therefore, this parameter determines the salinity levels of the water altogether with chloride and electrical conductivity (EC). This study will use the salinity classification by *Stuyfzand* (1989), as used in the classification of water types, *table 2.3-3.*

MAIN TYPE	Cl^- (mg/L)	MAIN TYPE	Cl^- (mg/L)
Fresh	≤ 150	Brackish - Salt	1000 – 10,000
Fresh – Brackish	150 - 300	Salt	10,000 – 20,000
Brackish	300 - 1000	Hyperhaline	> 20,000

Table 2.3-3 *Stuyfzand* (1989) division in main types on the basis of chloride concentration.

2.4 Types of contamination

2.4.1 Seawater intrusion

The current increasing trend of population growth in coastal areas is rising the demand for water in these areas. This demand is often challenging to be fully covered, and often other water sources are exploited in order to fulfil it, being groundwater one of these sources is groundwater. Coastal aquifers are very dynamic ecosystems, they are characterised by their freshwater-seawater sharp interface, which naturally fluctuates closer or further away from inland by tides, and other climatological events (Laprise and Pepin, 1995; Marfai *et al*., 2008; Willlis, 1998). Up to this present day it has been conceptualized following the research of: *Custodio and Bruggeman*, 1987 and *Henry*, 1959. These authors define the seawater intrusion as the steady state sharp-interfaced saltwater wedge underlying fresh groundwater and extending inland. Similarly defined by *Freeze and Cherry*, 1979; as the migration of seawater into freshwater aquifers under the influence of groundwater development *figure 2.4.1-1*.

Nowadays, other research accuses these models as oversimplification of the real situation, dismissing other characteristics of the subsoil; the heterogeneity of the soil, fluctuations of fluid densities, temperatures, and pressure gradients of groundwater (Simmons, *et al.*, 2001, Werner *et al*., 2013). This research is portraying the heterogeneity instead of the isotropy and homogeneity of the subsoil. By displaying the importance of the heterogeneity of this medium, which is described in differently by each author, from permeability distributions of sinusoidal and stochastic, geochemical reactions, different mixings from dispersive to kinematic along the interface, the effects of tidal and wave run-up, and extreme events such as tsunamis and storm surges, all influencing the distribution of fresh and saline groundwater in coastal aquifers (Custodio, 1987; De Louw *et al*., 2013; Jakovovic *et al*., 2016).

The subsoil is also experiencing other influencing pressures that did not exist before, such as climate change, geothermal activities, sea level rise or the presence of wastewater disposals (Carretero *et al*., 2013; Custodio, 2002; Döll, 2009; Ghabayen *et al*., 2006; Kundzewicz *et al*., 2007; Santucci *et al*., 2016; Sherif and Singh, 1999). The salinization of coastal aquifers is therefore a growing concern, especially given the prospects of global change, such as sea level rise and climate change (Döll, 2009; Ferguson and Gleeson, 2012; Van Lanen *et al*., 2013). This natural fluctuating state draws a balance between the freshwater aquifers and the salt groundwater from the ocean or sea body. This balance can be easily altered, not only by climate change, but also by anthropogenic activities. If groundwater is abstracted unsustainably it can lead to a subsequent lowering of groundwater levels and a deterioration in groundwater quality, also known as upconing in the sharp freshwater interface, *Figrue 2.4-2* (Custodio, 2002; Kim *et al*., 2003; Kruse and Mas Pla, 2009; Lloyd *et al*., 1982). This process is not only indicated by an increase of TDS but may also be accompanied by a shift towards $CaCl_2$ water types, if cation exchange is triggered (Appelo and Postma, 2005).

One of the reasons for decline in water quality is groundwater salinization through intrusion of seawater or relict saline groundwater from adjacent aquifers (Custodio, 2002; Kruse and Mas Pla, 2009; Santucci *et al*., 2016). These processes may trigger chemical reactions between the aquifer-forming rocks and groundwater, where the groundwater composition is altered by mixing between the intruding saltwater and fresh groundwater originally occupying the coastal aquifer (Cary *et al*., 2015). Rocks have geochemical properties, which can determine the dominant chemical processes during mixing (Carreira *et al*., 2014; Mollema *et al*., 2013).

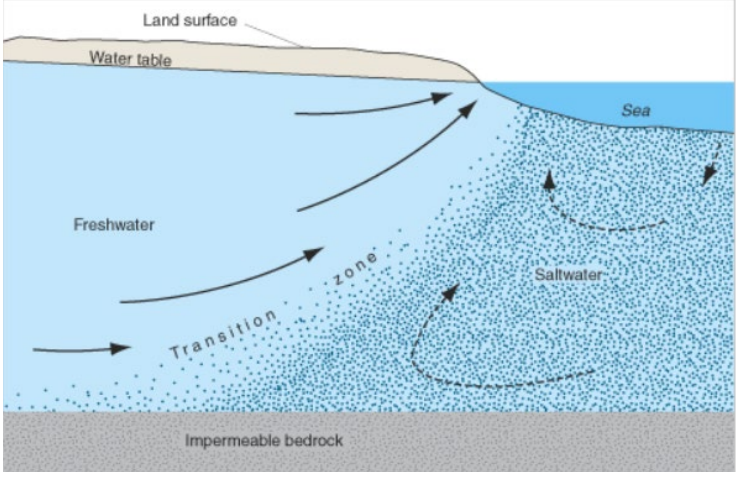
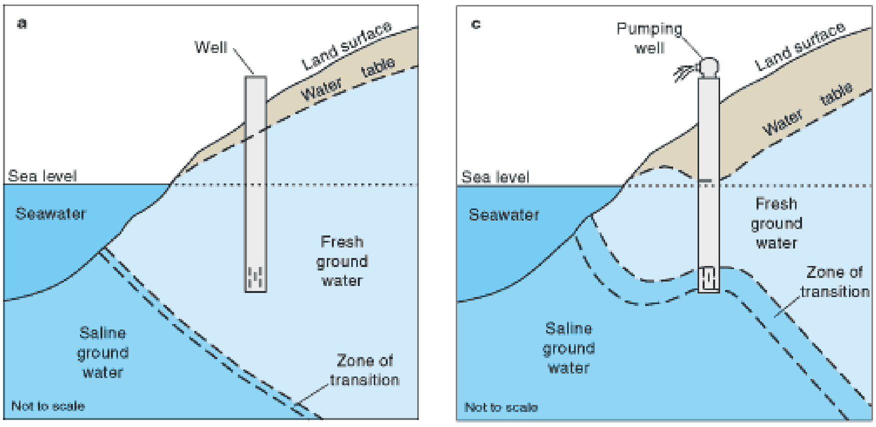
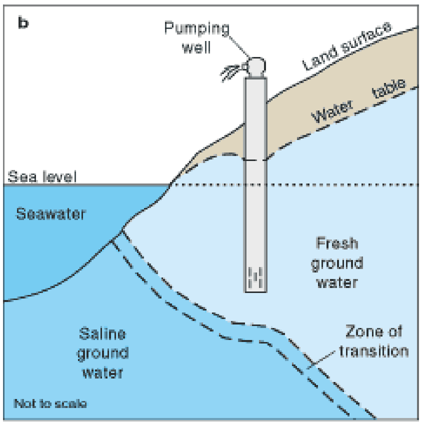


Figure 2.4.1-1 Freeze and Cherry 1979 conceptual model of the freshwater-saline water interface from a coastal aquifer, modified from *Cooper 1964*.



Nonpumping well in an unconfined (water-table) aquifer under conditions of equilibrium--no intrusion has occurred.



Well pumping from an unconfined (water-table) aquifer--seawater intrusion not affecting salinity of pumped water.

Figure 2.4.1-2 *USGS* conceptual model of the effects of pumping from a hypothetical ground-water system that discharges to a stream. (Modified from Heath, 1983).

2.4.1.1 Salinization mechanisms

Salinization of ecosystems might be results of agriculture, industry, natural conditioning or residencies. In the case of the study area of Semarang, this research recognises the land use of aquaculture, industry and residency (Suares, 1989). Groundwater is naturally high in dissolved solids from dissolving rocks and organic materials. Some rocks or minerals have a higher dissolution compared to other, which may affect the groundwater of each particular area (Sajil Kumar, 2016). The lithological formation of Semarang lowland has two types forming two different aquifers, as previously explained one is the Alluvium and the other is the Damar. Damar is tuffaceous sandstone, conglomerate and volcanic breccias. Whereas, the young alluvium formation consists of calcareous and shell bearing clay, with thin intercalations of sand, and occasional clay layers.

In the coast of the city there are aquacultures set in the coastline of the city, have increased in number with the urban development of the city. This expansion has removed the local ecosystems, mangroves. These ecosystems are known to control and diffuse saline waters in the shoreline. Without these ecosystems it is suspected that the salinity has increased. However, this should not have affected to the present groundwater, but rather to the animals living in the mangroves. Many industrial processes can increase the salinity, especially in wastewaters (Sajil Kumar, 2016; Suares, 1989). Semarang city does not have water treatment plan, and residencies and industries dump their wastewaters to the canal system taking it to the river and ending to the sea. These practices are thought to not only be affecting the salinity of groundwater but also to nitrate levels. Residencies in lowlands do not often possess septic systems, instead they often have a "hole" sanitation system, *Annex I.* Without the cementation of these systems there is a risk of contamination of nitrates to the dug wells of the area. For this matter this study will have a further analysis in nitrogen-compounds in *Chapter 6 Discussion.*

Industries of Semarang make use of groundwater for their production of goods. They declare that their abstraction is regulated and monitored every year to avoid over-abstraction and protect the surrounding areas from contamination (Putranto, Hidajat, and Susanto, 2017). However, research explains that Semarang is suffering from severe cases of saline intrusion along the coastline, in the lowlands (Abidin, *et al.*, 2013; Foster and Chilton, 2003; Imam Wahyudi, *et al.*, 2017; Jago-on *et al.*, 2009; Kagabu *et al.*, 2012; Yamano *et al.*, 2009). Even though research often refers to industries over-abstracting groundwater, often studies do not go in depth in this issue, and there is an existent need for knowledge of the groundwater system. Thus, in this thesis will look into the salinization mechanisms of Semarang lowlands.

Salinization mechanisms and origins can be understood through the studying the hydro-chemical analysis (Alcalá and Custodio, 2008; Mondal, *et al.*, 2010). The hydro-chemical analysis may start with a previsualisation of the large number of samples of chemical data through a graphical analysis in bivariate plots, Piper, Stiff, or Gibbs diagrams (Appelo and Postma, 2005; Piper, 1994). This is often supported by a statistical analysis to further understand the correlation between and amongst the studied chemicals, such as Principal Component Analysis (PCA) and Pearson. These techniques are applied in this research and from now on will be cited in this study with its abbreviations for ease of read.

The works of *Ghesquière, et al.*, (2015) and *Skrzypek*, *et al.*, (2013) show the efficiency of the previsualization techniques at identifying chemical processes and the evolution between water types. One of the most known conservative ions is chloride (Cl^-), which happens to play an important role in salinization mechanisms. This ion happens to be preserved during salinization, allowing a path for research to track the origins and mechanisms of salinization processes. Thus, these mechanisms may come to surface through the analysis of chloride versus other major ions (Appelo and Postma, 2005).

2.4.1.2 Paleo- or connate waters

The presence of paleo-seawater intrusions is recorded in confined and semi-confined aquifers in coastal zones worldwide (Kim *et al*., 2003; Groen *et al*., 2000; Raidla *et al*., 2019). Connate water or paleo-water is saline water trapped within the pore space during the rock formation, *figure 2.4.1.2-1* (Freeze and Cherry, 1979). This often happen in marine environments were sedimentary clay and silt formations under trap these saline waters (Raidla *et al.*, 2019). When this entrapped groundwater is released back into the subsoil matrix due to anthropogenic influences, or extreme weather events such as climate change, it affects the salinity of the aquifer (Kim *et al.*, 2003. Research in Semarang defines the presence of two aquifers systems with different compositions. Being the alluvium aquifer, and the Damar aquifer. The Alluvium aquifer comprises two groups, the Garang aquifer and the Quaternary marine aquifer (Abidin *et al.*, 2010; Makoto *et al.*, 2012; Putranto and Rude, 2011). This latter one may be affecting the currently occurring process of salinization, and this is expected to show evidence in the result analysis, in *Chapter 5.* In this chapter this research will analyse the water composition to spot any influence from connate waters in the current pollution at the unconfined aquifer. Therefore, salinization processes of Semarang can be understood by making use of these hydro-geochemical study practices.

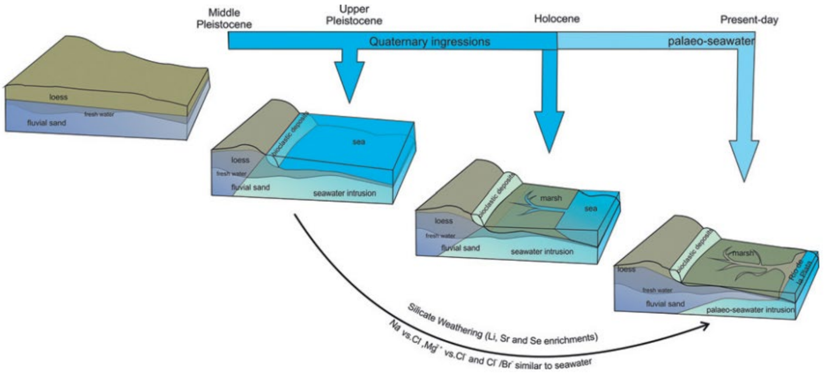


Figure 2.4.1.2-1 Freeze and Cherry 1979 conceptual model of the freshwater-saline water interface from a coastal aquifer, modified from *Cooper 1964*.

2.4.2 **Nitrates**

Nitrogen compounds are the most spread worldwide contaminants, differing from non-point to multi-point contamination (Pang *et al.,* 2013; Stigter *et* al., 2006). This contamination is often found to originate from agricultural practices. Nitrogen and nitrate/nitrite exposure are extensively studied within literature (Krishna Kumar and Sinha*.,* 2010; WHO, 2011). Previous research shows that human exposure to concentration greater than the permissible limits suppose a health risk to animals and humans: NO_3^- 50mg/L and NO_2^- 3mg/L. This is linked to several diseases, such as gastric cancer, methemoglobinemia (blue baby syndrome), diabetes, and thyroid disease (Kumar *et al.,* 2015; WHO, 2011).

This research expects to find nitrate pollution in Semarang lowlands, because literature states that the infrastructure of the city for black and grey waters is not environmentally friendly (Sadler *et al.,* 2016). Wastewaters are not treated but only transported though a canal infrastructure from the household to river to sea. This infrastructure has often breeks and creeks that may be contributing to the pollution in groundwater. Also, the sanitation system of most households (soak pits) does not have many regulations, and are often thought to be a source of point pollution (Sadler *et al.,* 2016; Yustiani, 2016). This automatically supposes a risk of contamination and will be further investigated in *Chapters 5* and *6.*

The nitrogen cycle end with a nitrogen gas phase, before it enters back into the cycle in form of precipitation, or is fixed by light. Despite of this endpoint in denitrification it can be trapped at any of the intermediate stages, which is extremely important as nitrite is significantly more toxic than nitrate (Stigter *et al*., 2006; WHO, 2004). However, the nature of nitrite is more reactive compared to nitrate. It is often found at very low concentrations; its presence is an indication of ongoing oxidation. Previous research of *Van Metre et al*., (2016) and *Zhou et al.,* (2015) will be followed in order to analyse these nitrogen compounds by making use of point-map representations.

2.4.3 **Escherichia Coli (E. coli)**

Escherichia coli is often used as indicator of faecal contamination and to test the water quality of places (WHO, 2017). The normal conditions of the soil environment are usually not generally elevated enough to support the growth of E. coli (Bartram and Pedley, 1996; Sudarno, 2016). Therefore, when these bacteria are found it is considered as evidence of faecal contamination. Similarly, to nitrite this variant of pollutant is highly reactant, this research will also analyse this compound in point-map representations. This would not only give an overview of the dug wells sampled in Semarang lowlands, but also the fluctuations between the pollution points of source.

Chapter 3 Study Area

This section describes in detail the various characteristics of Semarang lowlands in Indonesia, from its environmental challenges, to its hydrogeology going through the climatic conditions and geology.

3.1 Semarang's environmental threats

Semarang is under a climate change threat and this is increasing with time; as seas are rising and lands are subsiding they fear the capital city will inevitably end up underwater (Hadipuro and Indriyanti, 2009). Semarang's topography has a role to play in setting the conditions to be a prone flood area. It consists of two major landscapes, namely lowlands and coastal areas in the North and hilly regions in the South (Abidin, Andreas, Gumilar, and Sidiq, 2013; Imam Wahyudi, *et al.*, 2017;).

The North of Semarang has the city centre, harbour, airport and railway stations, and is relatively flat with topographical slopes ranging between 0° and 2°, and altitude between 0 and 3.5 m. Differently, in the southern part includes slopes up to 45° and an altitude up to about 350 m above sea level (Hadipuro and Indriyanti, 2009). *Putranto, Widiarso,* and *Susanto (2017)* characterize the northern part of Semarang with a relatively higher population density and land use with prominent presence of industries and business, when compared to the southern part. The northern area is at the same time the classified as the most vulnerable one of the whole city in verse of sea level rise, groundwater quality problems, and land subsidence (Marfai and Lorenz, 2007; Supriyadi and Andya Satya, 2017).

The land use of the southern part consists of residential housing, offices, retail, public use and open space areas (Putranto *et al.*, 2017). This area is more protected from the afore-mentioned threads of the city, but still under risk of flush floods caused by extreme-precipitation, and river over-flow (Harwatasari and Van Ast, 2011). The river system of the city of comprised by two rivers running through the city, one on the east side and the other one on the west side. These rivers divide the city into three parts (Abidin *et al.*, 2013; Hadipuro and Indriyanti, 2009). The river system represents a thread to Semarang's inhabitants, as it is prone to flush floods during the rainy season.

Semarang experience three flood-types; local inundation caused by extreme-rainfall events, river flooding due to water overflow from the hinterland, and tidal flood caused by high tide from the sea and the natural topography of the city (Abidin, *et al.*, 2013; Harwatasari and Van Ast, 2011; Imam Wahyudi *et al.*, 2017; Marfai and King, 2008). The above-mentioned water sources supply to mangroves, aquaculture, and industries in the area of Semarang, which evidences the high demand for water in this capital city and explains the common use of a third source, being groundwater (Putranto *et al.*, 2017). Being the above activities dependent on water, and the city economy depending on these activities, it evidences to the importance to protect the coastline, and to improve the water management of the city. By achieving this study believes that this high risk of flood destructions can be reduced, as well as the current groundwater quality problem. As aforementioned, the North of the city is the most populated area of Semarang, and therefore it will be were the area were more people will be affected by the negative connotations brought to the city by climate change. This are only enhanced by the anthropogenic activities happening in the city, which are bought to believe to be affecting the groundwater quality of northern Semarang. The activities subject of such accusation are the unregulated groundwater abstractions of industrial areas of Semarang City, which are located in the lowlands. This area is therefore the selected one for this study, and represented in *figure 3.1-1*.

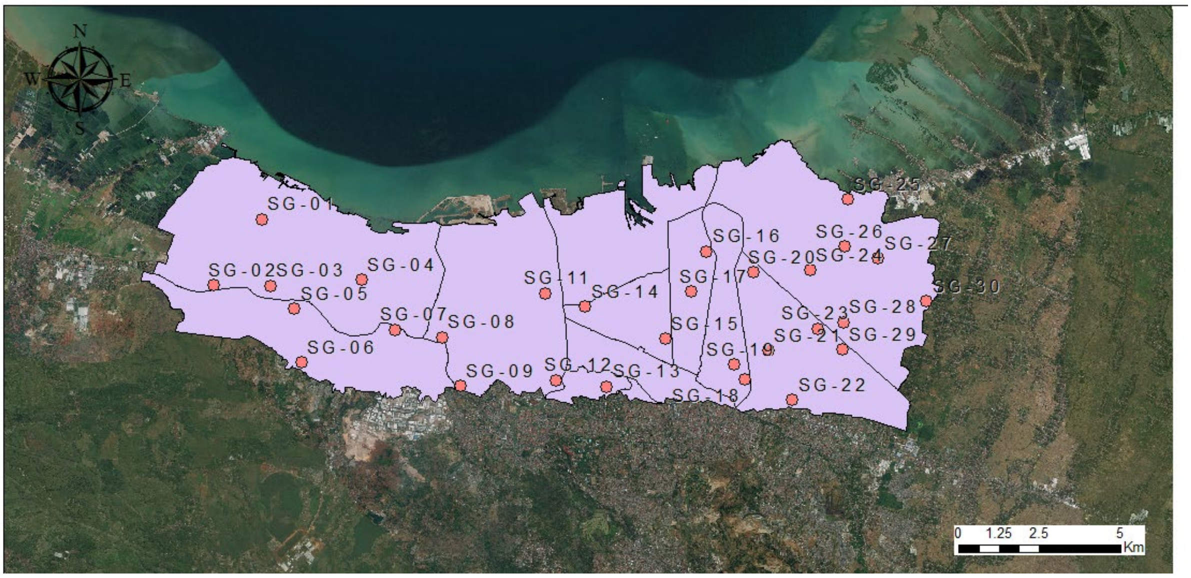


Figure 3.1-1 The purple area marks the study area of this research, delineated are the sub-districts, and marked in round red circles are the 30 sampled dug wells in Semarang City.

3.2 **Climate**

This study is based on the capital port City of Central Java Island, Semarang, which is located on the northern coast of this island (Abidin, Andreas, Gumilar, and Sidiq, 2013). Semarang has an average of air temperature from 2010 to 2014 of 28°C, and it is climatologically characterised by having two seasons i.e. the dry season, and the rainy season (Bandan Pusat Statistik, 2015; Putranto *et al.*, 2017). The estimated annual rainfall in Semarang-Demak urban varies with season, ranging from dry season being 174 mm/month to wet season being 2,396 mm/yr (BMKG, 2008). *Putranto, Widiarso, and Susanto, (2017)* states that the highest records of precipitation occur from December to January, whereas the lowest precipitation is recorded from August to September. The yearly precipitation, the yearly temperature and the annual evapotranspiration are respectively evaluated to 2511.45 mm/year; 27.5 C; and 182.78 mm/year (Rahmawati, 2010).

Semarang as a coastal developing city holding a population of more than 1.55 million people in 2010, *figure 3.2-1,* (Bandan Pusat Statistik, 2010). Semarang is at a worryingly vulnerable position, as the population of the city has not stopped growing, and the climate adversities have only increased over the last years. The climate adversary effects which Semarang has experienced up to date are mainly caused by climate change; such as sea level rise, degradation of water quality, floods, and land subsidence (Abidin, Andreas *et al.*, 2013; Foster and Chilton, 2003; Imam Wahyudi, *et al.*, 2017; Jago-on *et al.*, 2009; Kagabu *et al.*, 2012; Marfai and Lorenz, 2007; Yamano *et al.*, 2009). *Putranto* and *Rüde* (2011) calculated the groundwater recharge of an unnamed aquifer based on the meteoric water balance obtaining 316 mm/a as result. If groundwater is being overabstracted, the pumping rate will be above this calculated recharge, and can cause environmental impacts in the aquifer. Therefore, with the increase in extreme climate and water issues it is becoming rather important to know the current situation of groundwater, and the possible adaptations of Semarang to reduce the adverse impacts caused by climate change.

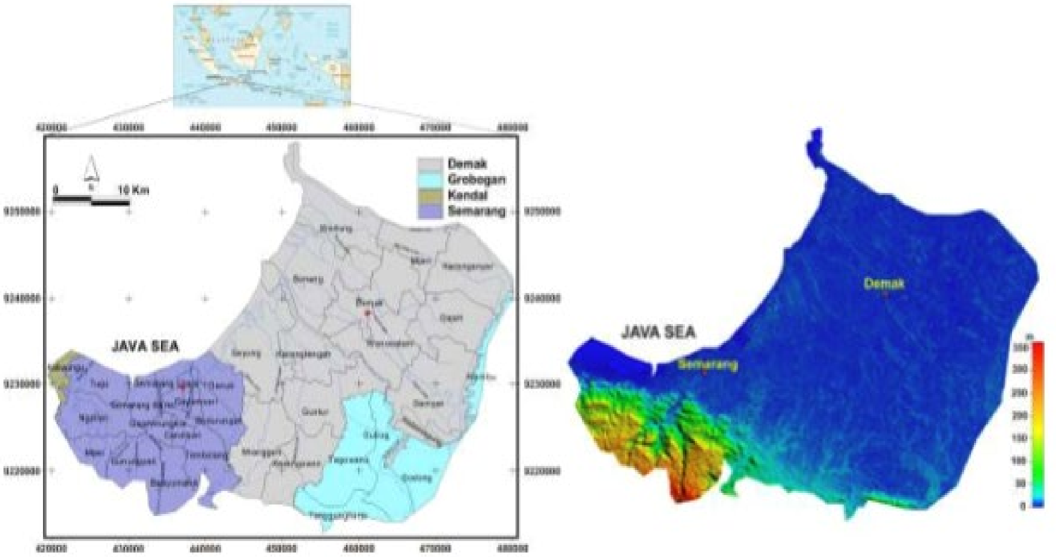


Figure 3.2-1 *Putranto and Rüde (2011)* illustrating Semarang's Digital Elevation Map (DEM).

3.3 **Geology**

According to *Abidin et al., (2013)* "Semarang has three main lithologies, namely, volcanic rock, sedimentary rock, and alluvial deposits". Geologically, the area setting consists of Damar, and Kalibiuk, formations. The baseline formation of Semarang consists of Tertiary Clay stone of the Kalibiuk Formation. Overlying this Formation is the Damar Formation, which consists of Quaternary volcanic material, being the recharge source for groundwater in Semarang City. These two formations are known to crop out in the southern part of the Semarang area, underlying the alluvial deposits. The latter are known to be located within the northern part of the city (Thanden *et al*., 1996; Sukardi and Budhitrisna, 1992; Suwarti and Wikarno, 1992).

Putranto and Rüde (2011) explain in their research that "the northern part of the Semarang area is covered by Kali Garang deltaic alluvium up to a depth of 80 to 100m in the coastal area, finding their aquifers at depths ranging from 30 to 80m". This alluvium is very young; hence it makes its compressibility very easy, which makes the found land subsidence phenomenon a naturally ongoing event in Semarang (Marfai and King, 2008; Putranto and Rüde, 2011). This natural event is known in literature to be enhanced by anthropogenic activities from the industry and growing population (Abidin *et al.,* 2013). Both of these users make unmonitored abstraction of the groundwater from different aquifers **(**Abidin *et al.,* 2013; Kuhen *et al.,* 2010; Lubis *et al.,* 2011; Marfai and King, 2008; Putranto and Rüde, 2011; Rahmawati *et al.,* 2013).

The alluvial aquifer found in the coastal areas of Semarang consists of a beach, floodplain, tidal, near-shore, and alluvial fan deposits, as illustrated in *Figure 3.3-1*. Several studies *Abidin, Andreas, Gumilar, and Sidiq, 2013* and *BGR, 2009* have reported that in the period of 1695 to 1991, the shoreline of Semarang progresses relatively quick toward the sea, namely about 2 km in 2.5 centuries or about 8 m/year in average (Rahmawati, *et al.*, 2013). This cocktail of land progression towards the sea and land subsidence, is declining the groundwater quality of costal aquifers in Semarang. By increasing the saline intrusion of the unconfined aquifers, often used as water source by most of their inhabitants.

Therefore, Semarang is up to date experiencing a natural consolidation process, causing land subsidence in the northern part of Semarang, and has been exhaustively studied (Abidin *et al.,* 2013; Lubis *et al.,* 2011; Marfai and King, 2008; Marfai and Lorenz, 2007; Purnama and Marfai, 2012; Putranto and Rüde, 2011; Kuhen *et al.,* 2010;). This land subsidence is rated to be up to 10 cm/yr in some areas in the North of Semarang (Abidin, 2005; Abidin et al, 2010;). This is causing major problems at a socio-economical scale, damaging all kind of infrastructures in the city and delaying the development of it. Land subsidence is not a new phenomenon for Semarang. However, this natural process is being accelerated by the increases in population and urban development in the area through excessive groundwater extraction, and load from buildings and structures (Abidin et al, 2010; Lubis *et al.,* 2011; Marfai and Lorenz, 2007; Purnama and Marfai, 2012).

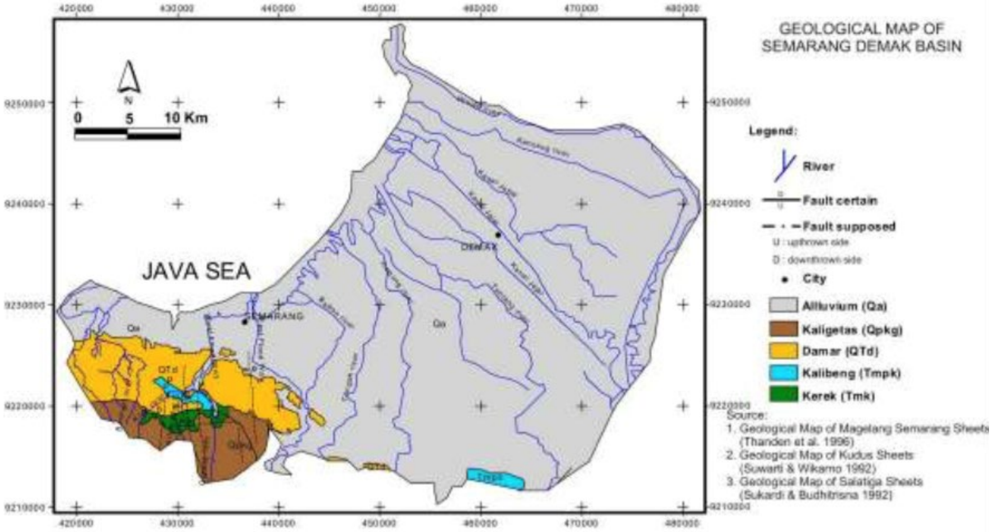


Figure 3.3-1 *Putranto and Rüde (2011)* illustrating Semarang-Demak Geological map.

3.4 Hydrogeology

Previous reports describe that there are two aquifer systems in Semarang: an unconfined aquifer and a confined one (Arifin and Mulyana, 1990; Arifin and Wahyudin, 2000; Mulyana and Wahid, 1994; Putranto *et al.*, 2014; Said, 1974; Sihwanto *et al.*, 1988; Spitz and Moreno, 1996;). As mentioned in *section 2.4.1.1*, the alluvial deposits consisting of intercalating sand and clayey sand (Abidin, *et al.*, 2013). *Putranto and Rüde (2016)* mention in their research "in this alluvium sediments aquifers are found at depths ranging from 30 to 80 m". Furthermore, the depth of the groundwater table of this alluvium area ranges from 0.1 to 21.8 m below ground surface with increasing depth towards hilly areas in the South (Putranto *et al.*, 2014; Susana and Harnandi, 2007).

The variations of the water table are hold onto two different reasons. The first one is linked in literature to seasonal variations of high and low in the rainy and dry seasons (Hadipuro and Indriyanti, 2009; Putranto, Widiarso and Susanto, 2007). The second one is linked to the topographic shape of the city of Semarang (Abidin, 2005; Abidin *et al.,* 2013; Putranto and Rüde 2011; Rahmatullah, 2010;). Marine sediments in the coastal areas and volcanic ones in hilly areas are the predominant form in the confined aquifer. This confined aquifer is known to be composed by multiple layers separated by clay layers, acting as aquitards. Literature illustrated in *Figure 3.4-1* that the confined aquifer comprises three groups; those are Quaternary marine, Garang, and Damar. The Quaternary marine and Garang groups are quite similar in the lithological characteristics. They can only be distinguished by a hydrogeochemical source. Moreover, the Garang aquifer contains freshwater, whereas the Quaternary marine aquifer shows brackish or salty water. On the other hand, volcanic-sedimentary rocks dominate the Damar aquifer (Putranto and Rüde, Groundwater Problems in Semarang Demak Urban Area, 2011). Two main types of sediment; soft and hard rock in Semarang, and therefore this study will be looking at two different systems of recharge. This study aims to support and develop new knowledge in the groundwater quality of the area and its system and processes.

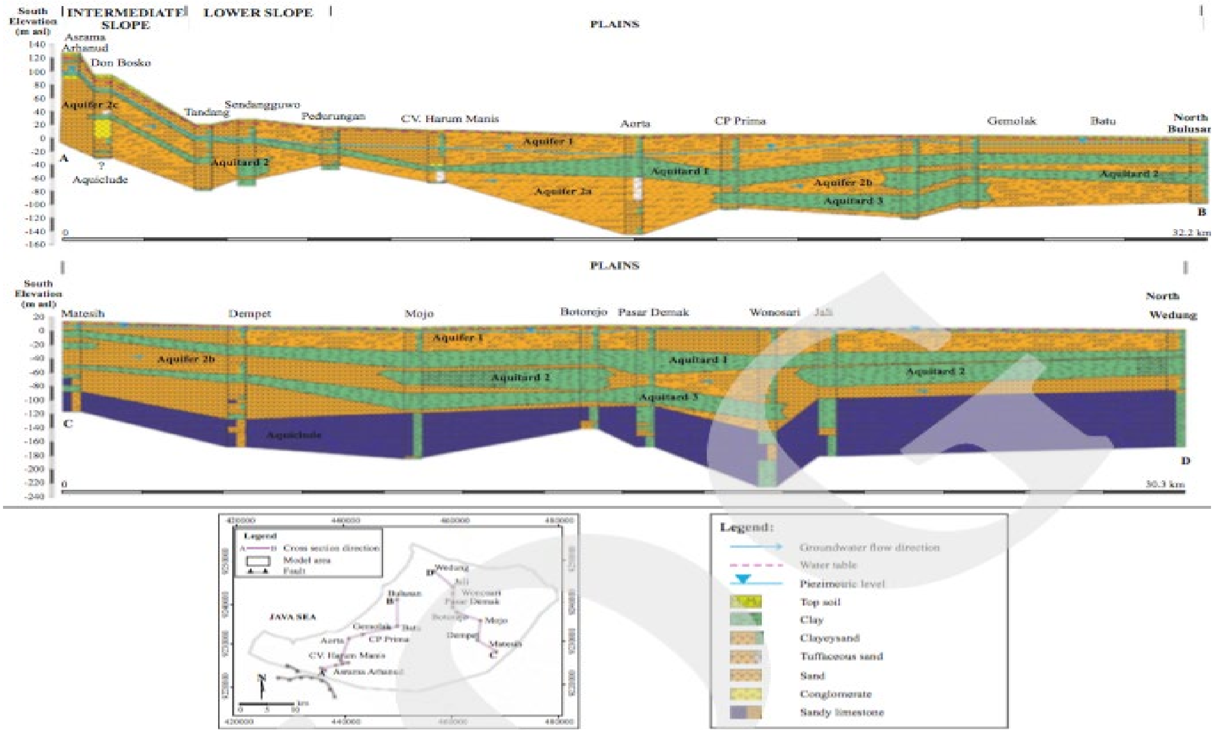
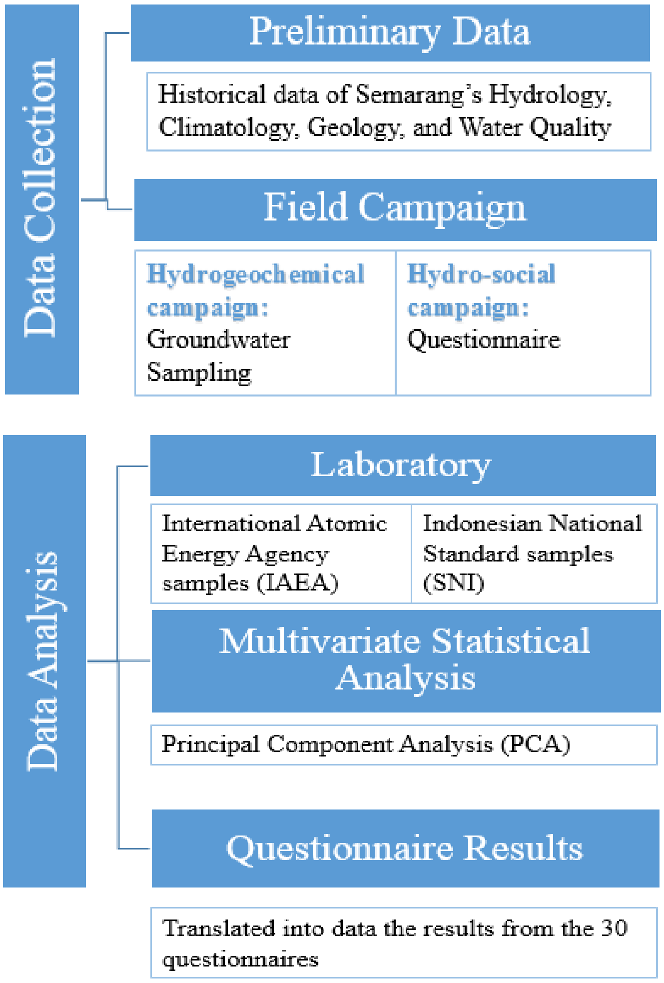


Figure 3.4-1 Cross-section of Semarang from Putranto and Rüde (2016) showing the various lithologies, number of registered deep wells, and total abstraction in Semarang-Demak groundwater basin (Directorate of Environmental Geology (DGTL), 2003; Dinas Energi dan Sumber Daya Mineral (DESDM) Prov. Jateng, 2012).

Chapter 4 Materials and Methodologies

This section details the various applied methods to answer the research questions of this study. Describing the used materials and applied methods to achieve the goals and test the hypothesis of this research.



Scheme 1. Graphical representation of the methodology applied in this master thesis.

4.1 Preliminary Data Collection

4.1.1 Hydrogeochemical campaign

This research carried out a pre-collection of historical data previous to the hydrogeochemical field campaign. During this pre-campaign historical data is collected, including; the history, geology, hydrogeology, hydrology, and climate of the study area. The historical geological, hydrogeological, hydro-chemical and hydrological data is abstracted from the main published works in hydrogeology of the Semarang City. The climate data is obtained from the regional climatological centre in Semarang City, Meteorology, Climatology, and Geophysics Agency in Semarang. The land use and neighbourhood delineation information is abstracted from the website of *Tanahair.indonesia.go.id. (2019).* This research applied two methods for groundwater sampling; one method used the protocol by the International Atomic Energy Agency (IAEA), and the second protocol is the Indonesian National P, named Standard Nasional Indonesia (SNI) (Groundwater Sampling Procedures for Isotope Hydrology, 1998; SNI 6989-58-2008 Metoda Pengambilan Contoh Air Tanah, 2015). During the second sampling campaign these two different protocols used; IAEA and SNI, and also included the sampling of *Escherichia coli*, from now on referenced in this thesis as *E. coli*. The limitations for human consumption of the water quality are sourced from two different sources, from the Global standards of WHO (Guidelines for Drinking-water Quality, 2017), and the National Indonesian Standards (Peraturan Menteri Kesehatan Republik Indonesia Nomor 492/Menkes/Per/IV/2010 tentang Persyaratan Kualitas Air Minum, Dengan Rahmat Tuhan Yang Maha Esa, Menteri Kesehatan Republik Indonesia, 2010).

4.1.2 Hydrosocial campaign

This research uses global and local research on sanitation and drinking water. As well as, collecting data of the global and Indonesian standards for clean water and sanitation (Guidelines for Drinking-water Quality, 2017; Peraturan Menteri Kesehatan Republik Indonesia Nomor 492/Menkes/Per/IV/2010 tentang Persyaratan Kualitas Air Minum, Dengan Rahmat Tuhan Yang Maha Esa, Menteri Kesehatan Republik Indonesia, 2010; United Nations (UN), 2017; United Nations (UN) (2018); United Nations (UN), 2018). From the first sampling campaign (hydrogeochemical campaign) this study designed a questionnaire for the selected 30 dug well owners. This questionnaire followed research ethics of a voluntary participation and kept the privacy of the interviewee.

4.2 Methodologies for field data collection

4.2.1 Hydrogeochemical campaign

This sampling campaign is comprised by the physical and the chemical sampling of the groundwater from dug-wells in Semarang City. In order to understand the water quality of this study, is of high importance to identify its parameters. These defining practices are water quality are physical, chemical, and biological indicators using indicators such as pH, electrical conductivity (EC), total dissolved solids (TDS), hardness, turbidity and contaminant concentrations based on guidelines provided by agencies such as the World Health Organization WHO (2006) and the Bureau of Indonesian Standards (BSN) (Mahapatra et al., 2012).

The physical and chemical parameters sampled during this campaign are detailed in *figure 4.2.1-1.* The followed sampling protocol for E. coli was given by the Public Health Department of University of Diponegoro (UNDIP). From now on cited in this research as UNDIP. This protocol was designed to fit the sampling capacities of the university, following a similar methodology for the groundwater sampling by Bordner *et al.,* (1978), Environmental Protection Agency (EPA) (2002), and Harter *et al.,* 2014. The E. coli sampling method involved:

1. Collected in sterilized autoclave brown glass bottles of 300mL with leak proof lids
2. Neutralized with 3mL sodium thiosulfate (1mL of a 10% solution per litre of water).
3. After the samples were collected they were preserved and transported with a cooler.

The hydrogeochemical sampling campaign followed two different protocols. The first one is the groundwater sampling protocol by the International Atomic of Energy Agency (IAEA), and the second one is the groundwater sampling protocol by the national standard of Indonesia (SNI). The latter method was applied in the 2019 campaign and in the first field campaign in 2017 by the University of Diponegoro (UNDIP). Differently, IAEA protocol was only applied in 2019. SNI protocol differs from IAEA by its refrain to collecting 500mL water samples from each dug well (without filtering water), using an opaque plastic water bottle (not acidified), and kept at room temperature. Since the 2017 campaign was sampled using the SNI protocol, this study wanted to test for differences in their respective results. In the sampling campaign of 2019, the two types of dug well samples were processed differently in the laboratory following its respective protocol, details found in *Section 4.1*. The first group, IAEA, was ready to be directly analysed in the laboratory. The second group, SNI, was firstly measured for its colour, taste, smell, EC, pH and taken its turbidity measured. Before moving onto the preparation of the samples for their analysis of ions by filtrating and acidifying them.

Physical parameters	**Chemical parameters**	**Biological parameters**
• Groundwater table (WL) • pH • Alkalinity • Dissolved Oxygen (DO) • Temperature • Electrical Conductivity (EC) • GPS Location	• *Cations*: Ca^{2+}, Mg^{2+}, Fe2+, Mn^{2+}, K^{+}, Na^{+}, Li^{+}, NH_4^{+} • *Anions:* CO_3^{-2}, HCO_3^{-} Lab, Cl^{-}, $SO_4^{=}$, NO_2^{-}, NO_3^{-} • Total Hardenss (Kes; $CaCo_3$) • Taste (Rasa), Smell (Bau), and Colour (Warna) • Total Dissolved Solids (TDS)	• *Escherichia coli* (E. Coli)

Table 4.2.1-1 Table of the collected physical and chemical parameters for the groundwater samples.

4.2.2 Hydro-social data collection

The second field campaign was carried out for a deeper understanding of water uses. Via the previously mentioned voluntary questionnaire to all household owners of dug-wells. The aim of this questionnaire is to obtain an understanding of the current sanitary and clean water situation of Semarang City. At the same time as understanding the local knowledge on groundwater, water uses and practices.

4.3 Materials for Data Collection

4.3.1 Hydrogeochemical Campaign

This study made use of different materials for the collection of the groundwater samples for the physical parameters, the chemical parameters for the IAEA and SNI protocols, and *E. coli*, detailed in *figure 4.3.1-1.*

Sampling Equipment for Physical parameters	**Sampling Equipment for Chemical parameters**	**Sampling Equipment for *E. Coli***
• EC meter • pH meter • Alkalinity test w3n • Nitrate strips • Oxi 3310 SET1 2BA301 WTW DO meter • 50 meter tape • GPS GARMIN 64s	• 90x 120mL Sealing plastic water bottles • 30x 500mL Sealing plastic water bottles • 2x Syringes • 50x GxF cell membrane of 0.45μm, 25mm HLPC Certified filters • 30x GHP cell membrane0.45μm, 25mm HLPC Certified filters [2] • Acid (HNO3) for the preservation of cations • 3x Pipettes of 3mL • 2x Cooler box	• 30x 300mL Autoclave Brown Glass bottles • Aluminum paper • Sterilizer (fire) • Gloves • Cooler box

Figure 4.3.1-1 Table of materials used for the collection of physical and chemical parameters.

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[1] **GxF cell membrane filters:** multi-layered glass fiber prefilter. Acrodisc is a registered trademark of Pall Corporation.

[2] **GHP cell membrane filters:** hydrophilic PP membrane suitable for both aqueous and organic samples. Acrodisc is a registered trademark of Pall Corporation.

4.3.2 Hydro-social Campaign

The materials used in the hydro-social campaign were comprised by the production of 30 questionnaires to the dug wells' owners. Each questionnaire is had 22 questions of a,b,c-type, *Annex 1.*

4.4 Laboratory analyses

4.4.1 Hydrogeochemical laboratory analysis

The groundwater samples were analysed in the laboratory of "Laboratorium Mekanika Tanah and Batuan PAG Badan Geologi". As previously explained the IAEA and SNI sample groups where analysed differently in the laboratory. SNI had a turbidity test done, before moving onto the filtration and preservation via acidification to perform the analysis of ions. This protocol establishes a maximum period of storage of being under 2 weeks. IAEA samples were analysed directly with no need of pre-treatment. Both samples were analysed following the same laboratory methods, *table 4.4.1-1*. The laboratory protocol is under the Indonesian standards (SNI).

Measurement	Laboratory procedure
K^+, Na^+, Li^+, Ca^{2+}, Mg^{2+}	Ion Chromatography
Fe2+, Mn^{2+}	Atom Absorption Spectrophotometry
HCO_3^-	Volumteri (Alkalinity Test/Titrimetric)
Cl^-	Volumetri (Argentometri/Titrimetric)
SO_4^{2-}, NO_2^-, NO_3^-, NH_4^+	Spectrophotometry
pH	Potensiometry
EC	Conductometry
Colour	Spectrometry
Turbidity	Turbiditymetry
E. Coli	Dilution method

Table 4.5.1-1 List of the different laboratory procedures applied for the analysis of the groundwater samples of Semarang Lowlands.

4.4.2 Bacterial (E. coli) laboratory analysis

Following EPA's guidelines (2002) and SNI 01-2332.1-2006, *E. coli* samples were analysed as after its collection. This research did not hold these samples for longer than 6 hours, because of holding time limitations. Analyses on the samples were finished within 8 hours of sample collection. *E. coli* samples were analysed by the Most Probable Number (MPN) method following the dilution method by *Salamat et al.,* (1978). The coliforms were tested for by inoculation of samples into tubes of lactose broth by Collins and Lyne (1976):

1. This requires 3 series tube, which are the respective the presumptive test 10mL, confirmed test 1mL and completed test 0.1mL.
2. These are inoculated and incubated at 35 ± 0.5°C. After coliforms, these colonies were counted.
3. These tubes used the triplo repetition, which means that measurements were repeated three times (Dayanti *et al.*, 2018).
4. After taken the three measurements the code from obtained the positive results records, this study used the World Health Organisation (WHO) table to obtain the respective MPN Index and confidence limits. Find the results and WHO table in *Annex II.*

4.5 Data analyses

4.5.1 Hydrogeochemical data

The results from the laboratory analysis were plotted with ArcGIS and QGIS, to visualize the variation in time of the chemical components of the groundwater of Semarang lowlands. By making use of the geographic information, and the interpolation of data points to produce contour maps, and the distribution of the physical and chemical parameters.

Prior to the analysing of the laboratory results, this study performed the Electro Negativity (EN) principle to test for the reliability of the samples. This method calculates the ion balance errors of each sample, *Equation 4.5.1-1*. This principal says that water is not able to carry a net electrical charge, being positive or negative, but must always be electrically neutral. Since most dissolved species carry a charge, electronegativity demands that the sum of equivalents of positively charged species matches the sum of equivalents of negatively charged species (Appelo and Postma, 2005).

$$E.N(\%) = \frac{\sum cations + \sum anions}{\sum cations - \sum anions}\ x\ 100$$

Equation 4.5.1-1 Electronegativity principle equation.

The variation amongst the water samples was studied through the laboratory data. By analysing the ion concentrations and parameters for hydro-chemical facies and water types analyses and its classification. The data analysis of the analysed 30 dug wells was done through the software ANDAD (Gonçalvez de Sousa, 2002), and EasyQuim (UPC-CSIC, 2013). Grouping the chemical results into diagrams and charts to assist clustering and spatial distribution of the water types. In order to assist the classification of water types using the concept of hydro-chemical facies developed by Stuyfzand (1989).

This research will use *Appelo and Postma* (2005) mass balance calculation, in order to get a more detailed picture of the groundwater processes, and the contribution of sea water into the system. This formula is often used in the conservative mixing of seawater and freshwater to calculate each ion concentration (X), *equation 4.5-2*. This research chooses the freshwater sample from well SG14 as endmember, and the *Appelo and Postma* (2005) standard of seawater composition for the second endmember. The results will be displayed in the ratio and scatter graphs of major ions for both sampling campaigns, *Chapter 5 Results*.

$$m_{i_{mix}} = f_{sea} * m_{i_{sea}} + m_{i_{fresh}} * (1 - f_{sea})$$

Equation 4.5-2 *Appelo* and *Postma* (2005) mass balance equation of seawater contribution in groundwater.

Where $m_{i_{mix}}$ (in meq/L) is the mix concentration of specific ion (i), f_{sea} is the fraction of seawater, and sea and fresh indicate the conservative mixture of seawater and freshwater endmembers. m_i is the ion concentration of each endmember. The hydrochemistry results require to undergo into a statistical analysis to further understand the groundwater processes occurring. A systematic study of correlation and regression coefficients of the water quality parameters not only helps to assess the overall groundwater quality but also to quantify relative concentration of various pollutants in water (Dash *et al.,* 2006). At the same time as studying the origins of the groundwater through water types and chemical pairs. In this research, an attempt has been made to evaluate the quality of groundwater in the lowlands of Semarang and thereby to analyse correlation and regression study of various physico-chemical parameters, *Figure 4.5.1-1*. These physico-chemical parameters were chosen with the knowledge that groundwater often consists of seven major chemical elements; Ca^{+2}, Mg^{+2}, Cl^-, HCO_3^- Na^+, K^+, and SO_4^{-2}. In addition to these ions this research added other minor ions; Fe^{2+}, Mn^{2+}, Ammonium (NH_4^+) and nitrates (NO_2^-, NO_3^-, and E. coli).

	2017	2019		2017	2019
Elevation	x	x	**K^+**	x	x
Water Table		x	**Na^+**	x	x
Temp. ***Field***		x	**NH_4^+**	x	x
EC ***Lab.***	x	x	**HCO_3^-** ***Field.***		x
EC ***Field***		x	**HCO_3^-** ***Lab.***	x	x
pH ***Lab.***	x	x	**Cl^-**	x	x
pH ***Field.***		x	**$SO_4^=$**	x	x
Ca $^{2+}$	x	x	**NO_2^-**	x	x
Mg^{2+}	x	x	**NO_3^-**	x	x
Fe2+	x	x	**TDS**	x	x
Mn^{2+}	x	x			

Table 4.5.1-1 Concentrations analysed for sampling campaigns of 2017 and 2019.

4.5.2 Multivariate analyses of Hydrogeochemical and physical parameters

This study used a multivariate statistical analysis for the groundwater samples, to identify the controlling processes of the unconfined aquifer of Semarang City. These statistical analyses used the data from the field campaign. The results from these field campaigns gave us the chemical parameters which were present throughout the 30 dug wells, and were used to identify the significant role they play in the classification of their water qualities. This classification helped with the understanding of fluctuating concentrations of predominant cations, anions and their interrelationships. This chemical data is then presented in graphical form to obtain a simpler understanding of the complex groundwater system. The methods used to represent the groundwater chemistry are Piper plot, Gibbs plot, Schöeller, and Principal Component Analysis (PCA), which from now on Principal Component Analyses will be referred as PCA in this thesis. These methods have been used in many parts of the world to show the latent relationships amongst the various ionic concentrations in individual samples, and are making use of these statistics in the work with the same objective (Pan and Ritcher, 2019).

4.5.3 Principal Component Analysis (PCA)

PCA is a statistical method which allows to reduce the extension of a large dataset by explaining the correlation amongst its variables (Abou Zakhem *et al.,* 2017; Helena *et al.,* 2000; Ravikumar and Somashekar 2017). PCA obtains eigenvalues from the sampled data, and forms Principal components (PC), from now on referred in text as PC, which are unrelated to each other (Abou Zakhem *et al.* 2017; Pan and Richter, 2019; Ravikumar and Somashekar 2017). To process the results of this research using PCA, it was used the cutting point of 1 for the eigenvalues of the results of 2019 and 2017. PCs gives details regarding the total variance of the sampled data, in this case of groundwater from the dug wells in Semarang lowlands. This research followed the works from the authors *Cattell and Jaspers* (1967), to choose the cut-off significance point of >1 for the total variance of PC of the PCA analysis. This research grouped the loadings larger than 0.5 to observe what correlation exists between those variables. The results are interpreted and discussed in *Chapter 6* by making use of site characteristics: land use, Sanitation system, and climate factors.

This multivariate method is applied in this research by using the multivariate statistical software ANDAD 7.10 (Gonçalves de Sousa, 2002). This research uses this software to carry out a multivariate statistical analysis: PCA. PCA performs in terms of a smaller number of underlying factors (principal components or PCs) without losing much information (Helena *et al.,* 2000; Jackson, 1991; Meglen, 1992). The analysed variables using this PCA are detailed in *figure 4.5.3-1.*

PCA Variables		
Cations	**Anions**	**Others**
Ca^{2+}	Cl^{-}	E. coli
Mg^{2+}	SO_4^{2-}	WT
Fe2+	NO_2^{-}	pH
Mn^{2+}	NO_3^{-}	DO
K^{+}		Alk
Na^{+}		
$NH4^{+}$		

Table 4.5.3-1PCA variables for sampling both campaigns of 2017 and 2019. WT stands for Water Table, DO stands for Dissolved Oxygen, and Alk stands for Alkalinity,

4.5.4 **Escherichia Coli (E. Coli) and Nitrogen components analysis**

The results from the laboratory analyses of E. coli and Nitrogen compounds nitrate/nitrite were analysed by visualising the spatial distribution of 2017 and 2019 results through the software ArcGIS (Osrmby *et al.*, 2010). Global water guidelines of WHO were used for reference and scaling (WHO, 2015).

4.5.5 **Hydro-social campaign qualitative analysis**

This qualitative analysis was based on the 30 interviews to dug-wells owners that will be carried out during the fieldwork in Semarang. This data was analysed using Excel, and used to contribute with the understanding of the perspective of inhabitants of Semarang lowlands on groundwater. At the same time, this data also provided information on the influence of sanitary infrastructures to the quality of groundwater.

Chapter 5 Results

This section describes the results obtained during the fieldwork campaign in May of 2019 and 2017. Starting with the general characterisation of the hydrogeochemistry of the area, and moving into the various kinds of pollution found to be present in Semarang Lowlands. Therefore, this section does not only treat with chemical, also spatial, and statistical data. The latter is analysis carried out with the aim to understand the significance of the chemical reactions happening and the interrelations amongst the measured chemical components.

5.1 Hydrogeochemistry

5.1.1 Ion balance error after the laboratory processing

The results for the principle of electronegativity (EN %) for 2017 and 2019 sampling campaign are displayed in *figure 5.1.1-1*, showing the reliability of the results of both sampling campaigns. *Figure 5.1.1-1* displays a higher error balance for IAEA compared to SNI sampling method. IAEA has 26 samples in the 1-5% range, where SNI has 24 samples. In the -4 – 0 range, IAEA has 4 samples and SNI has 6. The electronegativity of the 2017 sampling campaign was also analysed using the EN principle. Results are displayed in *Figure 5.1.1-1*, showing a high error balance for 2017 compared to 2019. SNI 2017 has 15 samples in the 6-10% range and one sample above this range (10.1%).

The conservation of groundwater samples is rather important to avoid any contamination. This contamination may be originated from chemical, biological and physical reactions, caused by bacteria, spillages, precipitation, etc (IAEA, 2014). Since this study has two different sampling methods, SNI and IEAE a validity of SNI results is required for the comparison of both years. The first campaign of 2017 followed the Indonesian National Standard (SNI) of groundwater sampling, *Annex II*. This standard differs from the International Atomic Energy Agency (IAEA) groundwater sampling method, *Annex II*. Therefore, both methods were compared in order to observe its differences between the results of SNI to IEAE. In the EN 2017 results there is a higher error percentage in 2017 compared to 2019, but it remained within the acceptable limits. However, the electronegativity results of SNI from 2017 to 2019 were quite variable, *figure 5.1.1-1.* This study speculates that this difference between EN (%) may be subject to the time the samples were hold before their analysis. A delay in the delivery of water samples gives the solution more time to react and precipitate, or oxidize, changing the original chemistry, which was not the case for this research but may have influenced the skewness of the EN(%) results, *figure 5.1.1*-1. When calculating the Ion Balance Error (%) for cations and anions it displayed that where the problem relies in the cations, *figure 5.1.1*-1. Since all samples fall within the acceptable EN (%), this research can use them for the purpose of this study, which is to compare the hydrogeochecmistry of the two

sampling campaigns.

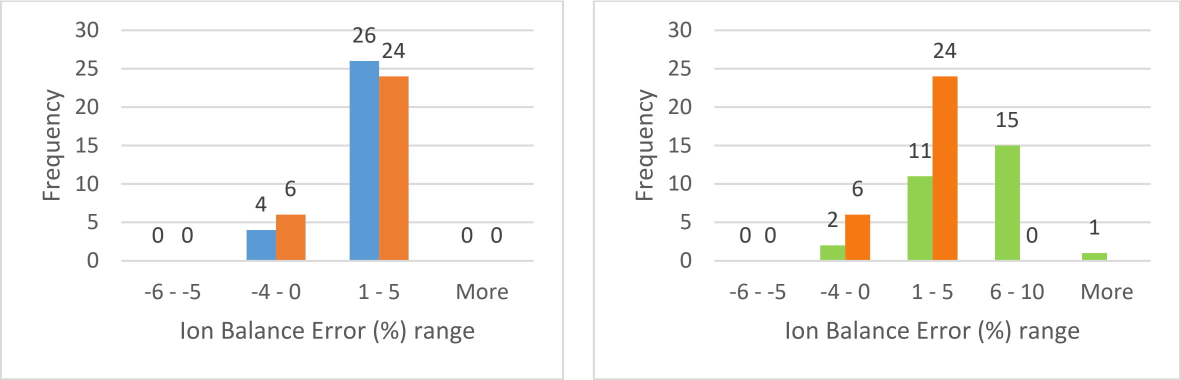


Figure 5.1.1-1 The histogram on the left is from the 2019 sampling campaign displaying the electronegativity values for the International Atomic Energy Association IEAEA (in blue) and for the Indonesian National Standard (SNI in orange). The histogram on the right displays the electronegativity (%) ranges for the Indonesian National Standard (SNI) for the sampling campaign of 2019 (in orange) and for 2017 (SNI in green).

This study applied another quality assurance calculation for further understanding of the surplus (6-10 %) of electronegativity in 2017. The results, displayed in *Annex II*, showed that the excess percentage of error belongs to the cations found in solution. The results of 2017 hint to this thesis that there might have been influenced by the sampling collection practices, and this will be discussed in *Chapter 6 Discussion.*

5.1.2 Natural groundwater chemical processes and evolution

Figure 5.1.2-1 shows the results of the Gibbs diagram, where it illustrates that the 30 dug well samples for Semarang lowlands are mainly within two categorised areas: being rock and oceanic/evaporation dominance for 2019 and 2017. *Figure 5.1.2-1* illustrates in blue the ratios for cations Na/(Na+Ca) and anions (Cl/(Cl+HCO3) for 2019, and in orange for 2017. There are small differences between both sampling years. At first sight 2019 cation samples are less spread out when comparing it with 2017 samples. This observation is also found in the anion ratio. The anion figure shows that most of the samples are concentrated on the left side of the Gibbs diagram, and seven samples plot in the area of oceanic or evaporation domain. These observations show a fluctuation between sampling years, and a chance of having seawater intrusion in some of the dug well samples. These observations add up to the previous suspicion of the dug well groundwater quality being polluted, and will be further discussed in *Chapter 6 Discussion.*

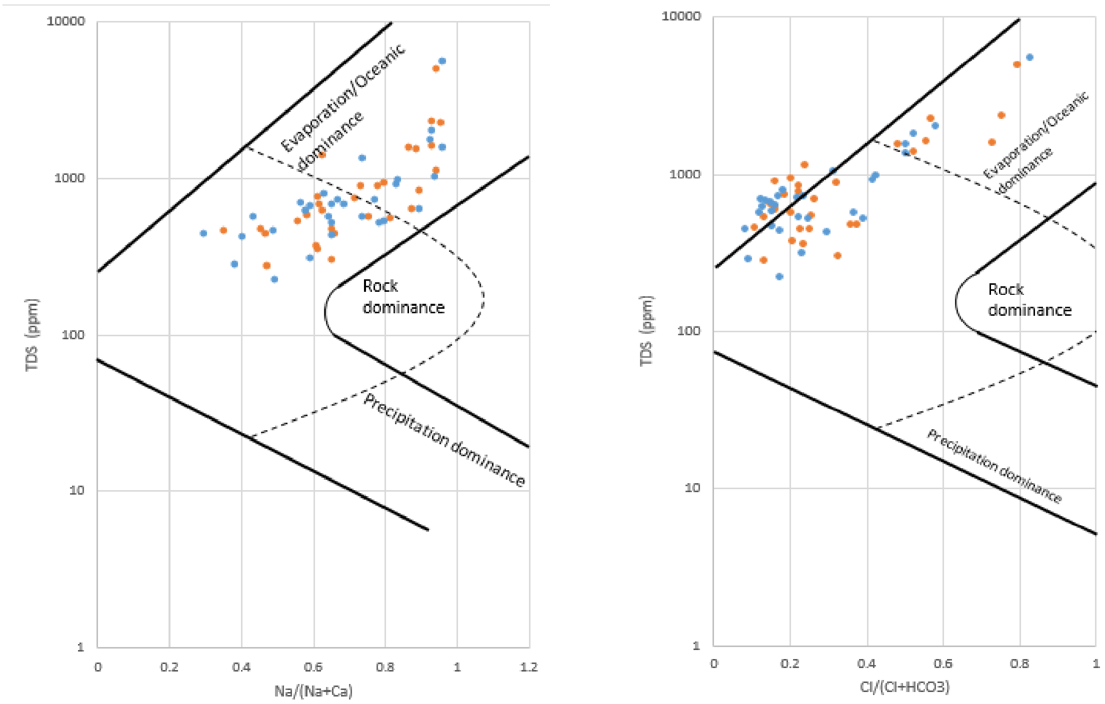


Figure 5.1.2.-1 Gibbs diagrams for 2017 (in orange) and 2019 (in blue), left for cations and the right for anions, for the 30 dug wells in Semarang Lowlands**.** Within the black dashed line there is the rock dominance area.

Similarities and differences among groundwater samples are revealed through the Piper diagram, *figure 5.1.2-2.* Within these triangles the distribution of major cations and anions of the 30 dug well samples is observed for 2017 and 2019. These samples are then combined and illustrated within the diamond shape area (Appelo and Postma, 2005). These combinations will be representing the main groundwater facies found in Semarang lowlands. Piper diagram results shows a high dominance in cations of Ca, and Na, and in anions of HCO_3 and Cl for both years. In both years, the data clusters over the groundwater type Ca-HCO_3 and Na-HCO_3 for fresher waters (<1500 µS/cm), and spreads to right side of the diamond shape, reaching towards the groundwater facies of Na-Cl and Na-HCO_3 for more brackish waters (>1500 µS/cm). These 60 dug well samples fall within the groundwater facies of: Ca-HCO_3, Ca-Cl, Na-HCO_3 and Na-Cl. From these findings it is understood that in some dug wells there is some seawater intrusion in Semarang lowlands.

The differences between the more groundwater facies of brackish samples arise when comparing the dug wells samples from 2019 (light blue) with the 2017 (navy blue) ones. In 2019, brackish samples cluster on the lower right part of the diamond shape, showing up in the groundwater facies of Na-Cl and Na-HCO_3. In 2017, brackish samples are more disperse across the right side of the diamond shape. They appear to move from Ca-HCO_3 to Na-Cl and Na-HCO_3 water types. This is indicative to the brackish dug well samples of 2019 and 2017 to be under a different influence. Since 2019 appears to be more abundant in sodium compared to 2017, which shows to have less sodium and more calcium in its water types.

Freshwater samples of 2019 and 2017 differ between years. In white it shows the 2019 samples, which are mostly present on the lower right part of the diamond belonging to the water type Na-HCO_3 and Na-Cl. Differently in 2017 freshwater samples are more clustered on the left-hand side of the diamond shape, within the water type of Ca-HCO_3. Again, the results show a different mineralizatrion for groundwaters, which may be understood as having different influences in each year and therefore other processes may be ocurring, i.e. freshening. In order to reach clearer conclusions, this study takes these differences to a deeper analysis with bivariate plots, *figure 5.1.3-1.*

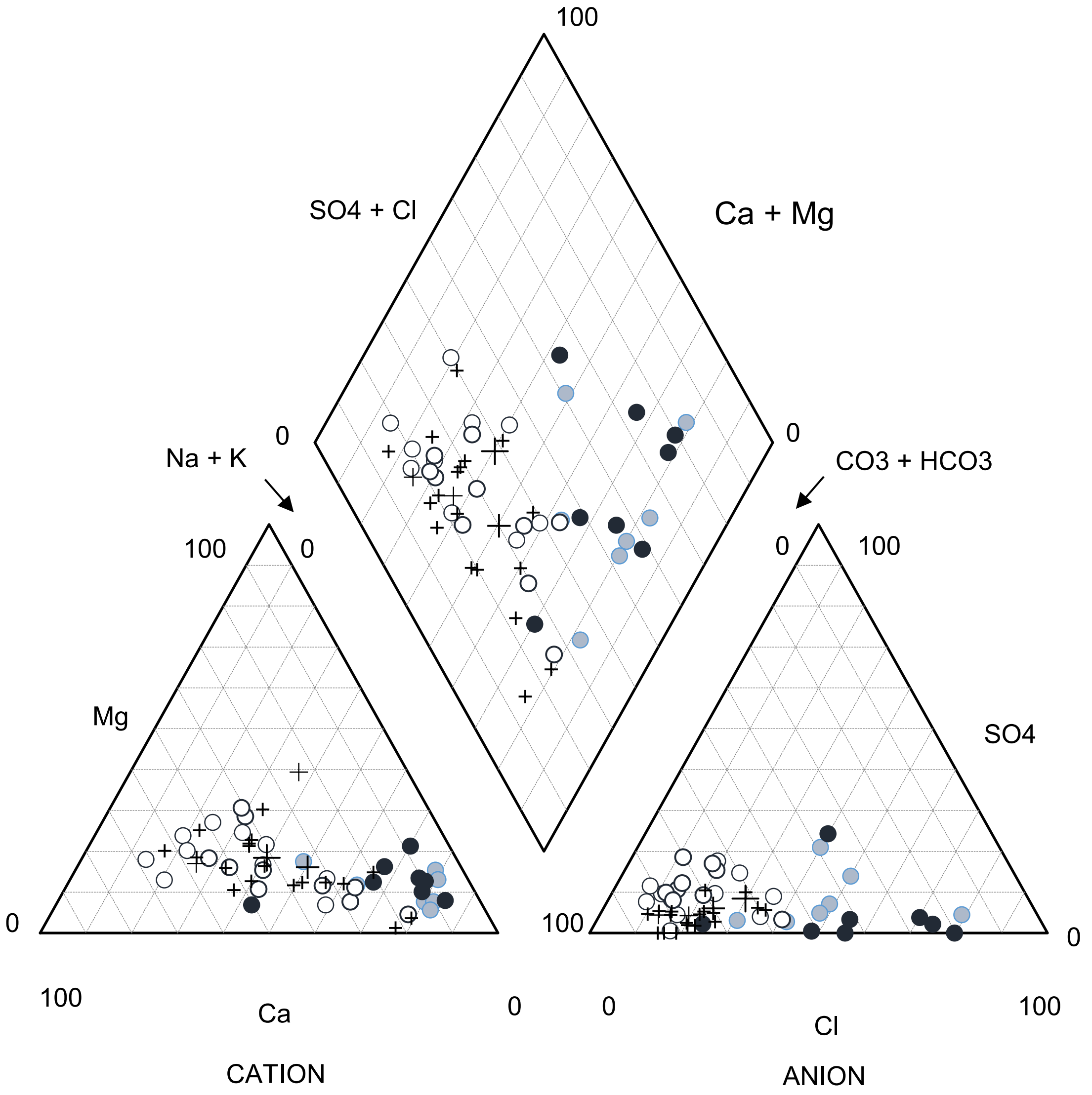


Figure 5.1.2-2 Piper graph of 2019 and 2017 sampling campaigns in Semarang Lowlands. The blue colours represent samples >1500 µS/cm, being the light blue 2019 samples and the navy blue 2017. The white and black symbols represent samples <1500 µS/cm, in white for 2019 and in black (+) for 2017.

Figure 5.1.2-3 spatially displays the distribution of the found water types in Semarang lowlands in 2019. Two main groups of water types are identified from this figure, corresponding to the Piper diagram results. The first one is comprised by the predominant water type of Ca-Na-HCO_3, with variant concentrations of Ca, Na and HCO_3, with a low concentration of Cl, with an exception in dug well SG6. The dug wells in this group are located from higher lands on the south-west, SG6, to the south-east SG30. The location of these samples is mainly found to be in urban area, with fewer dug wells at higher plains; i.e. SG6, and 9. They also spread from the coast, SG11, to inland, SG13. This first water-type is also found in a clear transect from coast to inland, presenting similar concentrations of Na, Ca, and HCO_3 by the dug wells SG11, 14, 15, 21, 19, 18 and 22. These dug wells show a slight change in water types as they get closer to higher lands. Starting at SG11 with a high concentration of Na and HCO_3 and smaller of Ca and Cl, and ending with almost zero Cl concentration and larger Na, Ca, and HCO_3. This transect has three exceptions of water type: SG14, which belongs to the first water type group; and dug wells SG6 and 21, which present a higher concentration in Mg and SO4 when compared to the rest of the dug wells on the transect. The second group is characterised by the water type Na-Cl-HCO_3, with a low concentration of Ca and higher mineralization. This group is divided in two locations, but both found at lower lands on the plains. First location is formed by SG1, 2, 3, and 4, and the second location is formed by SG16, 17, 4, 25, 26, 27. These dug wells coincide to neighbour industrial areas, and therefore it is understood that these are playing an influence to the groundwater quality.

The 2017 dug well samples, in *figure* 5.1.2-4, share the same distribution of water types as 2019 campaign, with some differences in the concentrations of Ca, Na, HCO_3 and Cl. The first water type group differs from 2019 in the dug well samples of SG10 were its concentration of $CaHCO_3$ is smaller. At the same time concentrations of dominant cation change from Ca to Na, indicating a higher mineralization in 2017 compared to 2019. This is mainly illustrated in coastal samples, for example SG16 and 17. These results are important evidence to seawater intrusion and industrial influences on groundwater quality, and therefore will be further discussed in *Chapter 6*.

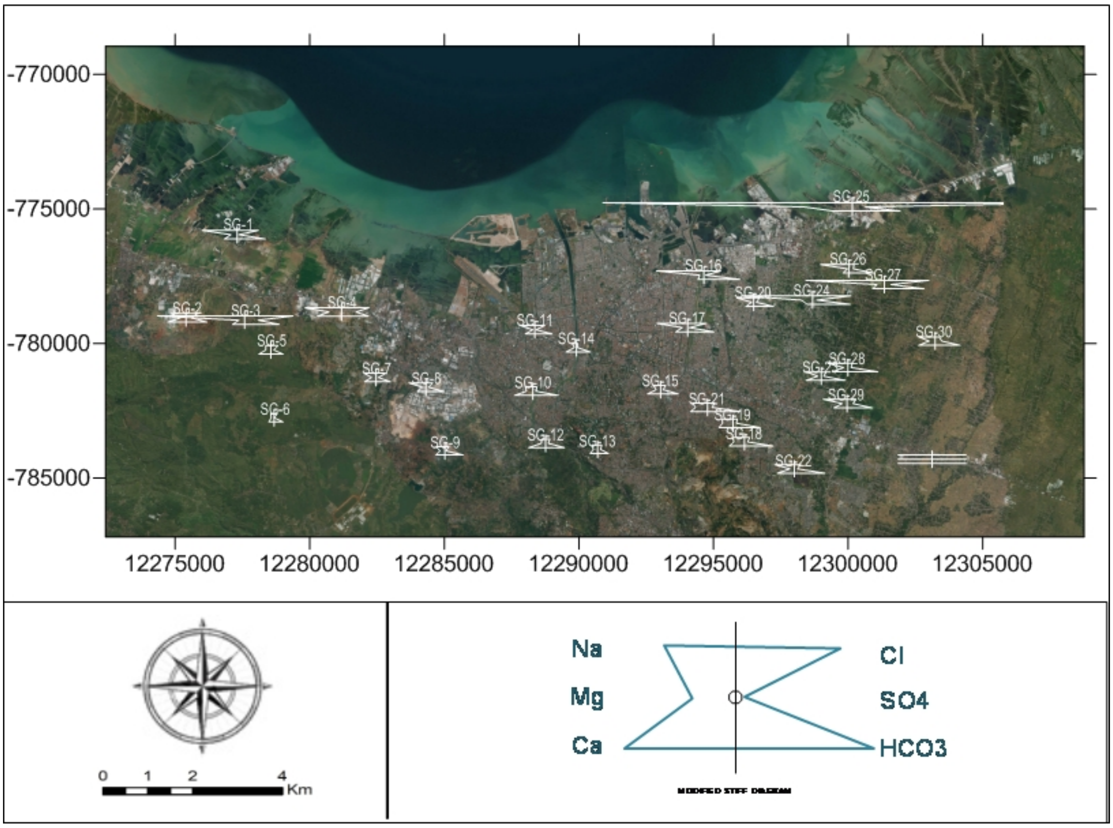


Figure 5.1.2-3 Spatial distribution of Stiff diagrams in the unconfined aquifer of Semarang in May 2019.

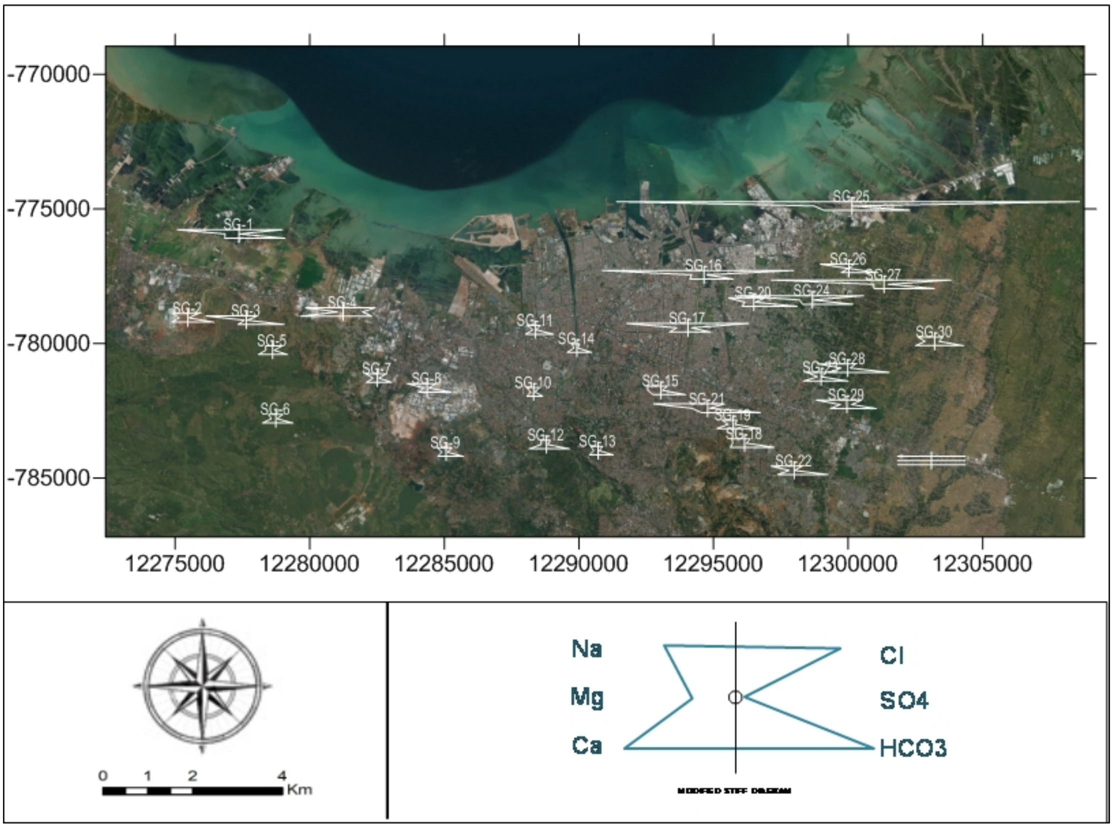


Figure 5.1.2-4 Spatial distribution of Stiff diagrams in the unconfined aquifer of Semarang in May 2017.

5.1.3 Major and minor ions results

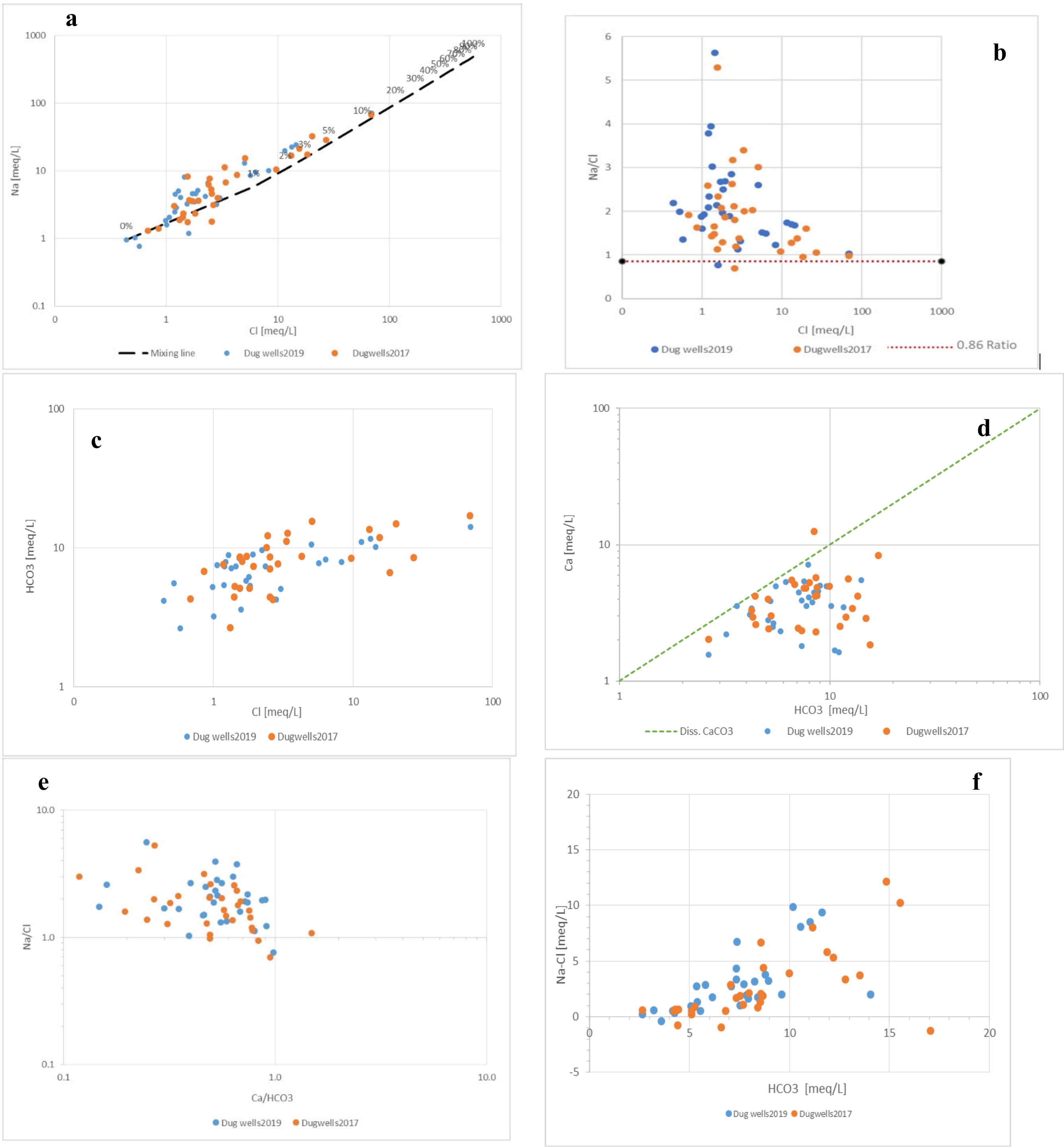
This subsection presents the results from the scatter and ratio plots of major ions, including the trajectories between the freshwater and saline water endmembers. The first one is obtained from the freshest water of the 30 dug wells (SG11), and the saline endmember is obtained from the *Appelo and Postma* (2005) standard seawater ion composition reference. In this study it is assumed in the results that these two endmembers had conservative mixing, in order to apply the *Appelo and Postma* (2005) mass balance approach expressed in *Equation 4.5.2-1:*

Figure 5.1.3-2a shows the sodium vs chloride concentrations for 2019 and 2017. In this figure the samples of this study are compared to pure seawater in order to check whether they fit along the mixing line. Most samples seem to plot above the conservative mixing line, indicating a higher concentration of Na over Cl. With an exception of 6 samples which are the previously observed 6 dug wells that deviate from the norm in Gibbs and Piper graphs, and are neighbouring industrial areas. These samples add up on the pre-mentioned evidences the sampled dug wells being polluted by seawater intrusion, which will be further discussed in *Chapter 6*. In the following figures for 2019 and 2017, *figure 5.1.3-2b,* shows all samples except one to be plotting above the 0.86 ratio. This figure only displays the ratio of the samples of this study. As getting closer to the marine ratio the concentration of sodium seems to decrease as chloride concentration increase. The relationship between Na and Cl is also highlighted in the Pearson results, as they appear to be highly correlated in both sampling years, in 2019 r = 0.96 and in 2017 r = 0.98. There is little to no deviations between years in this graph but nevertheless important for the discussion.

Figure 5.1.3-2d, shows that in both years there seems to be an increase in alkalinity through the dug wells, and some sort of linear relationship, which does not appear in the Pearson's results of 2019 and 2017, r = 0.19 and 0.28, respectively. SG25 is the one found in both years to have the most extreme values, with the highest concentration of bicarbonate: 14.07 meq/L in 2019, and 17.07 meq/L in 2017. The dug wells found on the negative side of the y-axis in both years when adding calcium, they become part of the highest samples. Indicating that they have a great contribution of calcium in their composition. These samples were found close to industrial areas for both years, *figure 5.1.2-3&4.* In 2017 shows that the samples above 12 meq/L are SG1, 20, 21, 24, 25, 27, and 28, and some of these dug wells have already been identified as the 8 dug wells with potential of seawater intrusion. In 2019 shows a smaller concentration of bicarbonate compared to 2017, and a single sample SG25 above the cut-off point of 12 meq/L. When this research uses 10 meq/L as cut of point, it results with 5 samples exceeding it: SG4, 16, 24, 25, and 27. Differently to 2017, all these dug wells samples belong to the 8 dug well group with potential of seawater intrusion.

Figure 5.1.3-2c displays an increase of salinity and alkalinity through the samples. These 6 previously spotted are the dug wells plotting furthest to the right. These have a higher concentration of chloride compared to the most groundwater samples. The concentrations of bicarbonate (HCO_3) and calcium (Ca), in *Figure 5.1.3-2d*, show the dug wells are found under the dissolution line of $CaCO_3$, which correspond to the Pearson correlation results of $r = 0.19$ in 2019 and $r = 0.28$ in 2017. This positive correlation shows salinity is not recent, where Cl would substitute HCO_3 it seems that Cl can originate from entrapped seawater or from a common source; wastewater or evapotranspiration, further discussed in *section Discussion 6.2.2*. Samples show a higher concentration over calcium, which may imply the dissolution of anorthite or calcite. Ca/HCO_3 and Na/Cl *Figure 5.1.3-2e* shows again little difference between years 2019 and 2017. This little difference is illustrated in the 2017 dug well SG4 with a maximum of 2, 1.25, which it does not repeat in 2019 samples. Also, in 2017, dug wells are scattered but they seem to be decreasing in the ratio Ca/HCO_3 as the ratio Na/Cl increases. This is indicative of a change from fresher waters to more brackish ones.

Figure 5.1.3-2f shows a positive correlation between Na-Cl and HCO_3, with an outlier (SG25). The positive correlation between Na and HCO_3 is also illustrated in the Pearson results for both years, in 2019 r being 0.76 and in 2017 r being 0.73. At the same time, Cl and HCO_3, also show a relationship of 0.65 in 2019 and of 0.63 in 2017, in its Pearson results. SG25 seems to have a change in its concentration from year to year, in 2017 is found in the negative side of the y-axis, whereas in 2019 is in the positive. An increase of dug wells having an excess of sodium over bicarbonate from 2017 to 2019 is observed. *Figure 5.1.3-2f* graph shows a clear correlation visualising silicate weathering at the same time as flushing, since high bicarbonate values are displayed. *Figure 5.1.3-2g* illustrates little variation in concentrations of Sulphate (SO_4) and Chloride (Cl) between the sampling campaigns of 2019 and 2017. In both years there seems to have a positive correlation between the two anions. This is evidenced though the Pearson analysis showing $r = 0.59$ in 2019 and $r = 0.63$ in 2017. All samples appear to be above the ocean ratio (SO4/Cl), in 2019 most samples lie between the 0 - 1% with a few samples reaching a 5%. Differently to 2019, in the results of 2017 appear to be at lower values, and are mostly found to be under the mixing line. Most samples lie between 0 -1% with a few reaching the 4% maximum, indicating that in most dug well samples sulphate dominates over chloride This is interpreted as a possible indication of more oxidizing conditions in 2019 compared to 2017, showing sulphate being more reduced in 2017. The relationship between sulphate and nitrate is further looked into in *figure 5.1.4-1*.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Mixing line
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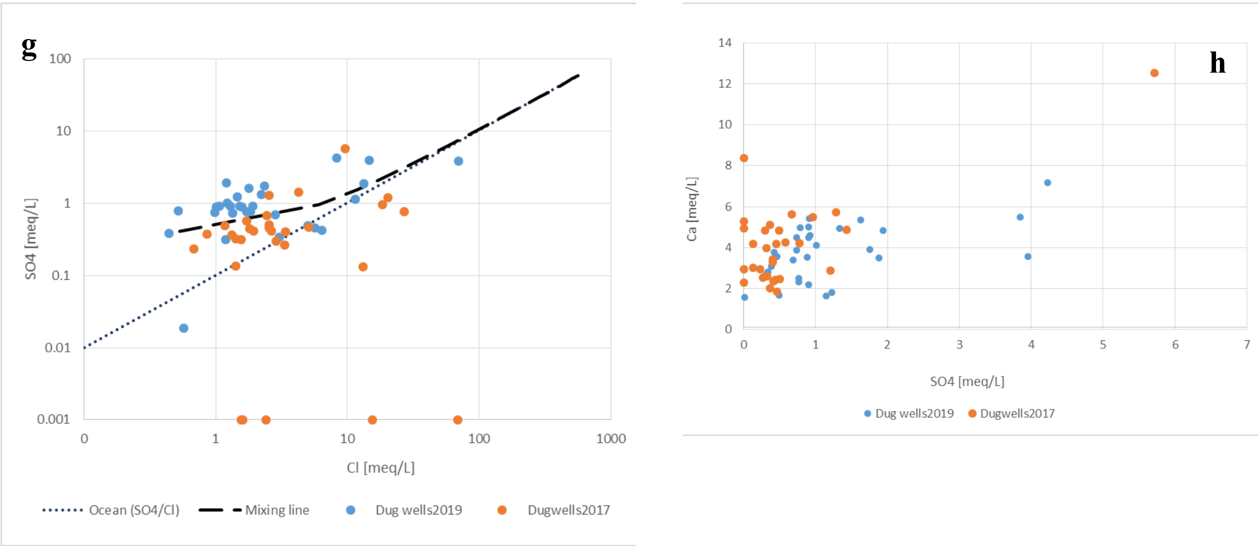


Figure 5.1.3-1 Scatter plots for the major ions per unit in meq/L for the 30 dug well samples from Semarang lowlands 2019 (blue) and 2017 (orange). Navy dotted lines indicate the ocean ratio of concentrations. Mixing lines are represented in the respective colours for each year in a line with a marker. This illustrates the conservative mixing between Appelo and Postma (2005) seawater endmember and a freshwater endmember (SG14). Lines with round markers represent the percentage contribution of seawater in steps of 1, 2, 3, 5, 10, 20, 30, 40, 50, 60, 80 and 90.

5.1.4 Groundwater quality and indicators of pollution of Semarang lowlands

The physicochemical properties of the shallow aquifer of Semarang lowlands are captured in *figure 5.1.4-1,* and compared to WHO and SNI guidelines. There is no data for the field values of water table and temperature for 2017. This repeats for measurements of alkalinity (HCO_3^-) and pH. The values used in this analysis were from the laboratory results. Differently, 2019 has a mean value of 28.95 °C, and an average of 14.32 m of water table across the 30 dug wells.

The obtained pH average values for 2019 and 2017 are 7.0 (standard deviation of 0.34) and 7.0 (standard deviation of 0.27) respectably. The measured pH values for 2017 are sometimes under the minimum of the permissible limit for pH but never over the WHO and Indonesian standards. This dug well is identified to be SG10, which is located next to an industrial area of Semarang lowlands.

EC values were classified following *Stuyfzand* (1989); the dug well samples fall within the fresh category, with 73.3% for 2019 and 2017. Fresh-brackish with a 13.3% in 2019 and 3.3% in 2017. Brackish samples are found for both years, being larger in 2017 with 20% and in 2019 with 10%. The smallest group with a 1 sample and a 3.33% of the samples in both years is the Brackish-salt classification. These more brackish samples are SG1, 3, 4, 16, 17, 24, 25, 27 in 2019, and in 2017 there is an addition of SG 21 and a loss of SG3. These samples are all located nearby industrial areas of Semarang lowlands, *figure 5.1-5*.

Total Dissolved Solids, according to WHO its desirable maximum permissible is up to 1500 mg/L. TDS standard deviation values for 2019 and 2017 show a great difference between samples: 925 mg/l, and 894 mg/l respectively. This indicates that there are samples which do go over the WHO limit. These samples are SG3, 24, 25, and 27 in 2019, which are all located near industrial areas, *figure 5.1-5*. In 2017 dug wells SG24, 25, and 27 are also exceeding the limitations, in addition to SG1, 16, and 17, which similarly to the previous samples are also located near industrial areas, *figure 5.1-5*. Having more samples in 2017 exceeding the permissible limits in comparison to 2019, contributes to the evidence of 2017 being more mineralized compared to 2019, and it will be further discussed in *Chapter 6*.

The hydrochemical parameters of Semarang lowlands are compared in *figure 5.1.4-1* with their respective guidelines' values for WHO, and Indonesian legislation Standards. The 2019 average abundance of ion concentrations for this research is in the order of HCO_3^-> Na^+> Cl^-> Ca^{2+}> SO_4^{2-}> Mg^{2+}> NO_3^->K^+ >NH_4^+ > NO_2^-. Differently the average 2017 abundance of ion concentrations is in the order of HCO_3^-> Cl^- >Na^+ >>Ca^{2+} >SO_4^{2-} >Mg^{2+} > K^+ > NO_3^- >NH_4^+ >NO_2^-. Because of the negligible concentrations (10^{-6}) of Mn^{2+} and Fe2+ these will be neglected from the analysis.

Chloride (Cl^-) has a WHO and Indonesian limit of 250 mg/L, with a range of 2403 – 15.1 mg/L and an average of 182.6mg/L in 2019. Differently, 2017 has a smaller range of 2374.2 - 23.5 mg/L. This indicates that some samples are exceeding the desirable limits for Cl^-, those are in 2017 SG1, 4, 16, 17, 24, 25, 27 and in 2019 are SG1, 3, 4, 5, 24, 25, and 27. These dug wells are located in the vicinities of industrial areas, *figure 5.1-5*.

The concentration of sulphate (SO_4^{2-}) has a health risk towards human organs. This may occur if the concentrations in water exceed the permission limits of WHO, being 250 mg/L. This element if is present with magnesium it may have a laxative effect on the human body. The sulphate content in the 30 dug wells for 2019 has a maximum range of 203 mg/L. Differently, 2017 exceeds the limit by having a maximum concentration of 274.5 mg/L, which adds up to the evidence of 2017 dug wells being richer in minerals than in 2019. This contributes to the indications to 2017 having higher concentrations versus in 2019. Both years share the same dug well exceeding the permissible limits by WHO and Indonesian standards, and this is SG4 located in the vicinities of an industrial area, *figure 5.1-5*. This supposes a health risk for the dug well owners, where the WHO and Indonesian standards are exceeded.

Calcium (Ca^{2+}) and magnesium (Mg^{2+}) are present throughout all 30 dug well samples, having higher concentrations of Ca^{2+} compared to Mg^{2+}. Calcium has a range of 31 – 144 mg/L in 2019, and a range of 37 – 251 mg/L in 2017. When magnesium in 2019 has a range of 6 - 171 mg/L and in 2017 has a range of 2 – 135 mg/L. By looking at both maximums it is understood that there might be an exceedance of the permissible WHO and Indonesian standards at some of the dug wells, which supposes a health risk for the dug well owners. In 2019 dug wells SG2, 4, 10, 22, 25 exceed the Ca^{2+} WHO 100 mg/L permissible limit but not the Indonesian standard. Most are found nearby industrial areas, except for SG22, which are located in the city centre and the latter is closer to higher plains, *figure 5.1-5*. In 2017 dug wells which are exceeding this permissible limit are SG4, 12, 17, 23, 25, 28, 30. These are mostly located next to industrial areas, except for SG12 and 30, which are found at close to higher plains, *figure 5.1-5*. This may be indicative of the two suspected influencers of groundwater quality, local geology and industrial activities.

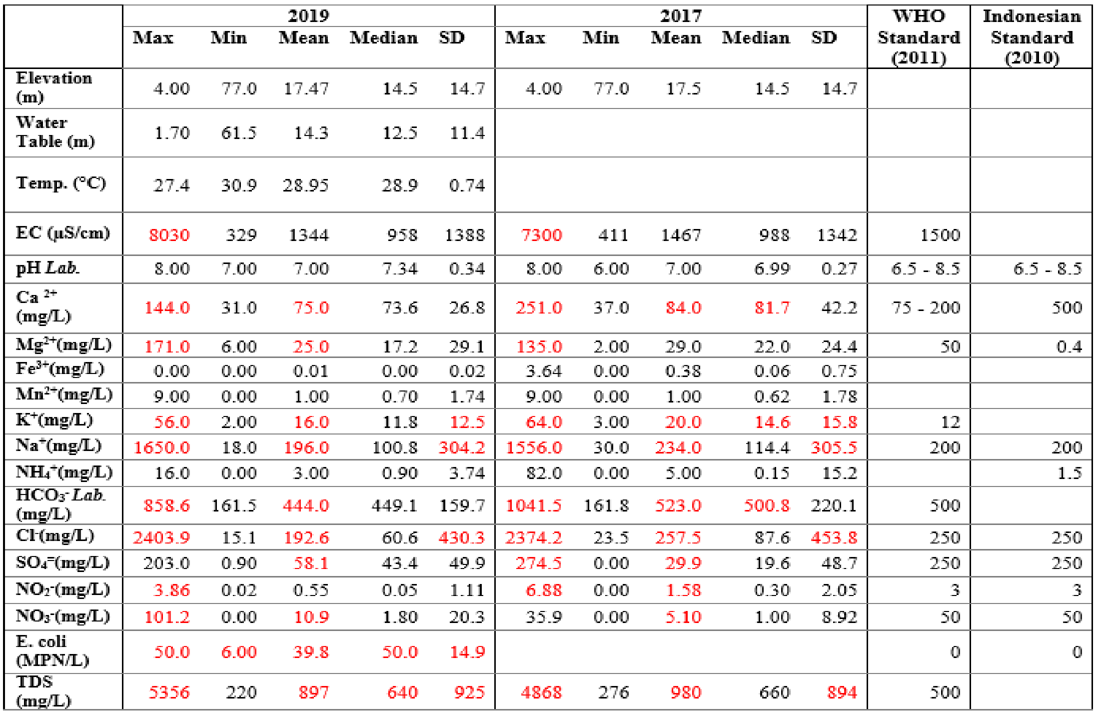
Sodium (Na^{+}) in 2019 has a range of 18 – 1650 mg/L, and a smaller range in 2017 of 30 – 1556 mg/L. By looking at the maximums of both years it is understood that in some of the dug wells there are times where the permissible limits set by WHO (200mg/L) and Indonesian standard (200mg/L) are exceeded. These are SG1, 3, 4, 16, 24, 25, 27, 29 in 2019, which are all located near industrial areas with the exception of SG29, located at near higher plains, *figure 5.1-5*. Similarly, in 2017 the dug wells exceeding the permissible limits are SG1, 3, 4, 16, 17, 21, 24, 25, 27, 29, which are again found near industrial areas with the exception of sample 21 and 29, *figure 5.1-5*.

The observed nitrate (NO_3^-) values for 2019 range from 0 to 101.2 mg/L, and 2017 has a range from 0 - 35.9 mg/L. Indicating that there are some samples which exceed the permissible levels by WHO and Indonesian standards. These samples are located in *section 5.1.4.2&3*.

Nitrite (NO_2^-) is present at smaller quantities compared to NO_3, but it does seem to exceed the permissible limits in some of the dug wells sampled for the 2019 field campaign, since it has a maximum value of 3.86 mg/L and minimum of 0.02 mg/L in 2019. In 2017 nitrite does exceed the permissible limits by WHO and Indonesian standards, as this research found it has a maximum value of 6.88 mg/L and a minimum of 0 mg/L. This potential contamination will be further studied within this hydrochemical analyses. These samples are located in *section 5.1.4.2&3*.

E. coli has a maximum of 50 and a minimum of 6 MPN/100mL in 2019, in 2017 there is no collected data. This indicates that all 2019 samples have E. coli present and exceed the WHO and Indonesian standard guidelines. These samples are located in *section 5.1.4.1.*

Throughout this result section of my research 2017 is characterised by having a greater mineral concentration when compared to 2019. Also, WHO and Indonesian standards are violated in various physico and hydrochemical parameters, and the most alarming ones are those which suppose a risk in the human health: TDS, EC, pH, Cl, SO_4^{2-}, Ca^{2+}, Na^+, Mg^{2+}, Na^+, nitrogen compounds, and E. coli. When the identified parameters are exceeding the WHO and Indonesian standard they tempt to be near industrial zones, however there are exceptions located at higher plains: SG22, 21, and 29.



	2019					2017					**WHO Standard (2011)**	**Indonesian Standard (2010)**
	Max	**Min**	**Mean**	**Median**	**SD**	**Max**	**Min**	**Mean**	**Median**	**SD**		
Elevation (m)	4.00	77.0	17.47	14.5	14.7	4.00	77.0	17.5	14.5	14.7		
Water Table (m)	1.70	61.5	14.3	12.5	11.4							
Temp. (°C)	27.4	30.9	28.95	28.9	0.74							
EC (µS/cm)	8030	329	1344	958	1388	7300	411	1467	988	1342	1500	
pH ***Lab.***	8.00	7.00	7.00	7.34	0.34	8.00	6.00	7.00	6.99	0.27	6.5 - 8.5	6.5 - 8.5
Ca^{2+} (mg/L)	144.0	31.0	75.0	73.6	26.8	251.0	37.0	84.0	81.7	42.2	75 - 200	500
Mg^{2+}(mg/L)	171.0	6.00	25.0	17.2	29.1	135.0	2.00	29.0	22.0	24.4	50	0.4
Fe^{3+}(mg/L)	0.00	0.00	0.01	0.00	0.02	3.64	0.00	0.38	0.06	0.75		
Mn^{2+}(mg/L)	9.00	0.00	1.00	0.70	1.74	9.00	0.00	1.00	0.62	1.78		
K^+(mg/L)	56.0	2.00	16.0	11.8	12.5	64.0	3.00	20.0	14.6	15.8	12	
Na^+(mg/L)	1650.0	18.0	196.0	100.8	304.2	1556.0	30.0	234.0	114.4	305.5	200	200
NH_4^+(mg/L)	16.0	0.00	3.00	0.90	3.74	82.0	0.00	5.00	0.15	15.2		1.5
HCO_3^- ***Lab.*** **(mg/L)**	858.6	161.5	444.0	449.1	159.7	1041.5	161.8	523.0	500.8	220.1	500	
Cl^-(mg/L)	2403.9	15.1	192.6	60.6	430.3	2374.2	23.5	257.5	87.6	453.8	250	250
$SO_4^{=}$(mg/L)	203.0	0.90	58.1	43.4	49.9	274.5	0.00	29.9	19.6	48.7	250	250
NO_2^-(mg/L)	3.86	0.02	0.55	0.05	1.11	6.88	0.00	1.58	0.30	2.05	3	3
NO_3^-(mg/L)	101.2	0.00	10.9	1.80	20.3	35.9	0.00	5.10	1.00	8.92	50	50
E. coli (MPN/L)	50.0	6.00	39.8	50.0	14.9						0	0
TDS (mg/L)	5356	220	897	640	925	4868	276	980	660	894	500	

Table 5.1.4-1 Statistics of physico-chemical parameters of the 30 dug wells in Semarang Lowlands. World Health Organization (World Health Organization 2011) and Indonesian standards (Peraturan Menteri Kesehatan Republik Indonesia, (2010) for drinking waters of study area.

Figure 5.1.4-1a shows the relationship between the saturation indexes of sulphate against nitrate for 2019 and 2017. These results were obtained through the software of Phreeqc, and they illustrate a very different behaviour between the two components in in both years. In 2019 a great number of samples are clustered on the left side of the graph, between 0 – 0.1 NO_3 mmol/L and in 2017 samples are clustered at the bottom of the graph, never exceeding the 0.7 NO_3 mmol/L in exception of one sample: SG25. In this figure there are a number of samples identified as suspicious (inside a red circle) and will be taken to further analysis in the *Chapter 6 Discussion.*

Figure 5.1.4-1b displays the relationship between pH and pCO_2 in 2019 and 2017. Similarly, this figure shows a difference in behaviour of groundwater between the sampling years. In 2017 dug wells fall between the range -1 and -1.5 pCO_2, whereas in 2019 dug wells reach a wider range from -1.25 down to -2.75. This can be interpreted as reduction condition and again is a suspicious behaviour (highlighted in red) which will be taken to further discussion in *Chapter 6 Discussion.*

Figure 5.1.4-1c displays the Saturation Index of calcite versus calcium. It displays the concentrations of these components for both sampling years. This time concentrations diverse mildly when compared to *figure 5.1.4-1a&b*, however 2017 has a wider range when compared to 2019. At the same time, in red, it is identified some suspicious behaviour which will be further discussed in *Chapter 6 Discussion.*

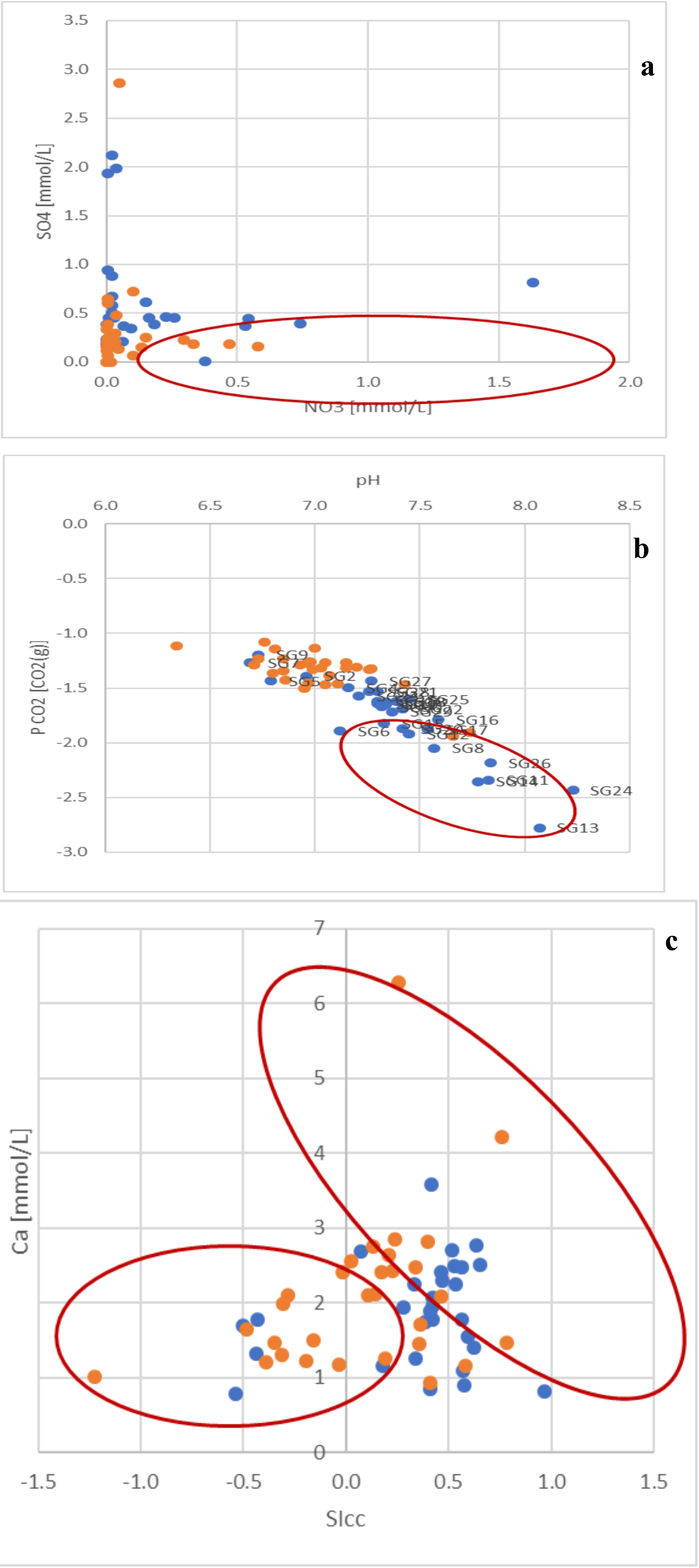


Figure 5.1.4-1 Scatter plots of Saturation Indexes of calcite (SIcc), nitrate (NO3), and Carbon dioxide pressure (pCO2) for 2017(orange) and 2019(blue) sampling campaigns of groundwater in Semarang lowlands. Dug wells are labelled within the figure (SGX). Circles indicate detected anomalies.

Figure 5.1.4-2a, illustrates the concentrations of alkalinity against magnesium for the 2017 (orange) and 2019 (blue) campaigns. In this graph it is clear there are 1 common outlier, SG25, which is close to an industrial area. 2017 has a higher alkalinity compared to 2019 and higher magnesium concentrations. This graph also shows a correlation between these two components for both sampling campaigns.

Figure 5.1.4-2b, shows the concentrations of Saturation Index of dolomite (SIdol) against alkalinity for the 2017 (orange) and 2019 (blue) campaigns. In 2017 there is a clear correlation between these two components, and it is less clear in 2019. 2019 presents the highest SIdol in SG24 (near industrial area), and 2017 has the lowest concentrations for SIdol in SG10 (near city centre). SG10 acts as outlier.

Figure 5.1.4-2c, shows the concentrations of magnesium against SIdol for the 2017 (orange) and 2019 (blue) campaigns. Shows SG25 again as a clear outlier for both years, and SG10. There is no clear correlation between these two components, however concentrations appear to have higher concentrations in 2019 compared to 2017.

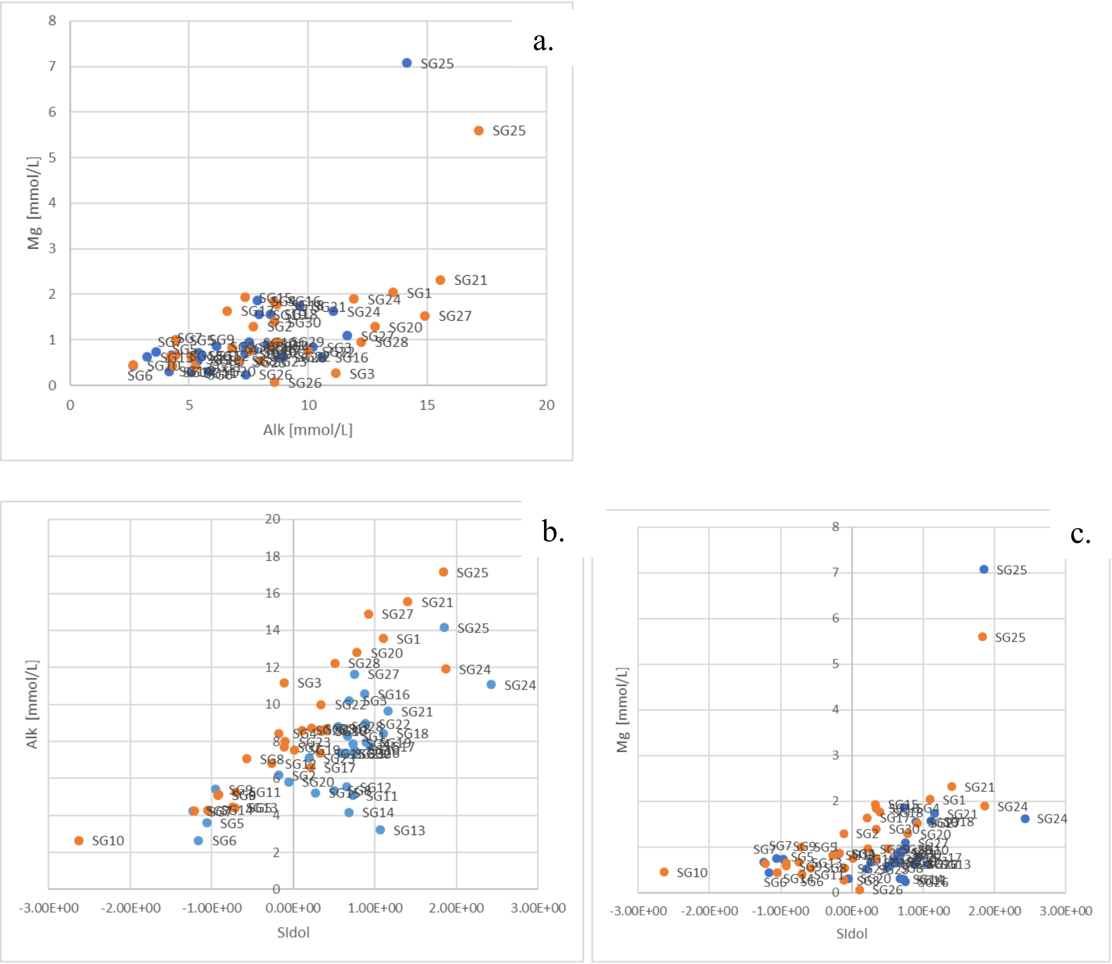


Figure 5.1.4-2 Scatter plots of Saturation Indexes of dolomite (SIdol), and Alkalinity (Alk) form 2017(orange) and 2019(blue). Dugwells are labelled within the figure.

5.1.4.1 E. Coli

Figure 5.1.4.1-1 shows that in all dug wells there is E. coli, with a dominance of samples larger than 50mg/L. This dominance is observed in dug wells SG- 6, 9, 14, 19, 30, and 26 falls within the range of 20-30 MPN/L, as well as samples falling within the range of 10 – 20 MPN/L are SG-5, and 22. All 30 dug well samples are polluted by E. coli in 2019. These are alarming results for the health of the dug well owners, and its implications will be discussed in *Chapter 6.*

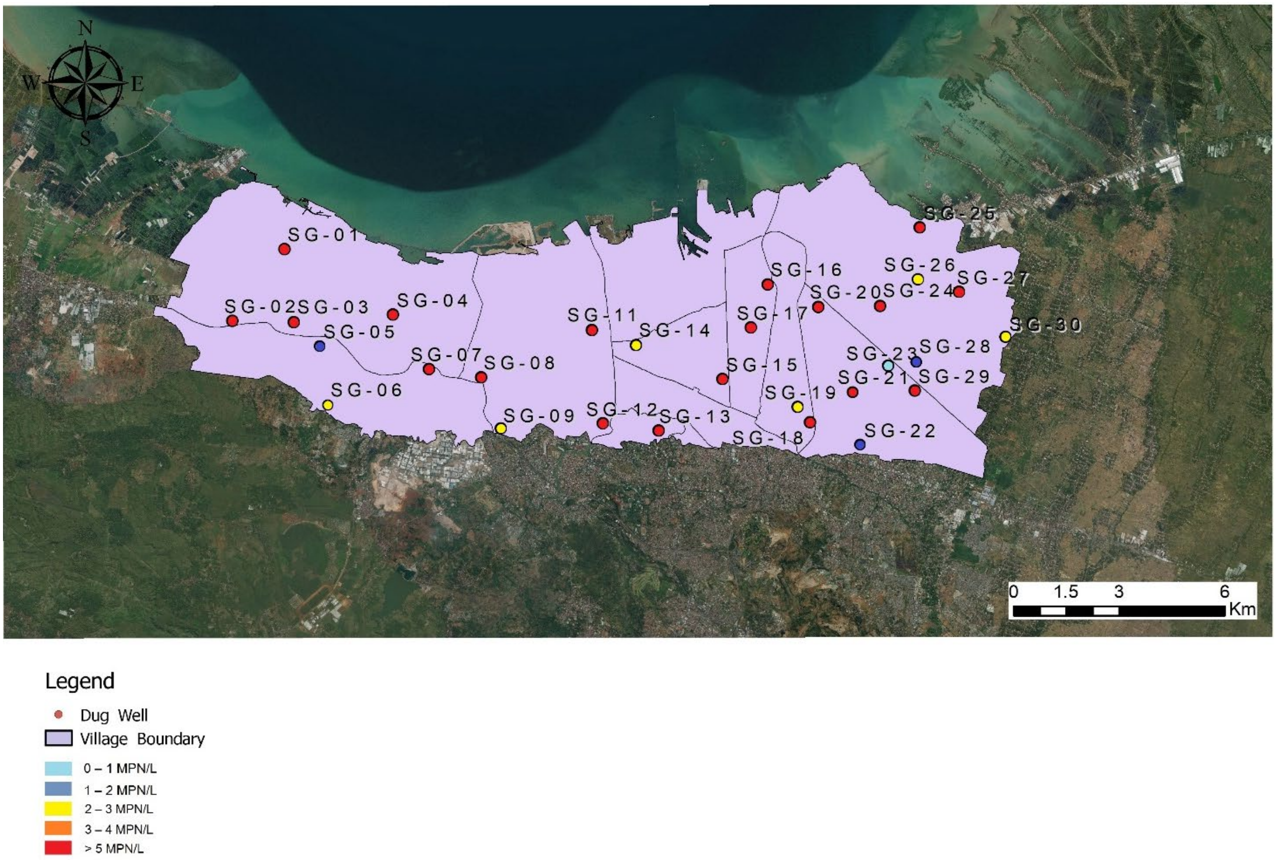


Figure 5.1.4.1-1 Semarang City lowlands map, with the scattered data of E. coli sampled during the fieldwork campaign of May 2019.

5.1.4.2 Nitrate

Figure 5.1.4.2-1a shows the nitrate concentration of 2019, there it illustrates two dug wells which exceeding the WHO and SNI permissible concentration of 50 NO_3 mg/L, SG2, and 12. Most of the dug wells are found between 0 and 10 mg/L. *Figure 5.1.4.2-1b* displays the nitrate concentration for the sampling campaign of 2017. Different to 2019, this year had no dug wells exceeding the permissible limits by WHO and SNI. Most samples fall within the range 0 – 10 mg/L, except SG5, 6, and 12. Dug wells SG5 and 12 occupy a space in the range 10 – 20 mg/L, whereas SG6 falls within the range of 30 – 40 mg/L. This research takes note of these results for *Chapter 6*, where the health implications will be discussed alongside of the reasoning behind the presence of nitrate at polluting concentrations.

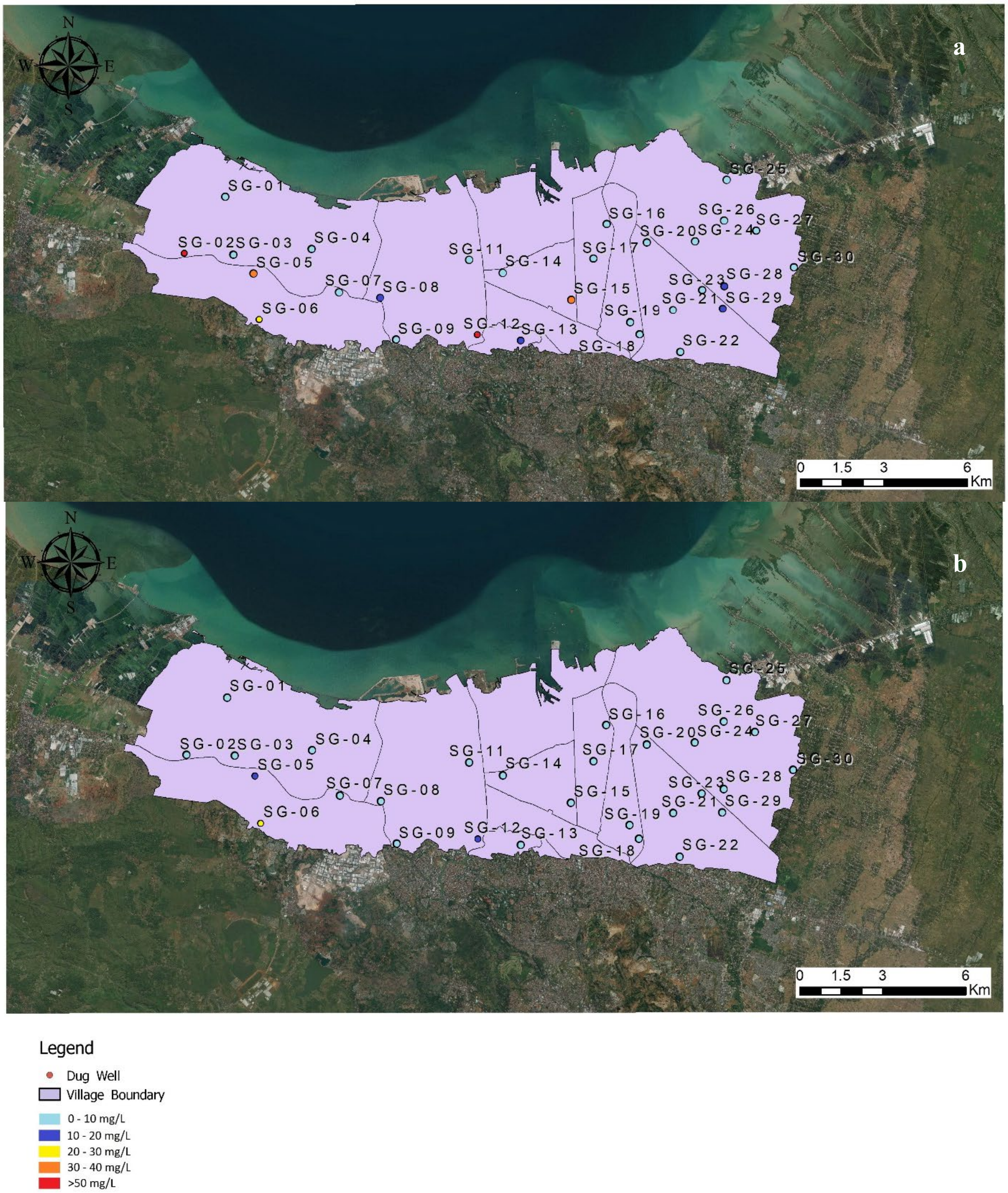


Figure 5.1.4.2-1 Semarang City lowlands map dug wells illustrating the scattered data of Nitrate (NO_3) sampled during the campaign in 2019 (a) and 2017 (b). WHO nitrate drinking water limits is 50 mg/L, and 50 mg/L is for the Indonesian standard.

5.1.4.3 Nitrite

Figure 5.1.4.3-1a shows two maps of the nitrite concentrations for 2019 and 2017. In 2019 three wells exceeded the WHO and SNI permissible limits of 1 and 3 NO_2 mg/L, and most samples fall between 0 to 1 NO_2 mg/L except SG 22, 24, and 27. In *Figure 5.1.4.3-1b* displays the NO_2 samples for the 2017 sampling campaign. When comparing this year to 2019 this study easily spotted that the nitrite concentrations are noticeably more variant. Finding wells at the range 0 - 1, 2 – 3, 3 – 4, and more than 5 NO_2 mg/L. These results show most of the dug wells in 2017 exceed the WHO and SNI permissible limits of 1 and 3 NO_2 mg/L, respectively. These results are relevant for the discussion of presence of nitrogen compounds in Semarang lowlands, found in *Chapter 6 Discussion.*

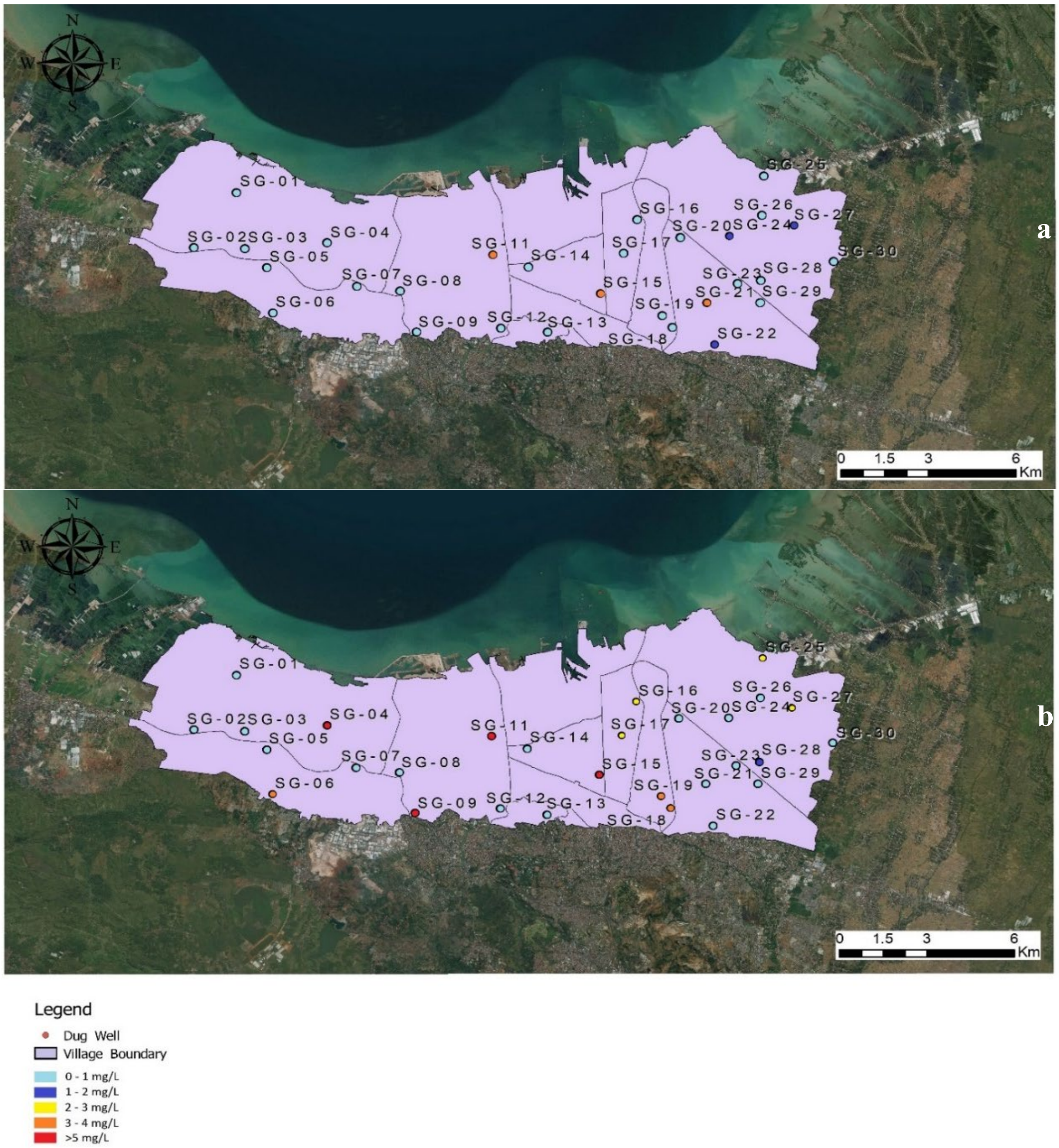


Figure 5.1.4.3-1 Semarang City lowlands map dug wells showing the scattered data of Nitrite (NO_2) sampled during the campaign in 2019 (a) and 2017(b). WHO nitrite drinking water limits is 1 mg/L, and 3 mg/L is for the Indonesian standard.

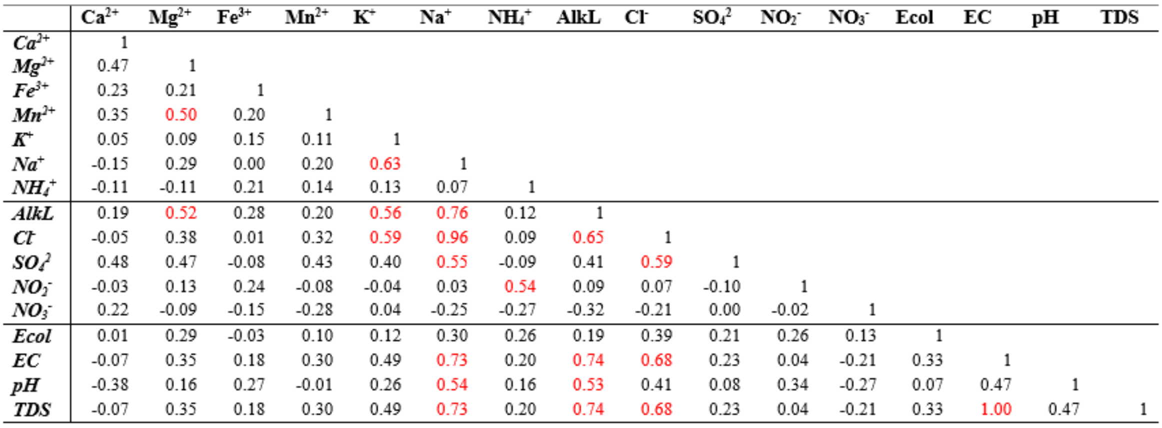
5.2 Statistical analysis

5.3.1 Pearson correlation coefficient (r)

This research adopted the significance level of 0.5 for the correlation coefficient (r) to the variables that underwent the statistical analysis (Triola, 1999). Since Pearson coefficient assumes a normality of variables, and linearity, this research dismissed the outlier sample 25. This dug well was interfering in the results of the analysis as its value it outlines when it is compared with the other dug wells.

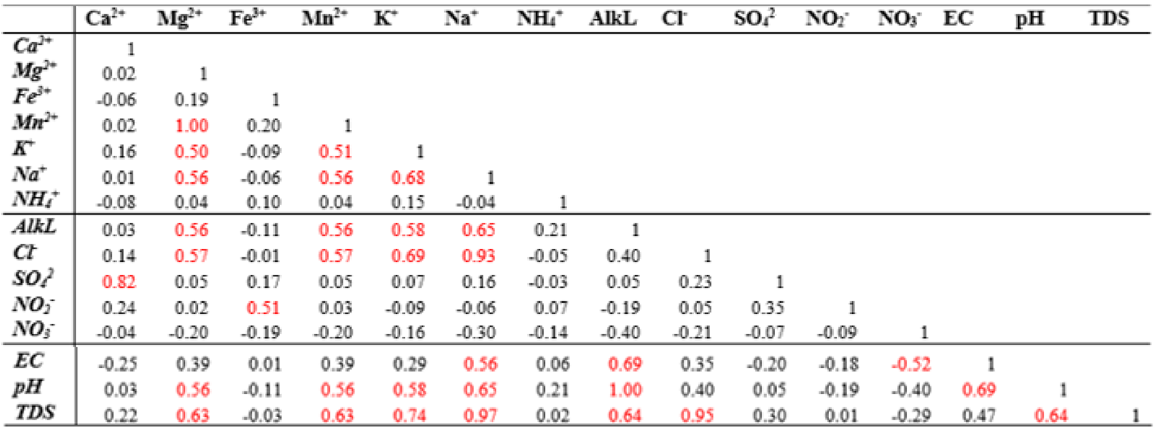
Table 5.3.1-1 shows the results for Pearson analysis on the 2019 dug well samples. This matrix shows how various chemical parameters from the sampled 30 dug wells are correlated. Some of these relationships have already been identified in the bivariate plots in *section 5.1.3*. These are various pairs, starting with the Mg^{2+}, $Mn^{2+}$and HCO_3^-, NO_2^- and NH_4^+, SO_4^{2-} and Cl^-. Potassium is significantly correlated with 3 chemical variables: Na^+, HCO_3^-, and Cl^-. The first pair is indicative of seawater intrusion, causing high Mg and possibly cation exchange. The second pair shows an interesting relationship for the chapter of discussion, as it is indicative of ongoing nitrification of NH^{4+}. NH^{4+}shows a positive correlation with nitrite. Also, it is significant to mention the negative correlation between nitrate and nitrite, which is only significant enough. The latter group of relationship pair is also indicative of cation exchange between anions. Na^+ is significantly correlated with HCO_3^-, SO_4^{2-}, Cl^-, EC, pH and TDS, adding to the evidence of a potential polluting event of seawater intrusion.

Table 5.3.1-2 shows the results for Pearson analysis on the 2017 dug well samples. In this correlation matrix there are different pairs to 2019 results, which are being significantly correlated, SO_4^{2-} and Ca^{2+}, and two similar pairs, SO_4^{2-} and Cl^-, NO_2^- and Fe^{3+}, and NO_3^- and EC. The first pair might be correlated due to sulphate reduction. The second pair might be indicative of cation exchange, and the third pair might be subject to the change of groundwater chemistry caused by anthropogenic influences. In this year, magnesium is significantly correlated to Mn^{2+}, K^+, Na^+, HCO_3^-, Cl^- pH, and TDS. Manganese is significantly positive correlated to K^+, Na^+, HCO_3^-, Cl^- pH, and TDS. Potassium is significantly correlated to Na^+, HCO_3^-, Cl^-, SO_4^{2-}, pH and TDS. Sodium is significantly correlated to HCO_3^-, Cl^-, EC, pH, and TDS. Finally, bicarbonate is significantly correlated to Mg^{2+}, Mn^{2+}, K^+, Na^+, Ec, pH, and TDS. These correlations can also be interpreted as consequence of cation exchange, sulphate reduction, freshening processes, at the same time as being influenced by seawater intrusion. This will be further studied in the *Chapter 6 Discussion.*



	Ca^{2+}	Mg^{2+}	Fe^{3+}	Mn^{2+}	K^+	Na^+	NH_4^+	AlkL	Cl^-	SO_4^{2}	NO_2^-	NO_3^-	Ecol	EC	pH	TDS
Ca^{2+}	1															
Mg^{2+}	0.47	1														
Fe^{3+}	0.23	0.21	1													
Mn^{2+}	0.35	0.50	0.20	1												
K^+	0.05	0.09	0.15	0.11	1											
Na^+	-0.15	0.29	0.00	0.20	0.63	1										
NH_4^+	-0.11	-0.11	0.21	0.14	0.13	0.07	1									
AlkL	0.19	0.52	0.28	0.20	0.56	0.76	0.12	1								
Cl^-	-0.05	0.38	0.01	0.32	0.59	0.96	0.09	0.65	1							
SO_4^{2}	0.48	0.47	-0.08	0.43	0.40	0.55	-0.09	0.41	0.59	1						
NO_2^-	-0.03	0.13	0.24	-0.08	-0.04	0.03	0.54	0.09	0.07	-0.10	1					
NO_3^-	0.22	-0.09	-0.15	-0.28	0.04	-0.25	-0.27	-0.32	-0.21	0.00	-0.02	1				
Ecol	0.01	0.29	-0.03	0.10	0.12	0.30	0.26	0.19	0.39	0.21	0.26	0.13	1			
EC	-0.07	0.35	0.18	0.30	0.49	0.73	0.20	0.74	0.68	0.23	0.04	-0.21	0.33	1		
pH	-0.38	0.16	0.27	-0.01	0.26	0.54	0.16	0.53	0.41	0.08	0.34	-0.27	0.07	0.47	1	
TDS	-0.07	0.35	0.18	0.30	0.49	0.73	0.20	0.74	0.68	0.23	0.04	-0.21	0.33	1.00	0.47	1

Table 5.3.1-1 Pearson correlation (r) matrix of 18 physico-chemical variables in groundwater samples from the Semarang lowlands 2019. Numbers in red indicate significant correlation (r ≥0.5). AlkL stands for Alkalinity (HCO_3^-), Ecol for E. coli, EC, for Electrical Conductivity, and TDS for Total Dissolved Solids.



	Ca^{2+}	Mg^{2+}	Fe^{3+}	Mn^{2+}	K^+	Na^+	NH_4^+	AlkL	Cl^-	SO_4^{2}	NO_2^-	NO_3^-	EC	pH	TDS
Ca^{2+}	1														
Mg^{2+}	0.02	1													
Fe^{3+}	-0.06	0.19	1												
Mn^{2+}	0.02	1.00	0.20	1											
K^+	0.16	0.50	-0.09	0.51	1										
Na^+	0.01	0.56	-0.06	0.56	0.68	1									
NH_4^+	-0.08	0.04	0.10	0.04	0.15	-0.04	1								
AlkL	0.03	0.56	-0.11	0.56	0.58	0.65	0.21	1							
Cl^-	0.14	0.57	-0.01	0.57	0.69	0.93	-0.05	0.40	1						
SO_4^{2}	0.82	0.05	0.17	0.05	0.07	0.16	-0.03	0.05	0.23	1					
NO_2^-	0.24	0.02	0.51	0.03	-0.09	-0.06	0.07	-0.19	0.05	0.35	1				
NO_3^-	-0.04	-0.20	-0.19	-0.20	-0.16	-0.30	-0.14	-0.40	-0.21	-0.07	-0.09	1			
EC	-0.25	0.39	0.01	0.39	0.29	0.56	0.06	0.69	0.35	-0.20	-0.18	-0.52	1		
pH	0.03	0.56	-0.11	0.56	0.58	0.65	0.21	1.00	0.40	0.05	-0.19	-0.40	0.69	1	
TDS	0.22	0.63	-0.03	0.63	0.74	0.97	0.02	0.64	0.95	0.30	0.01	-0.29	0.47	0.64	1

Table 5.3.1-2 Pearson correlation matrix of 18 physico-chemical variables in groundwater samples from the Semarang lowlands 2017. Numbers in red indicate significant correlation (r ≥0.5). AlkL stands for Alkalinity (HCO_3^-), Ecol for E. coli, EC, for Electrical Conductivity, and TDS for Total Dissolved Solids.

5.3.2 Principal Component Analysis (PCA)

This study used PCA not only as a reduction technique but also for the visualization of correlations amongst the physico-chemical variables. This subsection details the results of this multivariate statistical analysis.

In *table 5.3.2-1* displays the results for the PCA eigenvalues of the 2019 showing 5 to 6 principal components. The first principal component (PC1) takes 33.59% of total variance, suggesting that there might be 1 or more other PCs that statistically explain the dataset. PC2 explains 13.32% of the total variance. The PC3 takes 12.41% of total variance, suggesting that there should be another PC to complete the statistical explanation of the resulting dataset. The 2019 eigenvalues are smaller when comparing to the 2017 ones, *table 5.3.2-2.* The identified three principal components explain the total 59.32% of variance, which gives an adequate representation of the dataset (Pan and Richter*,* 2019; Hassen *et al.,* 2016; Jiang *et al*. 2015; Hu *et al.,* 2013). These PCs have different components which influence to the total variance, and these are displayed in the *table 5.3.2-3* and will be explained in the next paragraph.

Table 5.3.2-2 displays the results for 2017, giving for its first PC (PC1) a 40.36% of total variance. Suggesting that this first component explained almost half of the total variance of this dataset. PC2 takes 14.09% of the total variance and PC3 11.94%. This reached to a 66.4% of the cumulative percentage, suggesting that the following PCs is contributing less to the explanation of total variance. This identified 3 principal components give an adequate representation of the obtained dataset (Hassen *et al.,* 2016; Hu *et al.,* 2013; Jiang *et al*., 2015; Pan *et al.,* 2019). For further detail, *table 5.3.2-4* shows which components are influencing the total variance. In the next paragraph these tables will be interpreted.

	EIGENVALUES		
COMPONENT	**Total**	**Percentage of Variance (%)**	**Cumulative Percentage (%)**
PC1	6.05	33.59	33.59
PC2	2.40	13.32	46.91
PC3	2.23	12.41	59.32
PC4	1.53	8.5	67.82
PC5	1.30	7.2	75.02
PC6	1.02	5.66	80.68
PC7	0.91	5.08	85.75

Table 5.3.2-1 Table of variance (%) for the PCA factors of the sampling campaign on 2019.

	EIGENVALUES		
COMPONENT	**Total**	**Percentage of Variance (%)**	**Cumulative Percentage (%)**
PC1	7.26	40.36	40.36
PC2	2.54	14.09	54.45
PC3	2.15	11.94	66.4
PC4	1.61	8.92	75.32
PC5	1.22	6.78	82.1
PC6	0.99	5.5	87.6
PC7	0.75	4.17	91.78

Table 5.3.2-2 Table of variance (%) for the PCA factors of the sampling campaign on 2017.

Table 5.3.2-3 shows the PC groups for 2019. Highlighted in red *table 5.3.2-3* shows the parameters considered significant >Absolute (0.5). In PC1 there are nine parameters and they are grouped in three categories: (1) Physical: Electrical conductivity, pH, (2) Cations: Na^+, K^+, Mg^{2+}, (3) Anions: HCO_3^-, Cl^-, and SO_4^{2-}. These parameters seem to be related and expressing the influence of the local geology in the groundwater processes. Another interesting relationship found in PC1 is the weak association of E. coli with all nitrogen compounds: NH^{4+}, NO_3^-, NO_2.

Differently, PC2 is formed by a single parameter belonging to the (2) Cations group, Ca^{2+}, which is negatively correlated to PC2. This PC might be indicative of the cation exchanger caused by the freshening process, where Calcium is released from the exchanger. At the same time, PC2, has a very weak negative relation with SO_4^{2-}, E. coli and all nitrogen compounds: NH_4^+, NO_3^-, NO_2^-. This might be indicative of an ongoing oxidation process in Semarang lowlands, probably caused by the pollution of waste waters, and therefore will be taken to further investigation in *Chapter 6 Discussion.*

PC3 comprises three parameters, which are grouped into (2) Cations: NH_4^+, and (3) Anions: NO_2^-, and SO_4^{2-}. This PC3 might be indicative of the ongoing nitrogen-processes which might be triggered by some point source pollution from faecal waste waters.

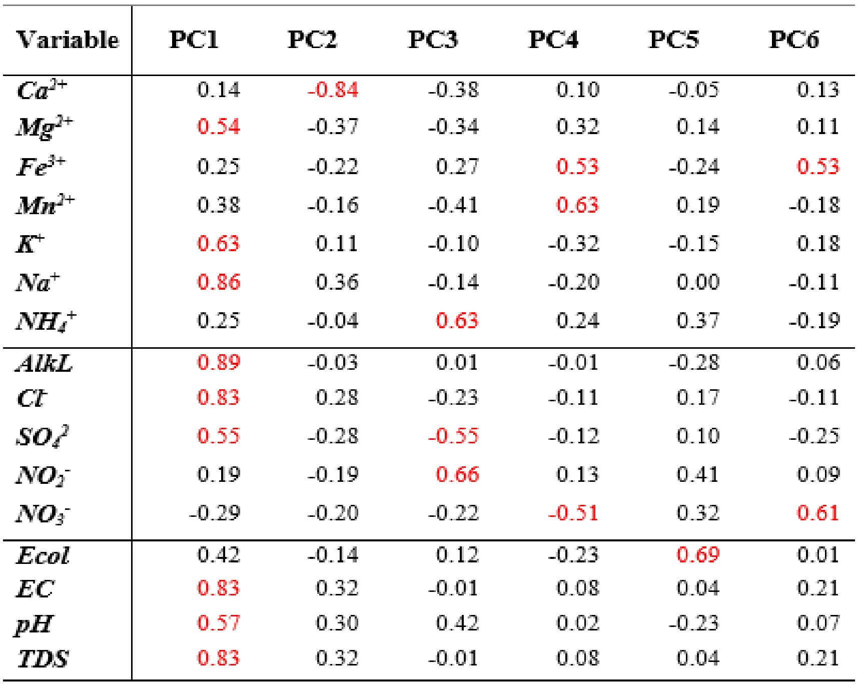
Similarly, PC4 comprises three parameters also grouped within the groups 2 and 3, being (2) Mn^{2+}, Fe^{2+} and (3) NO_3^-. This time PC4 carries a negative correlation with NO_3^-, and a weaker negative relation with SO_4^{2-}. PC5 is composed by the biological indicator: E. coli. The final PC6 is comprised by NO_3^-, this time positively correlated, and Fe^{2+} which has the smallest contribution to the total variance.

PC groups for 2017 are illustrated in *table 5.3.2-4.*, and highlighted in red are the parameters considered significant $|>0.5|$. The first group of PCs, PC1 is comprised by 10 parameters, which are grouped in four categories: (1) Physical: Electrical conductivity, pH, (2) Cations: Na^+, Mn^{2+}, Mg^{2+}, and (3) Anions: HCO_3^-, Cl^-. Also, this first PC has a weaker but negative correlation with most nitrogen compounds; NO_3^-, NO_2^-.

PC2 is formed by two parameters belonging to the (2) Cations group: Ca^{2+} and the (3) Anions group: SO_4^{2-}. These compounds result to be negatively correlated. These relationships might be indicative of the ongoing process of cation exchanger, potentially caused by the intrusion of seawater. At the same time PC2 shows that SO_4^{2-} is not correlated anymore to the first component, showing that the outlier was biasing the results in Pearson correlation.

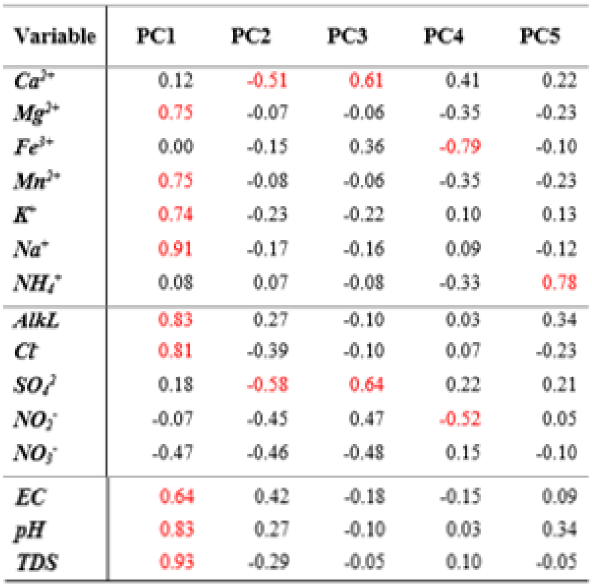
PC3 comprises the same 2 parameters as PC2, but this time are positively correlated. These had higher correlation in PC2 -0.51 and -0.58, and in PC3 0.61 and 0.64, respectively. Where they significantly differ is between SO_4^{2-} , and the nitrogen compounds of NO_2^-, and NH_4^+ where in PC2 are found to have a more or less weak, but always with a negative correlation, where it is found positive in PC3.

PC4 comprises 2 parameters, also grouped within the groups 2 and 3: (2) Fe^{2+} and (3) NO_2^-. Differently, PC5 is composed by a single parameter, which belongs within the group of cations, NH_4^+. All of these collected evidences of the ongoing groundwater processes will be collected and discussed during *Chapter 6 Discussion*. There it aims to connect the influences of the anthropogenic activities, and natural conditioning to their corresponding groundwater processes of Semarang lowlands.



Variable	PC1	PC2	PC3	PC4	PC5	PC6
Ca^{2+}	0.14	-0.84	-0.38	0.10	-0.05	0.13
Mg^{2+}	0.54	-0.37	-0.34	0.32	0.14	0.11
Fe^{3+}	0.25	-0.22	0.27	0.53	-0.24	0.53
Mn^{2+}	0.38	-0.16	-0.41	0.63	0.19	-0.18
K^+	0.63	0.11	-0.10	-0.32	-0.15	0.18
Na^+	0.86	0.36	-0.14	-0.20	0.00	-0.11
NH_4^+	0.25	-0.04	0.63	0.24	0.37	-0.19
AlkL	0.89	-0.03	0.01	-0.01	-0.28	0.06
Cl^-	0.83	0.28	-0.23	-0.11	0.17	-0.11
SO_4^{2-}	0.55	-0.28	-0.55	-0.12	0.10	-0.25
NO_2^-	0.19	-0.19	0.66	0.13	0.41	0.09
NO_3^-	-0.29	-0.20	-0.22	-0.51	0.32	0.61
Ecol	0.42	-0.14	0.12	-0.23	0.69	0.01
EC	0.83	0.32	-0.01	0.08	0.04	0.21
pH	0.57	0.30	0.42	0.02	-0.23	0.07
TDS	0.83	0.32	-0.01	0.08	0.04	0.21

Table 5.3.2-3 The component matrix and principal components (PC) of 2019 sampling campaigns in Semarang Lowlands. In red are the considered significant coefficient │>0.5│. AlkL stands for Alkalinity (HCO_3^-), Ecol for E. coli, EC, for Electrical Conductivity, and TDS for Total Dissolved Solids.



Variable	PC1	PC2	PC3	PC4	PC5
Ca^{2+}	0.12	-0.51	0.61	0.41	0.22
Mg^{2+}	0.75	-0.07	-0.06	-0.35	-0.23
Fe^{3+}	0.00	-0.15	0.36	-0.79	-0.10
Mn^{2+}	0.75	-0.08	-0.06	-0.35	-0.23
K^+	0.74	-0.23	-0.22	0.10	0.13
Na^+	0.91	-0.17	-0.16	0.09	-0.12
NH_4^+	0.08	0.07	-0.08	-0.33	0.78
AlkL	0.83	0.27	-0.10	0.03	0.34
Cl^-	0.81	-0.39	-0.10	0.07	-0.23
SO_4^{2-}	0.18	-0.58	0.64	0.22	0.21
NO_2^-	-0.07	-0.45	0.47	-0.52	0.05
NO_3^-	-0.47	-0.46	-0.48	0.15	-0.10
EC	0.64	0.42	-0.18	-0.15	0.09
pH	0.83	0.27	-0.10	0.03	0.34
TDS	0.93	-0.29	-0.05	0.10	-0.05

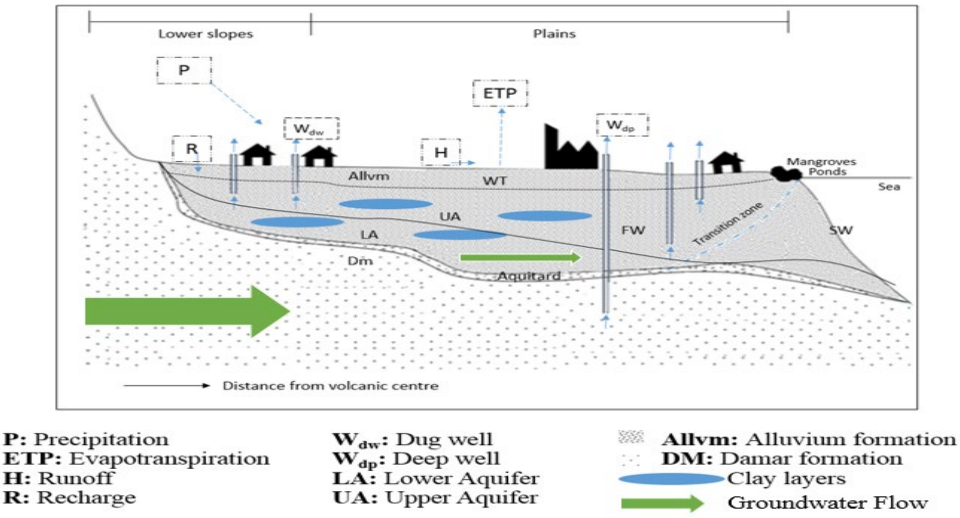
Table 5.3.2-4 The component matrix and principal components (PC) of 2017 sampling campaigns in Semarang Lowlands. In red are the considered significant coefficient │>0.5│. AlkL stands for Alkalinity (HCO_3^-), Ecol for E. coli, EC, for Electrical Conductivity, and TDS for Total Dissolved Solids.

Chapter 6 Discussion

This section contextualises all previously identified evidence towards the groundwater processes influencing the composition of groundwater quality of Semarang lowlands. This section will discuss and evaluate the types of pollution found in Semarang lowlands, the potential implications towards the quality of groundwater and health risks for the inhabitants of this area.

6.1 General traits of the unconfined aquifer of Semarang lowlands

Previous research explains that the groundwater in Semarang lowlands flows from South to the North of the city, where it meets the coastline (Lloyd *et al.*, 1985; Putranto and Rüde, 2015). The direction of the flow is relevant for the chemical analysis of groundwater in the Semarang lowlands. Knowing the direction of flow provides information about the chemical evolution in the study area. The South of Semarang lowlands is a 'less productive aquifer area', and is thus understood to be the recharge area of the basin (Putranto and Rüde, 2015), *scheme 6.1-1*. Contrastingly, the North of Semarang is classified as being a 'productive aquifer area', and is known to be the discharge point (Lloyd *et al.*, 1985; Putranto and Rüde, 2015). Additionally, this is where this freshwater meets the more saline water, *scheme 6.1-1*. The direction of the groundwater will therefore influence the understanding of the groundwater processes in this study area, from *section 6.1 to 6.3.*



Scheme 6.1-1 Cross-section of the conceptual model of Semarang lowlands by Anna San Llorente.

6.1.1 The hydrogeochemical evolution of the upper aquifer of Semarang Lowlands

Groundwater chemistry is influenced by processes that occur before the water infiltrates into the soil, or while the water travels through the soil (Belkhiri *et al.,* 2010). The processes that occur prior-infiltration often involve the evaporation and transpiration rates of a region (Appelo and Postma, 2005). The Gibbs diagram is commonly used to establish a relationship between lithological characteristics and the composition of water (Gibbs, 1970; Purnma and Marfai, 2012). In *Chapter 5 Results* shows the 30 dug well samples for Semarang lowlands are mainly within two categorised areas, being rock and evaporation dominant for 2019 and 2017 *figure 5.1.2-1*. Another plausible interpretation of the evaporation influence in the Gibbs diagram, reflected in Cl^- dominance in the diagram, is oceanic influence. The oceanic influence on groundwater quality of the dug wells is confirmed through Piper graphs, where some water types are characterized as brackish waters; $NaHCO_3$. This research makes use of the works of *Todd* and *Mays* (2005) to interpret the Gibbs diagrams, which leads to an understanding of the local lithology playing a significant role in the groundwater chemistry for both sampling years. Furthermore, groundwater is subject to atmospheric influences such as groundwater abstractions, wastewaters, evaporation or the local dry-deposited dust particles and gases, in other words, the local soil matrix (Appelo and Postma, 2005). In Semarang lowlands, Damar and Alluvium rock formations dominate the material that is being weathered (Abidin *et al.,* 2010; Putranto and Rüde, 2005). This weathering of two key rock formations, along with oceanic influence, plays a major role in the groundwater chemistry of this study area, varying spatially; closer to highlands dugwells are influences by Damar formation and dug wells on the plains are influenced by the Alluvium formation, *figure 6.2.1-1&2*.

Groundwater often reflects the local geological formations, and groundwater flow (Appelo and Postma, 2005). The ongoing groundwater processes occurring in an area can be identified by studying the compounds and minerals found in the discharge areas. In this case study of Semarang, the discharge area is known to be in the lowlands. This has been confirmed throughout the various results. For example, *figure 5.1.3-1f* evidences that this study is dealing with groundwater at a discharge point, as there is a higher Na surplus in 2019, which seems consistent with earlier observations in the graph of *section 5.1.2* (Appelo and Postma, 2005). At the same time, this is indicative to this study as it is also showing a source of sodium in Semarang lowlands. This source of sodium would be identified as the local geology, which is comprised by the alluvium formation.

By studying the behaviour of other hydrogeochemical components, other groundwater processes and influences in Semarang lowlands are revealed. Ca and HCO_3 ions result from calcite dissolution and silicate weathering (Appelo and Postma, 2005). Calcite dissolution originates from the presence of calcium carbonate in the alluvium sediments, *equation 6.1-1*.

Calcium carbonate is present in the alluvium formation in the form of forams, molluscs and coral colonies. This layer is described by *Putranto* and *Rüde (2011)* as "thick a layer of calcareous and shell bearing clay". The alluvium formation is composed by this calcium-rich layer with interlayers of clay layers composing the unconsolidated alluvium, along with siltstone or sandstone (Lloyd *et al.,* 1985; Putranto and Rüde, 2011). For this reason, it is not surprising to find its influence in the Piper and Gibbs diagrams. Silicate weathering seems to play a more significant role in the groundwater of Semarang lowlands, although it is not repeated throughout all dug wells or in both sampling years. Both years present, more in 2017, dug wells which are undersaturated in Semarang lowlands, *figure 5.1.3-1*. This reveals younger waters, with high nitrate concentrations. On the other hand, sulphate seems more reduced in 2017, and in overall, 2017 samples shift to higher salinities. The suspect of this are wastewaters from industrial areas. Nitrate is heavily reduced, specially, and then nitrification seem to be occurring due to oxic conditions. pH is much lower and pCO2 is high, *figure 5.1.4-1a,b,&c*. This is indicative of an open dissolution system and reduction is causing high alkalinities, which high alkalinity is found at very high concentrations in 2017. These processes are also common paths of Cl^- and HCO_3, which can be caused by evapotranspiration or wastewater influence. Differently, in 2019 pCO2 is much lower and higher pH, this evidences a closed system dissolution compared to 2017.

The change from 2017 to 2019 may also be caused by the so-called freshening process or silicates predominance of Na. This freshening process appears repeatedly in various results; *figure 5.1-2* shows the appearance of fresher samples in 2019 when compared to 2017 in the northeast part of Semarang lowlands. Silicate dissolution is regarded as is a very slow process (Appelo and Postma, 2005) and, taking into consideration this study's time-length of 3 years, this does not give enough time to have such clear and fast influence to the groundwater of Semarang lowlands. In addition to the freshening event from 2017 to 2019, 2017 freshwaters concentration has a Ca dominance in 2017 and a Na dominance in 2019, *figure 5.1.3-1e*. There is no great difference in Ca concentrations between the two years, *figure 5.1.3-1d*, which means that the shift in the piper diagram is due to increased Na concentrations in 2019. This increase of sodium may originate from silicate weathering, which may be caused by an extreme weather event or an unusual discharge. Another interpretation can be linked to the recharge rates, being in 2019 less than in 2017, and therefore older and more saturated waters are captured; finding Na^+, HCO_3 and Ca^{+2}. However, 2019 has fresher waters nearer to the coast, and further discussion is done in this research in *section 6.2.1.* Research by *Putranto and Rüde (2011)* could help explain the fluctuations in water-types from year to year. The study identified 2 groups in the alluvium aquifer; Garang aquifer and Quaternary marine aquifer. These groups have been found to not differ lithologically, but in groundwater quality. Garang aquifer is characterised by fresher waters compared to the more saline Quaternary marine aquifer (Haryadi *et al.,* 1991; Sihwanto *et al*., 1988; Susana and Harnadi, 2007). The results of this study bring to light the fluctuations in the aquifers groundwater bodies.

This research identified an influence of the alluvium aquifer in some of the 30 dug wells samples for both fieldwork campaigns. When investigating the origins of sodium and calcium ions, results showed Na at higher concentrations than Ca, indicating a more alkaline sample *(figure 5.1.3-1d)*. This alkalinity may have a geological origin, since groundwater under volcanic influence (Damar) is characterized by silicate-type water, Ca-Na-HCO_3, concurring with the Piper results. In the Piper diagram results there is a high dominance in cations of Ca and Na, and in anions of HCO_3 and Cl for both years, similar to in previous research (Purnama and Marfai, 2012; Putranto and Rüde, 2011; Putranto and Rüde, 2016; Rahmawati and Marfai 2013). This identification is also found in previous studies, where *Lloyd et al., (1985)* and *Putranto* and *Rüde (2011)* characterise Indonesian groundwater as alkaline-rich in consequence of the historical volcanic activity in Java. This activity is associated with the subduction of the Indian Ocean crust and is predominantly calc-alkaline to potassic-calc-alkaline in nature (Putranto and Rüde, 2016).

At the same time, alkalinity found at higher concentrations could also be caused by the freshening of the previously mentioned samples in *section 5.1.3*. This may be caused by an unregistered extreme weather event, or higher precipitation from 2017 to 2019, which is further discussed in *section 6.2.2*. Despite the higher concentrations of alkalinity versus calcium, bicarbonate is not present in excess. This indicates that the bicarbonate found in the sampled groundwater is linked to other cations. Therefore, these influences are identified as part of the natural conditioning of Semarang lowlands groundwater characterisation. This influence of local lithology to the groundwater quality is not only evidenced in the hydrogeochemical analysis of this research, but also in the statistical analysis of this thesis, *section 5.3.* Where PCA illustrates in its first principal component (PC1) the correlation between the components which characterise the local geology of Semarang lowlands; Mg^{+2}, K^{+}, Ca^{+2}, Na^{+}, and HCO_3^{-}. The correlation with Cl^{-} shows the influence of more rich waters, probably older, as well as seawater intrusion in the sampled dugwells. These statistical evidences make all previous interpretations plausible.

CO_2 content in soil depends on biological productivity, a function of temperature, humidity, soil conditions, and carbonate speciation with pH, *figure 5.1.3-1 and 5.1.4-1* (Appelo *et al.,* 2014). This process is also evidenced through the Pearson and PCA analysis, where it stablished a relationship between Ca and SO_4^{-2} in 2017 greater than in 2019, in *section 5.3*.

$$CaCO_3 + CO_2(g) + H_2O \;\leftrightarrow\; Ca_2 + 2HCO_3{}^{-}$$

Equation 6.1-1 Calcite dissolution reaction.

Further evidence towards the influence of local lithology to groundwater quality is found in the Mg vs Alkalinity (HCO_3) relationship, t*able 5.3.2-1&2*. A positive relationship between these variables can be observed. Strangely, the highest Mg concentration was found in dug well SG25, showing similar levels of Mg as in the coast of Semarang lowlands and in the middle of the industrial area. Saturated Index of dolomite (SI dol) for 2017 is higher than 2019, *figure 5.1.3-1b*. Normal concentrations of Mg are between 0 – 2 mmol/L, which is reflected in most of the dug well samples except for SG25. Also, alkalinities are very high in concentration in 2017 when compared to 2019. These concentrations reflect the prior-knowledge of this research on the presence of volcanic rocks. *Figure 5.1.4-2* evidences the presence of magmatic rocks of Semarang lowlands at the same time as the rock influence in the dug well samples. By showing a positive relationship between SI dol and Alkalinity, the differences in alkalnities between sampling years, and great differences amongst sample solution states. For instance, in 2017 samples have a lower saturation but higher alkalnites when comapred to 2019 samples. Also, 2017 samples are more undersaturated when comapred to 2019 samples, and 2017 sampels have higher concentrations of Mg comapred to 2019, with the exception of sample SG10. This relationship between Mg and alkalinity is also evidenced in the statiscial analysis in Pearson and PCA, t*able 5.3.2-1&2* and *table 5.3.2-1&2*. Furthermore, dug wells show large variation between sampling years; some of the observed dug wells in 2017 behaving completely differently (saturated) to their correspondent in 2019.

Groundwater is not only influenced by the local geology of an area, which in this case is made up of marine sediments and volcanic breccia, but also anthropogenic activities. Previous research has found that Semarang City is under the risk of seawater intrusion, caused by the overexploitation of its aquifers (Irawan *et al.*, 2018; Purnama and Marfai, 2012; Putranto and Rüde 2016; Rahmawati and Marfai 2013). This may contribute to the hypothesis that seawater intrusion influences the groundwater quality, a theory supported by the high concentrations of magnesium found in *figure 5.1.4-2.* This relationship between magnesium and alkalinity could be due to seawater mixing and possibly cation exchange. This is also identified in Pearson's analysis of 2017, where magnesium and chloride positively correlate. This statistical result supports this interpretation, as 2017 is the year with highest salinity. In *Chapter 6.2* the results of *figure 5.1.4-2* are discussed further in their relation to the suspected seawater intrusion in Semarang lowlands.

Figure 5.1.3-16g shows some of the dugwell samples have a deficit in sulphate. The concentrations of anions Cl and SO_4 are very different between sampling years, *figure 5.1.3-1g*. In both years a positive correlation between the two anions can be observed, evidenced though the Pearson analysis, showing $r = 0.59$ in 2019 and $r = 0.63$ in 2017. All samples appear to be above the ocean ratio (SO_4/Cl), and only a few go above 1 *(figure 5.1.3-1g)*, further evidencing the sulphate deficit. The data shows sulphate concentrations to be much higher in 2019, with most samples falling between 0 - 1% and a few samples reaching a 5%. Sulphate is also contributed by atmospheric deposition from the combustion of fossil fuels (Slater *et al.*, 2002). Sulphate, like NO_3-N, is involved in biological processes and can be temporarily retained in soils or biological materials. The many sulphate trends found during this study illustrat~~es~~ the ion's mobility, and iron acting as an intermediate process (Appelo and Postma, 2005). Sulphate reduction involves the consumption of a substantial amount of hydrogen ions and the production of HS^- at certain pH levels (Hassen, Hamzaoui-Azaza, and Bouhlila, 2016; Santucci, Carol, and Kruse, 2016; Werner *et al.,* 2013).

Further evidence to the previous observations are the calculations of the saturation index for calcite (SIcc) and its CO_2 pressures, *figure 5.1.4-1b&c*. At common temperatures and pressures, the dissolution of calcium sulphate ($CaSO_4$) is in equilibrium with the solid phase of gypsum, but not with anhydrite. If disequilibrium of the solid-solvent system occurs, gypsum precipitates (Hassen, Hamzaoui-Azaza, and Bouhlila, 2016; Werner *et al.,* 2013). However, there is no natural source of gypsum present in the Semarang lowlands (Purnama and Marfai, 2012; Putranto and Rüde 2016; Rahmawati and Marfai 2013). Since there is no natural source of $CaSO_4$ it is understood that there is an additional source of sulphate, as alkalinity and pH showed highly variable concentrations. Through the findings of *figure 5.1.4-2*, an interesting behaviour is observed for sulphate concentrations from 2017 to 2019. Furthermore, this study does not discard the ongoing anthropogenic activities in the study site. These do not only refer to the presence of industries, but other land and water impacts related to the ongoing urban development of Semarang City. Thus, this sulphate behaviour is taken off as it may be an indication of other kinds of pollution occurring in Semarang lowlands, and these are thought to be point-source pollution from urban and industrial wastewaters. This will be further discussed in *the section 6.3.*

6.2 Salinization mechanism

Chebotarev (1995) established the design of the typical sequence of groundwater evolution for anions. He found that with distance and time along the flow path, there is a tendency for the groundwater chemistry to vary from HCO_3 to Cl-type of water with increasing salinity. In Pearson's results, *table 5.3.2-1&2*, there was a clear correlation between HCO_3 and Cl^-, which cannot be explained by seawater directly. The change from HCO_3 to Cl-type water -type in the flow path is not alone, it is often followed by a variation in the dominant cation from Ca to Na. This evolution is only reflected within some of the dug well samples in *figure 5.1.3-1,* because most of the aquifer forming minerals and also many soils contain carbonate minerals (Appelo and Postma, 2005; *Chebotarev,* 1995; Nonner, 2015). In Semarang lowlands this origin belongs to the Damar formation, which is where most dug wells are found. However, there are 10 – 5 dug wells which plot at Cl- and Na-type. Knowing the natural evolution for cations and anions by C*hebotarev (1995),* this research finds these samples particularly interesting. As all the dug well samples are collected from the Alluvium aquifer, this research expected to obtain similar results. Furthermore, often fresh groundwater occurs in the centre of the Gibbs diagram, indicated to be the area of water-rock interaction. Nonetheless, groundwater can extend to the entire range of Na/(Na + Ca) values at TDS mid-range, as a result of the local aquifer (contains silicates) and soil properties of each area. Thus, this difference among what it seems to be the main water type might indicate that other processes outside the natural flows of the area are affecting the local groundwater chemistry.

Ion exchange, dissolution, and mineralization processes in the aquifer can be identified by plotting major cations, such as calcium, magnesium, and sodium against bicarbonate, sulphate, or chloride. As well as by studying the data distribution patterns with ratio lines such as the 0.85 ratio line found in *figures 5.1-6a*, and *b*. Throughout all bivariate plots in *figure 5.1.3-1* many similarities between the two sampling years can be observed. However, there are also many disparities. These differences help with tracking groundwater processes from year to year, including any pollution events that occur. When looking at the Na/Cl ratios for both years it is noticeable that they are higher in 2019 compared to 2017, *figure 5.1.3-1b, and e*. This indicates a reoccurring freshening event at dug wells nearer the coastline *(figure 5.1-4&5)*, adding to previous evidence. This event is evidenced once more when looking at the groundwater composition; dug wells are more brackish in 2017 (20%) than in 2019 (10%). However, the results of Gibbs and Piper diagrams show that some of the groundwater samples might be under the contamination of seawater, as the freshening event only affects a few samples in 2019, and in 2019 dug wells have lower salinity compared to 2017. The contaminated dug wells samples happen to be located inside or in the vicinities of an industrial area of Semarang lowlands*, figure 5.1-5*, and *figure 6.2.1-1*. These findings begin to evidence (1) the presence of diffusive pollution (sea water intrusion) and (2) the influence of industrial areas to groundwater quality in Semarang lowlands.

Seawater intrusion has become a common event in coastal areas of Indonesia, triggered by climate change and anthropogenic activities. This is often related to the overexploitation of groundwater aquifers, and Semarang City is not an exception (Irawan *et al.*, 2018; Purnama and Marfai, 2012; Putranto and Rüde 2016; Rahmawati and Marfai 2013). Seawater intrusion is evidenced throughout the results of this thesis, *chapter 5*. This research has started identifying such pollution from the pre-mentioned event of freshening occurring in the study area from 2017 to 2019, and the saline categorization of dug wells according to *Stuyfzand (1989)*. Furthermore, in the bivariate diagrams, *figure 5.1.3-1a, b,* and *g*, elements are normalized to Cl to facilitate comparison with the marine ratio. Most of all the dug well samples are above the 0.86 ratio, in exception of *figure b* and *g*, where some samples plot below. *Figure 5.1.3-1a and b* shows most samples following the oceanic mixing line up to 1%. There, 2017 dug wells fall between 1-10% and are categorised with an EC >1500 µS/cm. This study understands that these high levels of EC might not only be caused by the natural conditioning of Semarang lowlands (Quaternary marine sediments), but also by the industrial activities of the area. The first interpretation originates from previous knowledge of *Putranto* and *Rüde* (2011 and 2016), where they identify two groups of groundwater in the alluvium aquifer. The EC results can therefore be interpreted to likely originate from the Quaternary marine aquifer, since the influence of depositional environment at the time of its formation resulted in the entrapment of brackish water. This sediment can be released and mix with groundwater that is in the aquifer (Sihwanto *et al.* 1988).

The second interpretation is based on the over-exploitation of the groundwater aquifer by industries in the area. The fresh-seawater lens present in coastal areas is a dynamic system, which is preserved in its balancing fluctuations altered by natural tides and discharges from land. This system can be easily altered if the freshwater lens is reduced, letting seawater intrude into the system and risking the access to drinkable groundwater (>1500 µS/cm). As the Semarang lowlands is an area of ongoing development and strong industrial activities, this could be replicated in this study area. Industrial activities consume fresh groundwater from the deeper parts of the aquifer, and therefore might be affecting the freshwater – seawater interface. At the same time, wastewaters could also be affecting the groundwater of Semarang lowlands. The dug wells with high EC are located in the vicinities of industrial areas of Semarang lowlands, indicative of the presence of water with high salinities in the study area. When seawater intrusion occurs, there is a change in the exchanger of ions Ca and Na. Na exchanges for Ca, the concentrations of HCO_3 tend to increase with calcite dissolution or with time silicate weathering. This results in calcite precipitation if the groundwater is saturated with calcite. Both years have a high presence of bicarbonate, especially in its freshwaters and $NaHCO_3$-type water *figure 5.1-2&3*. After the salinization process the water becomes understaurated for calcite and this results in supersaturation of Na (Appelo and Parkhurst, 2014). Further evidence of saline intrusion is seen in *figure 5.1-4&5*, where 2019 samples are less saline compared to 2017 ones. This contributes towards the evidence of a freshening process happening from 2017 to 2019 in Semarang lowlands, and requires further studying the rainfall trends of 2017 to 2019. This may explain 2019 seeing more $NaHCO_3$ waters. Another interpretation towards this fluctuation between years in water–types is the occurrence of an extreme weather event or a great discharge into groundwater. Such an event should be significant to alter the water-type composition and benefit the quaternary marine sediment group in the alluvium aquifer in 2017 and the Garang group in 2019 Semarang lowlands. Also, industrial activities might be the cause of the fluctuation between these water types, as their use of groundwater might be releasing connate waters entrapped in the intercalated layers of clay in alluvium formation. Therefore, this research shows strong evidence of the change in groundwater quality from year to year, and the high salinity found in both year's dug wells. This leads to the question of the influence of (1) the natural conditioning of Semarang lowlands and (2) ongoing groundwater abstraction from the deeper parts of the unconfined aquifer might be having an impact to the groundwater quality of the shallower parts. In order to further understand the water evolution occurring in Semarang lowlands, it is recommended that continuous monitoring of groundwater quality is undertaken over a period of up to 50 years.

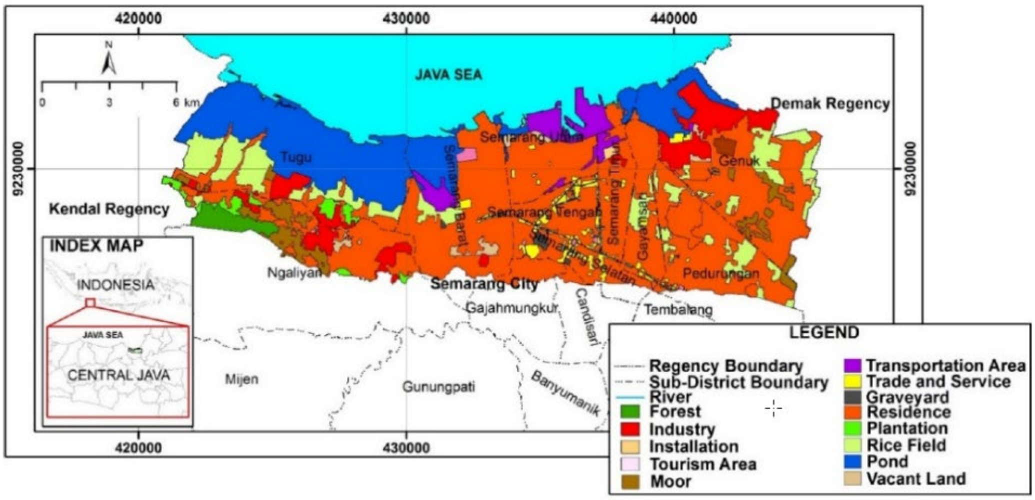


Figure 6.2-1 *Putranto, Widiarso and Susanto* (2017) land use map of Semarang lowlands.

6.2.1 **Influencers of the salinity of the unconfined aquifer of Semarang lowlands**

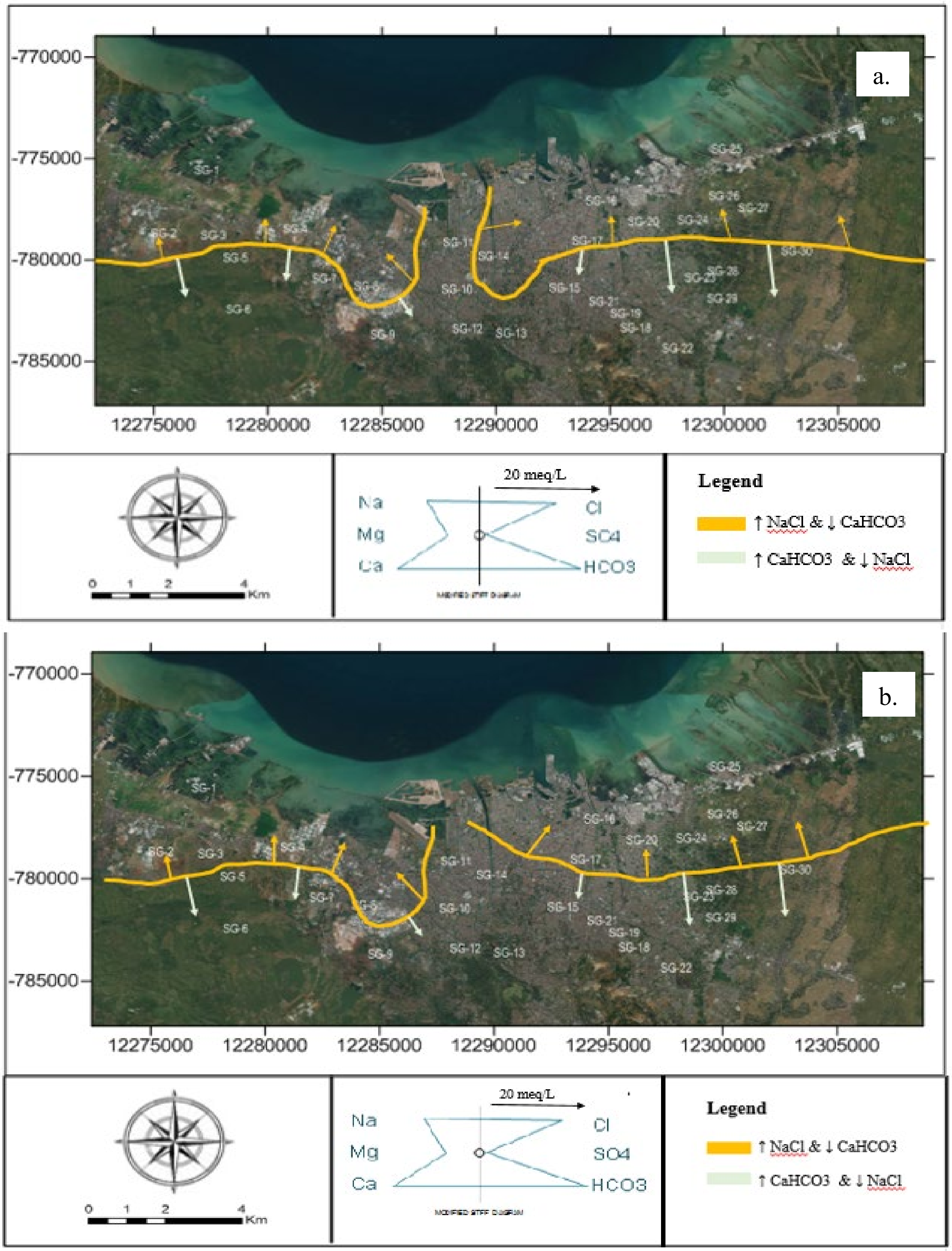


Figure 6.2-2 Conceptual representation of the spatial distribution of the water-types found in Semarang lowlands for 2019 (a) and 2017 (b).

This research changed the previous analytical perspective to a spatial point of view, and observed that the samples falling within the Na-HCO_3 and Na-Cl groundwater facies category are located in an industrial area, *figure 5.1-4&5*. As coastal samples are expected to behave similarly, and they are shown to not behave the same along the coastline. Since SG10, 11 and 14 vary of composition from the rest in 2019 and SG10 and 11 in 2017, *figure 6.2-2a&b*. It is then when is clearly recognised that the different groundwater-types in this Semarang lowlands seem to be grouped differently depending on the distance to industrial areas, *figure 6.2-2a&b*. This contributes towards the questioning of the real influence of industries might be having to the groundwater chemistry. This suspicion towards the industrial activities if supported by previous studies, where they have found a case of over-abstraction of groundwater by industries, which might be the influential cause for the seawater intrusion (Putranto and Rüde, 2015). If the water table drops then there might be high pumping rate, indicating industries are abstracting more groundwater than the groundwater system can recharge. Therefore, if saline intrusion is happening, it is making fresh water more saline. Evapotranspiration could be another reason. Since, high evapotranspiration makes the upper aquifer more saline.

The samples which are falling within the Ca-HCO_3, and Na-HCO_3 area are the dug-wells closer to the highlands of Semarang, *figure 6.2-2*. The same samples are found within the lowest EC range of 330-1800 µS/cm. This ranges fell within the threshold of freshwater to brackish water. When following the samples towards the Na-Cl facies area, the dug wells identified are those closer to the shoreline, and with a higher EC range (1800-8000 µS/cm). This shows a different picture to previous samples, as it changes from a freshwater-brackish water range to all samples being brackish, indicating that as closer to the shoreline there might be an influence of saline intrusion or a polluting activity altering the concentrations. However, dug well number 1, 11 and 14 are samples close to the shoreline, but did not fall within the Na-Cl groundwater facies category, *figure 6.2-2*. This leads to rethink the assumption of saline intrusion due to the natural conditioning of the unconfined aquifer, to another influence. These results suggest that the over-abstraction of the confined aquifer in industrial areas could be (1) releasing entrapped connate brackish groundwater from the quaternary sediments in the alluvium aquifer or (2) altering the salinity of the unconfined aquifer by promoting seawater intrusion from the sea, *section 6.2.2*.

6.2.2 **Origins of seawater intrusion**

Often hydrogeological articles and books show sharp, steeply inclined transition zones between fresh and brackish groundwater in the coastal areas (Groen *et al.,* 2000). This interface illustrates the steady state conditions of flow systems between active meteoric and marine groundwater (Appelo and Postma, 2005; Groen *et al.,* 2000). However, this condition is not always found in groundwater salinity distributions along many coasts, and often they do not comply with this concept (Groen *et al.,* 2000; Hathaway et al., 1979). For example, saline and brackish groundwater can be found far inland in coastal plains like those of The Netherlands, Suriname, South America and Java, Indonesia (De Vries, 1981; Groen *et al.,* 2000; Maathuis *et al*., 1996).

This research has found high salinity in some dug wells of Semarang lowlands located near and further away from the coastline. This finding leads to the questioning of the origins of these higher salinities; (1) which could be directly from the sea or (2) the release of paleowaters from the unconfined aquifer. Previous research explains that the alluvium aquifer has two groups which differ by quality not lithologically, the first one has fresher waters when compared to the second group which is characterised to more brackish ones (Putranto and Rüde, 2015; Putranto and Rüde, 2011). This research has identified a salinity fluctuation between the samples as well as between sampling years, from fresher to brackish characteristics. This fluctuation is especially distinctive between sampling campaigns, where groundwater changes from brackish in 2017 to less brackish in 2019, evidencing the presence of two water influences. From these findings this research observes that both interpretations (1) and (2) are plausible, and therefore require further investigation. Previous research explains that Semarang lowlands geological evolution entrapped brackish water in the clay layers of the alluvium formation, where the unconfined aquifer is formed during the Pleistocene–Holocene ingressions caused by the climate changes occurring during the Quaternary (Purnama and Marfai, 2012; Putranto and Rüde 2016; Rahmawati and Marfai 2013). Therefore, this research might have captured in its results the release of old brackish groundwater into the shallow aquifer potentially caused by the over-abstraction of groundwater done by local industries. Thus, this thesis looked into the origins of the detected brackish samples via major ion concentrations: Mg^{2+}, HCO_3, SO_4^{2-} and Ca^{2+}.

Often this is tested using the Br/Cl ratios or stable isotopes, however in this study looked into the major anions ratio, following the research works of (Gimenez and Morell, 1991; Morell and Gimenez, 1996; Somay and Gemici, 2009). These authors state that you can recognise the salinity origins via the Ca/Mg and $Ca/(HCO_3+SO_4)$, where if it is >1, it means that seawater intrusion is taking place, *figure 6.2.2-3.* The content of major ions that predominate in sea water (Cl^-, Na^+ and Mg^{2+}), demonstrates that such salinization is related to sea water (Morell and Gimenez, 1996; Gimenez and Morell, 1991). Also, the enrichment of Ca as the principal ion can be used as an indicator of seawater intrusion into groundwater (Gimenez and Morell, 1991; Morell and Gimenez, 1996; Somay and Gemici, 2009). The enrichment observed in the major ions (HCO_3 and SO_4^{2-}) with respect to the seawater mixture would show that the semi-confined aquifer water from the coastal plain corresponds to a paleowater intruding in the unconfined aquifer released from clay layers. This is also reflected in the positive correlation between the major ions, which can be interpreted as indicative of trapped seawater in clays, *table 5.3.1-1&2*. At the same time, this interpretation would give an explanation to the occurring freshening event from 2017 to 2019. Since the release of connate paleowaters would be subject to the pumping rates of groundwater in the deeper aquifer, which are carried out by industries in Semarang lowlands. This pumping rates may have varied from year to year, causing fluctuations of the groundwater type from fresh to brackish and vice versa.

This research has previously referred to the effect of recharge to groundwater fluxes. In this study are recharge can be altered by a change in rainfall or by a change of the groundwater abstraction practices. Therefore, the encountered salinity fluctuations could be indicative of less pumping of groundwater by industries or of more recharge in Semarang lowlands. Semarang city is characterized by having the rainy season from October until April, and the drier months from April until October, *Section 1.2*. Both fieldwork campaigns occurred during the drier months and less precipitation. In order to observe if the amount of rainfall is affecting the water type group of the alluvium aquifer, there is a need to check the 2017 and 2019 climatological data for the months of May in the database of the Indonesian Badan Meteorologi, Klimatologi, dan Geofisika, *figure 6.2.2-1&2.* These figures display the distribution of rainfall (mm) for both for the month of May of 2019 and 2017. Opposite to what is expected these figures evidenced that 2019 had a drier May when compared to 2017, by a 50mm difference. However, these figures only show the average monthly values for May 2019 and 2017, and therefore extreme weather events might be disguised in the data.

The results displayed in *figure 6.2.2-3* show an obvious influence of seawater for the Ca/Mg ratio, but this is reflected differently when looking at the $Ca/(HCO_3+SO_4)$. Thus, to reach further conclusions of the origins of brackish water there is a need of further research. As this research does not discard the influence of the industrial abstractions of groundwater occurring in Semarang lowlands by the existing industries.

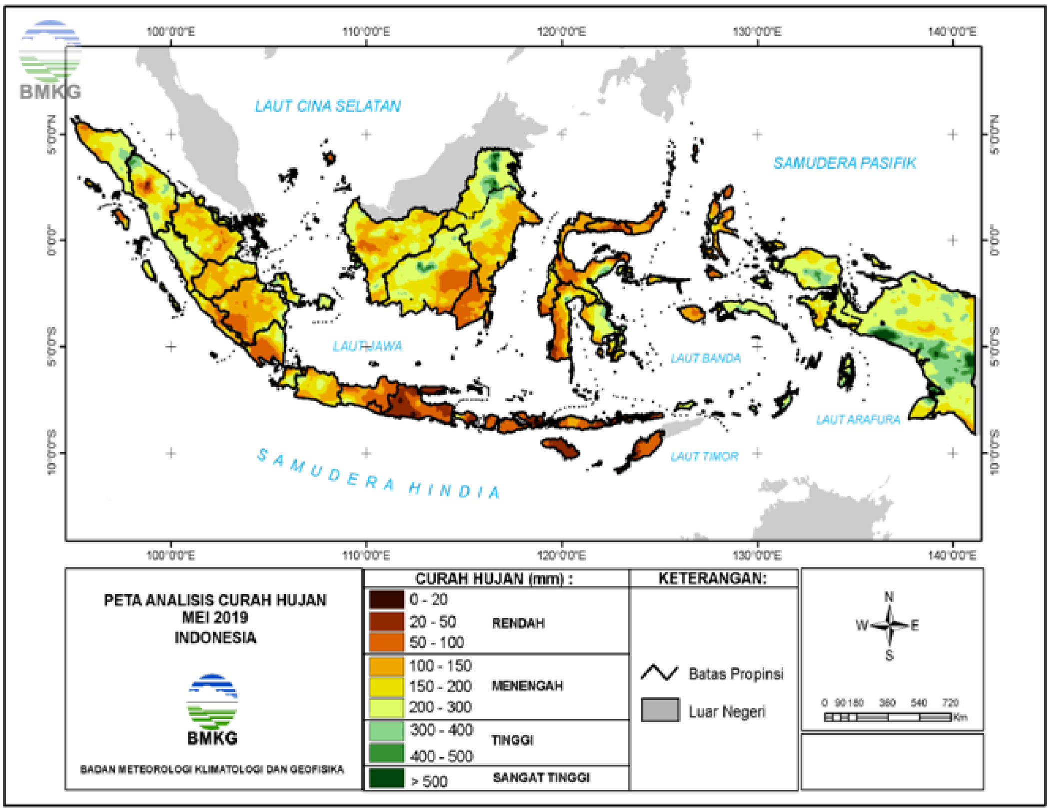


Figure 6.2.2-1 Precipitation distribution of May 2019 average precipitation (mm) of Semarang City.

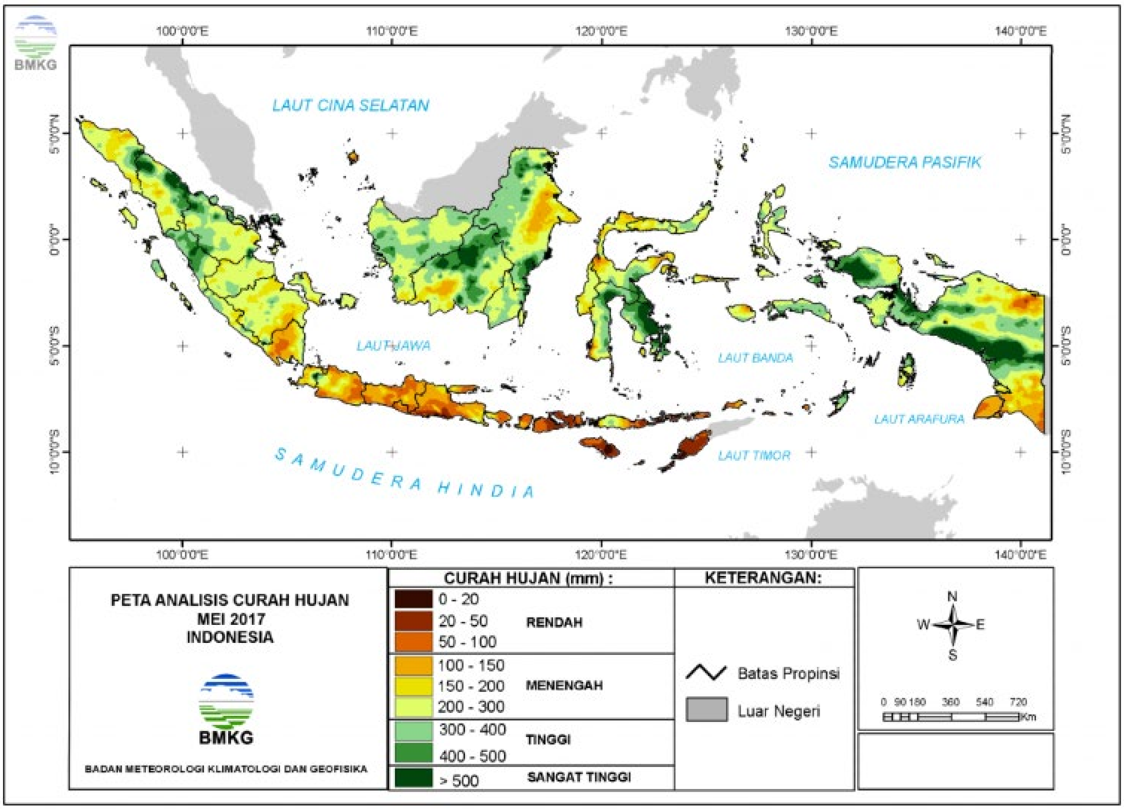


Figure 6.2.2-2 Precipitation distribution of May 2019 average precipitation (mm) of Semarang City.

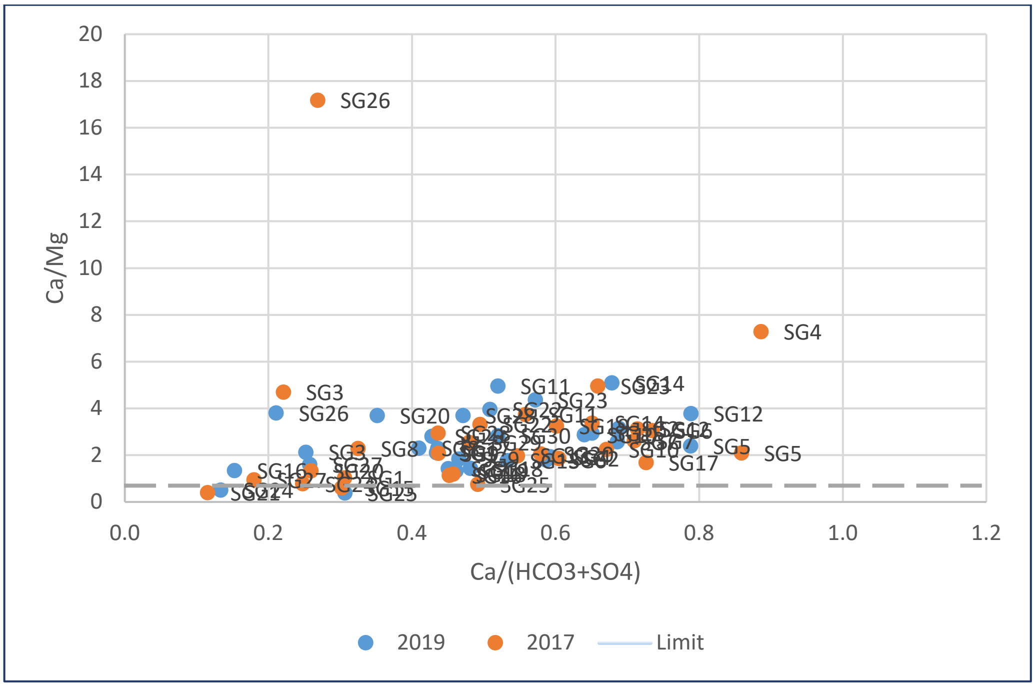


Figure 6.2.2-3 Scatter plots for the major ions per unit in meq/L for the 30 dug well samples from Semarang.

6.3 Influence of sanitation infrastructure and wastewater disposal on groundwater

6.3.1 Are there any other influences altering the groundwater quality in time and space?

Literature describes Semarang City as an urban area developing, its population was last recorded in 2010 with 1.55 million people (Bandan Pusat Statistik, 2010). With this growth anthropogenic activities increase in the area, which in the results of this research appear to have a strong influence on the natural conditioning of Semarang. This conditioning has been illustrated throughout the dug well samples from 2017 and 2019 campaigns, as these samples hint to this research that industrial activities may be playing an important role to the groundwater chemistry of Semarang lowlands. However, up to this section it has not been mention that the sanitary infrastructure of the city may also be influencing the groundwater quality of the sampled dug wells.

Nitrogen and nitrate/nitrite exposure are extensively studied within literature (WHO, 2011; Krishna Kumar and Sinha, 2010). Previous research shows that human exposure to concentration greater than the permissible limits suppose a health risk to animals and humans: NO_3^- 50mg/L and NO_2^- 3mg/L. This is linked to several diseases, such as gastric cancer, methemoglobinemia (blue baby syndrome), diabetes, and thyroid disease (Kumar *et al.*, 2015;

WHO, 2011). E. coli is also a compound identified as a health risk to human, and often link to faecal contamination. Therefore, the presence of these compounds in Semarang lowlands suppose a risk to human health and living, and its sources/origins need to be understood to reduce its concentrations and improve the health and lifestyle of residents. Nitrate and nitrite contamination are often found to originate from agricultural practices. This origin is discarded, as this research understood from the land use map that there are not a great number of agricultural practices to be the main source or be able to cause a great impact into groundwater quality, *figure 6.2-1*.

Templeton *et al*. (2015) states that the most common forms of onsite sanitation facilities of developing countries are pit latrines. These latrines are used as the isolative mean of human waste, despite not being complete as often the latrines conditions lead to nitrification of the contained waste. This research suspects that Semarang lowlands encases a similar case, as the distances from latrines to hand dug wells is very short. This suspicion only grows when analysing *figures 5.1.4.2-a&b,* where nitrate pollution is present in 2019 samples, and two of the dug wells exceeded the WHO and SNI permissible limit. At the same time, there are other nitrogen-compounds found in the sampled dug wells of both sampling campaigns, such as nitrite. Both sampling campaigns have more than a single sample exceeding the WHO and SNI permissible limit of nitrite. This is of major concern for the health of the inhabitants of the area, as nitrite is the most reactive form of nitrates and often very difficult to find in samples (Hill, 1991). Nitrite is found to be positively correlated with ammonium in Pearson and PCA, *table 5.3.1-1&2* and *table 5.3.2-3&4.* Pearson shows this correlation for both sampling campaigns, where in PCA differs. The PCA results of 2019 in *table 5.3.2-3* shows, once again, the nitrite and ammonium correlation. However, these results do not repeat in 2017 in *table 5.3.2-4*, but these components are still highlighted in the PC4&5. These results are an indication to nitrogen compounds playing a significant role in the groundwater quality of Semarang lowlands. This indicates that nitrogen-compounds are changing the local groundwater chemistry, these may be linked to denitrification and nitrification processes. Another nitrogen compound found in the results of this research is ammonium, and it is found in high amounts. Also, rates of nitrification are found for both sampling campaigns. If denitrification is occurring in the study area, it can act as a source of nitrite, although oxidation of ammonium is more common (*Van Metre et al.*, (2016); *Zhou et al.,* (2015). Nitrite was found in both sampling campaigns, presenting a higher concentration in 2017, *figure 5.1.4.3-1a&b.* High levels of Dissolved Oxygen Concentration (DOC) act as an indicator to this process, and indeed there are high levels in some of the dug wells, *figure 6.3.1-1*. As previously stated, if the concentrations of nitrate and nitrite exceed the permissible limits of WHO they suppose a health risk to humans and the living. Therefore, the results of nitrogen compounds are alarming, as they show that Semarang lowland's dug wells are enriched by ammonium, and denitrification process happening. These nutrient related processes are thought to be caused by wastewater production from industries and by a poor sanitation infrastructure of households, and takes this research to look into other potential sources of nitrogen compounds.

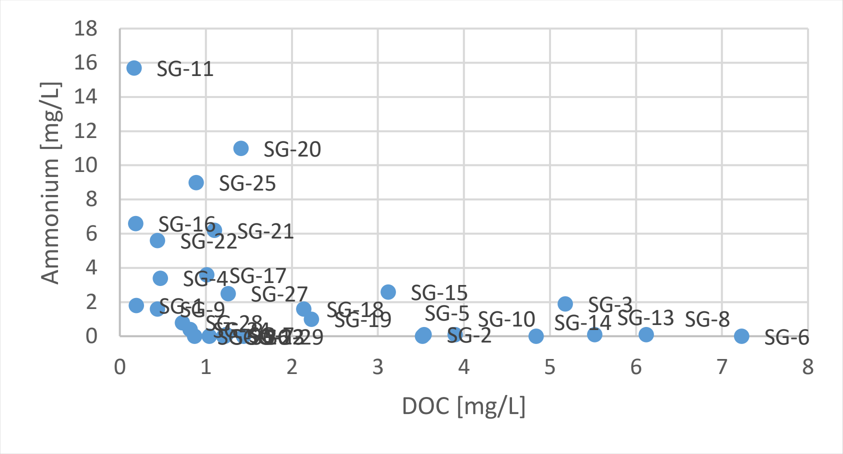


Figure 6.3.1-1 Dissolved Oxygen Concentration (DOC) sampled during the 2019 fieldwork campaign from May-June in Semarang lowlands.

After obtaining the previous findings, this research wondered if there were any other suspicious sources of nitrogen components in Semarang lowlands, aside from seepages from sanitary infrastructures. To find the answer to this question this research then takes a spatial analysis to visualise any existing patterns across the study area. When looking at the distribution of the polluted samples in *figure 5.1.4.2-1a&b and 5.1.4.3-1a&b* there is no clear distribution pattern for nitrate or nitrite. However, higher concentrations are observed inside or in the vicinities of industrial zones, and only in 2019 permissible limits by WHO and SNI are exceeded, *figure 5.1.4.2-1a*. The samples which exceed these permissible limits are also found to be neighbouring industrial areas. This may lead to the understanding of industries being one of the sources of nitrogen compounds to groundwater. These results only evidence a potential source of nitrogen compounds in industrial areas, and therefore further research is required. Differently, E. coli displays a rather consistent distribution throughout Semarang lowlands. This component is present in all 30 dug wells sampled in 2019, knowing that E. coli is linked to the pollution of faecal wastewaters this research understands that sanitary infrastructure has some influence over groundwater quality of Semarang lowlands. These findings are not out of the norm for urban areas in Indonesia. In 2012 the World Bank recorded that only 54% of the Indonesian population had access to acceptable disposal facilities, which could be private or shared (Sudarno, 2016; Templeton *et al.,* 2015). By knowing E. coli is a health risk to humans this research recommends an improvement of the sanitary facilities and practices. At the same time as not using dug well groundwater as water source until no E. coli is left present.

Even if the sanitary facilities are classified as satisfactory on hygienic terms, the risk of contamination of water wells is not erased (Sadler *et al.,* 2016; Templeton *et al.*, 2015). This research found that the nitrate pollution of some dug wells might be linked to the poor sanitary infrastructure. Previous research supports this interpretation, since described Semarang's sanitary systems for black waters has not kept pace to the urban development of the city, causing a lack of proper sanitation infrastructure, and leading to groundwater pollution (Sudarno, 2016). The most common sanitary infrastructure in the city are septic tanks, and often users are found to not follow the correct management of this human excreta disposal system. This is attributed to a bad design and/or poor management of sanitary infrastructures (Dayanti *et al.*, 2018; Harman *et al.*, 1996; Templeton *et al.*, 2015). And consequently, it implies a risk for the quality of groundwater to be contaminated by faeces, a water source where most of the population of the Semarang lowlands rely on for their daily water needs for washing (WHO, 2014). These water needs rarely include drinking and cooking, but two household owners declared in the survey that they sometimes make use of their groundwater for drinking, SG9 and 13, Annex I. Both samples fall close to the highlands yet they both have E. coli, and no exceeding permissible concentrations of nitrate or nitrite. These findings support the previous interpretation, which stated that nitrogen compounds have various sources.

Nitrate and sulphate shown a relationship in the statistical analysis of this study, *table 5.3.1-1&2*, where a positive relationship is stablished between sulphate (SO_4) and calcium (Ca) through the Pearson's analysis; 2019 has $r = 0.5$ and 2017 has 0.5. This rises the interest of this research to take it to further investigation, as it harnesses potential to be an indicator of sulphate reduction.

The main difference between sampling campaigns relies on the sulphate concentrations, showing that sulphate reduction might be happening into these groundwater samples. In 2017, sulphate seemed directly correlated to nutrients (PC2), and in other areas appears to be inversely correlated to nitrate (PC3), *figure 5.3.2-2*. T In 2017, concentrations are very low when compared to 2019 ones, and seemed indeed to be reducing in despite of nitrate being present, *figure 5.3.1-1&6.1-2*. Also, the group of dug wells which are behaving differently (*figure 5.1.4-*

1a) in 2017 is not the same group of dug wells in 2019, thus it is understood that sulphate is reducing. Previous research states that the nitrate concentrations are low when sulphate reduces (Stigter *et al*., 2006; WHO, 2004), and indeed concentrations of sulphate are low in *figure 5.1.4-1a,* where 2017 shows the lowest sulphate concentrations when compared to 2019. These fluctuating concentrations are understood to have an anthropogenic origin, most likely to be from industry since Semarang lowlands has many industrial areas.

Continuing with the investigation on the origins the sulphate reduction, *figure 5.1.4-1a* little differences between the years, yet in 2019 sulphate dominates over calcium, and in 2017 calcium over sulphate. In 2019 there is a change, this change is understood to be caused by a process of contamination. Also, in 2019 there are three outliers (SG3, 4, and 25) whereas in 2017 there is only a single outlier (SG24). All these dug wells fall in residential areas near industrial areas. Therefore, the sample location seems to have some influence on the groundwater quality of the shallow aquifer. PCA results of 2019 do not pick up on this relationship but they do in 2017, *table 6.3.2-1&2*. There are two plausible reasons behind nitrates not showing up in the 2019 PCA results (1) because the contamination mostly involves sulphates, or (2) because of denitrification. Furthermore, this research recommends further monitoring on the groundwater quality of the sampled dug wells and extend this monitoring to the groundwater of industries, as it has been displayed as potential pollution source throughout the results. This potential source of pollution alongside with the poor sanitary infrastructure require further attention, since it is a health risk to the inhabitants of the polluted areas in Semarang lowlands.

6.3.2 Groundwater quality, a defining feature determining water uses and practices of the dug well owners of Semarang lowlands?

The Sustainable Development Goals (SDGs) were designed to ensure an ecologically sustainable, economic, environmental, and social development (Kooy, Tina Walter and Prabaharyaka, 2016). This research focuses on SDG 6, clean water and sanitation for all. Even though all SDGs share a common challenge, which it has been defined by the authors *Kooy* et al., *(2016)* as “the integration of ecological sustainability with social inclusion.” In this view, Semarang is a city currently experiencing a rapid development, and therefore is at a crucial point to apply more sustainable practices.

How is this city developing in view to SDG6? And is their development inclusive? These are difficult questions to give a simple answer to, and this research tracked the water uses and practices of the 30 households, in order to answer them. The results of this research found that dug wells are often experiencing two types of pollution. Being of the diffusive-type pollution happening in the shallow aquifer of Semarang lowlands was found to be linked to the suspected over abstraction of groundwater of the area. The point-source pollution was found in this research results to be from nitrate, nitrite and E. coli, was linked to the sanitary infrastructure of Semarang lowlands. These results were obtained via this study's hydrogeochemical and statistical analyses, and it gave an understanding of the groundwater situation from 2017 to 2019, and how it linked to the inhabitant's water uses and practices. This knowledge on the relationship between water and the inhabitants of Semarang lowlands provides a new opportunity to detect the areas still needing improved access to safe water under SDG6 in Semarang.

At first sight, Semarang would not seem to have a water scarcity, as it is characterised by having tropical climate (Putranto and Rüde 2015). In despite of its abundance of water, not all is suitable for human consumption. This situation drives the city to a risk of water shortages. This research captured the water uses of the surveyed 30 dug wells, and these are often used for potable purposes; such as washing, cooking or drinking by several households or by individuals, *figure 6.3.2-1&2* (Sadler *et al*., 2016; Sudarno, 2016). Literature states that PDAM water is not always reliable for all inhabitants, for problems in the continuity of its distribution and water quality. Thus, PDAM is not considered by Semarang lowlands residents to be an assured source for water, because often it cannot give to its users the assurance to always be available and of good quality. This indicates that the reliability on PDAM water and preference for piped water is different in different areas of the city; highlands (south) and lowlands (North) (Marfai and King, 2008; Putranto and Rüde, 2011). At the same time, previous research explains that not all citizens of Semarang can afford the prices of PDAM, especially those with fewer resources (Putranto, Hidajat and Susanto, 2016). These families that cannot afford PDAM prices, can neither afford to buy bottled water to satisfy their water needs, and therefore are driven to use groundwater or PDAM.

The survey results show bottled water is used only for drinking purposes, *figure 6.3.2-2.* This is not uncommon to countries that have established and have been maintaining an unreliable piped water system, where bottled water has been perceived to be of better quality than piped water (Prasetiawan, Nastiti, Muntalif, 2017). This is the case in Semarang: through interviews to the 30 dug well household owners is understood that residents would rather purchase bottled water over the other available water sources, as they perceived it as better quality, *Annex I.* This suggests that these 30 dug well owners have a relationship of mistrust with the other available sources. *Annex I* show that often dug well owners refer to groundwater as being smelly and of unsuitable use for drinking. Dug well owners know that their groundwater has poor quality by its smell and from common knowledge. Either way there are only a few cases where dug well owners preferred groundwater (Artesian wells) or PDAM water over bottled water.

Previous studies explain that the Indonesian bottle water industry have been campaigning to market their product to highlight the appeal of bottled water regards to, not only good water quality and physical health, but also convenience, taste, mental health, and social and environmental values (Prasetiawan, Nastiti, Muntalif, 2017). This seems to create an easy route to escape the real issue, and a route that can be taken with ease for those who have the economic resources to access cleaner water.

The impacts from the over-abstraction of groundwater become evident at the ground level, as shallow aquifers are polluted with saline intrusion (Appelo and Postma, 2015). It is then feared further consequences to the water quality of the aquifers, if these unregulated activates continue. The results in this research gave an insight on how inhabitants of Semarang lowlands cannot rely on a single source of water but in multiple ones, *figure 6.3.2-2.* This scarcity of clean water needs to be addressed with urgency, to reduce the foreseen future consequences if the situation continues as is in the present.

The results from the sampling campaign of 2017 and 2019 reflect on the importance of good sanitation schemes (Templeton *et al.*, 2015). Sanitary infrastructures seem to be affecting the groundwater quality of all 30 dug well samples in 2019. The Indonesian government has many regulations, but often sanitation systems of households are unmonitored, as is a challenging task to be carried out throughout a city in development. Thus, the regulations are not well implemented. This source of point pollution has been evidenced through the E. coli measurements in *figure 5.1.4.1-1.* Thus, there is a need to improve sanitary practices and sanitation infrastructures (Sudarno, 2016).

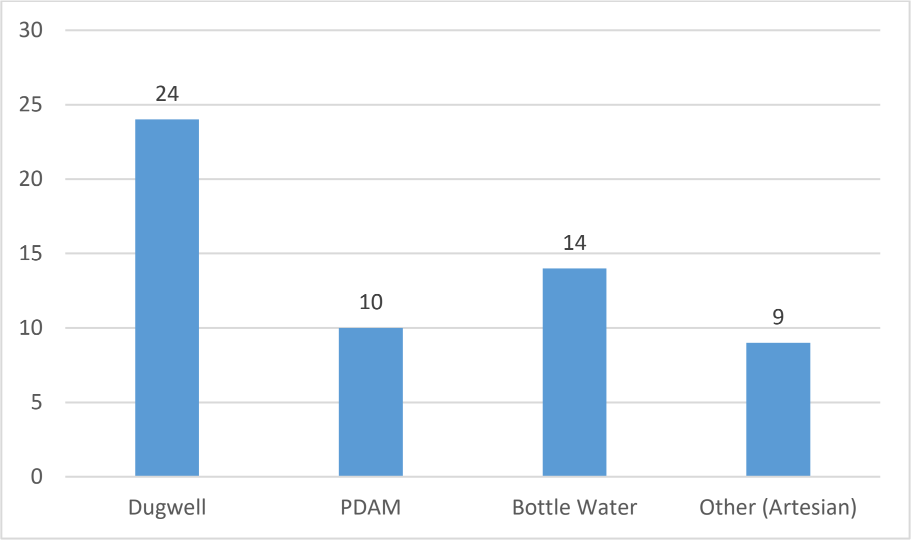


Figure 6.3.2-1 . Bar chart for the different water sources used for the 30 household owners of dug wells from Semarang lowlands during May-June of 2019.

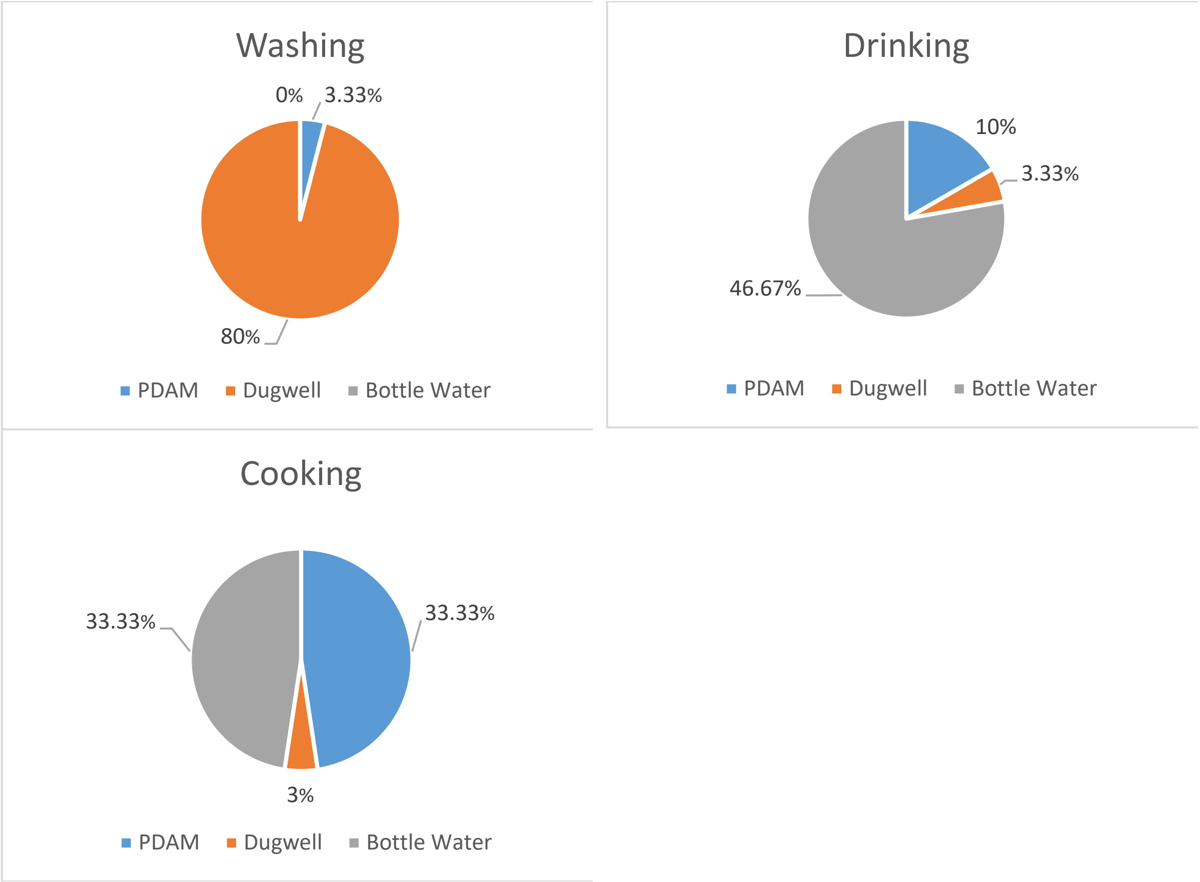


Figure 6.3.2-2 Pie charts of the surveyed water uses of the 30 household owners of dug wells sampled in Semarang lowlands during May-June of 2019.

Chapter 7 Conclusions

Semarang city is currently developing, and some of the new pressures appear to be influencing the groundwater quality of the city. This has been viewed throughout the results of this thesis, and therefore of the study area of Semarang lowlands, in the North of the city. In spite of the anthropogenic pressure on the groundwater of Semarang lowlands, there is a natural conditioning factor which defined the groundwater of the unconfined aquifer. This natural conditioning has been unveiled with the hydrogeochemical analysis in this thesis, where the compounds of sodium, calcium, bicarbonate and chloride were identified as the characterising hydro-geology of Semarang lowlands. These composed the typically found water types of the study area, shown in the Piper diagram results; in cations of Ca, and Na, and in anions of HCO_3 and Cl for both fieldwork campaigns. Statistical analyses of Pearson and PCA supported these findings, and therefore provided further evidence to the already existing hydrogeological literature of Semarang.

In overall, the results of the dug well samples did not vary from 2017 to 2019, only in specific analyses. These fluctuations brought to discussion to the possible sources of the composition of groundwater quality of Semarang lowlands, and this research explained various interpretations to the changes from year to year. First, this study identified the calcite dissolution to be consequential of the change of concentrations in 2017 dug wells. This groundwater process acts as a source of salinization for the samples, for this reason 2017 appears with a higher salinity compared to 2019. Second, it was hypothesised that another possible cause to these fluctuations could be an extreme weather event. Such events area a great input of freshwater, which would recharge the aquifer, and therefore acting as a source of freshening. Finally, the behaviour of industries as consumers of groundwater was taken into consideration; these could have disposed of their wastewaters or carried out less abstraction from one year to another, and therefore influenced the groundwater in one of these ways.

The local geology along with industrial activities are not the only influence to the local groundwater, also two kinds of pollution seem to be playing a role in the groundwater chemistry of Semarang lowlands. The first one is diffuse, related to the intrusion of sea water into the aquifers, and the second kind is point-source, linked to the poor-quality sanitation infrastructure of Semarang lowlands. The first, sea-water origins were linked to industrial abstractions of groundwater from deeper parts of the aquifer. These activities are understood to be either unbalancing the fresh-water sea-water interface, or be releasing entrapped brackish water from clay layers in the alluvium aquifer. The latter pollution was found through the presence of E. coli throughout all the dug well samples, nitrite, and some nitrate. Along with the statistical analysis backing to these findings, were nutrients relationships were evidenced in the Pearson and PCA results. Therefore, seawater intrusion and sewage were identified as sources of pollution to the unconfined aquifer, also known as Alluvium aquifer. To conclude, this research found that often groundwater accessible from private dug wells is of no good condition for human consumption. The water quality is altered by diffusive and point source pollution, these being seawater intrusion and nutrient related. Seawater intrusion seems controlled by larger industries and not the small well owners. Differently to nutrient related pollution, where well owners homes sanitary infrastructure seem to be influential on the bacterial (E. coli) activity and nitrogen-compounds concentrations. These types of pollution appeared to have influenced on the uses of this water source in Semarang lowlands. By end users discarding the possibility to use their own private dug wells as a water source for drinking purposes or even cooking. Therefore, dug well owners have to look for other water sources such as piped water (PDAM) or bottled water to have a reliable drinking water source.

The key audience for this research consists of end users, researchers, local politicians, policy makers, donors and water supply professionals. Local politicians and policy makers can use this research results to inform the design of urban water and sanitation development, and renovation of the infrastructure and spread awareness of the benefits of more sustainable sanitation practices on improved water quality, to get a step closer to SDG 6. These stakeholders are the ones required to pay more attention to the complexity of Semarang waters network, and its services. This should be done to ensure clean water and sanitation for all inhabitants of Semarang City. Based on these research findings it is understood that the city's sanitation system, wastewater management and groundwater monitoring are all interconnected, and – as such, the impacts of the connections between groundwater and wastewater systems needs more attention. Continued lack of attention will aggravate the risk to human and ecosystem health.

Chapter 8 Limitations and Future research

In this research a great number of evidences of the influence of the ongoing anthropogenic activities happening in Semarang lowlands was found. However, this does not assure these findings to be definite. Other processes not covered in this research cannot be discarded to have an impact to groundwater. These include volcanic emissions, and climate change. The first is known to contribute to massive amounts of mineral dust are uplifted into the atmosphere (1950 to 2400 Tg year−1; Ginoux *et al.,* 2004). Mineral dust affects the gas phase chemistry in the troposphere by providing a reactive surface that is able to support heterogeneous trace gas reactions (e.g. Usher *et al*., 2003). The second it is not directly considered in this research, since the time between sampling campaigns is only of three years. These considerations do not aim to discard the findings of this research, but rather bring criticism. Thus, it is recommended to further study and monitor Semarang lowlands, in order to continue and support this research.

Furthermore, the grey waters from Semarang produced from domestic or industrial waste are known to receive no treatment or partial treatment before being disposed; in fact, they directly discharge into the river (Ujianti *et al*., 2018). Consequently, this river is home of various kinds of pollutants with high concentration of nutrients, including contaminants from upstream agriculture and domestic sources and often exceeding the limit concentration value set by Indonesian Health Ministry (Amanah *et al*., 2019). In literature a small number of studies are found measuring the concentrations of nutrients in the riverine system and coastal area of Semarang, and even a smaller number for groundwater quality of the shallow aquifer (Uijanti *et al*., 2018; Sadler 2016; Siregar and Koropitan, 2016; Sudarno, 2016; Yustiani, 2016). This should be taken into consideration for future research. Furthermore, for future studies it would be of great improvement to carry out a continuous monitoring of the shallow aquifer of Semarang lowlands. As it would provide further detail on the fluctuations of groundwater composition in dug wells. Another addition to further studies would be to make a 10 year-period study of the concentrations, see if these levels have increased over the industrialization/urbanization decade, or how they are going to change in the future. At the same time, this research recommends to industries to follow monitoring practices in order to abstract sustainably the groundwater. In other words, to respect the recharging time of this source, and to not continue with the over-abstractions. If these practices continue this research fore-sees a dramatic consequence for the industries as well as for the local inhabitants, similar to what is observed with Jakarta’s groundwater.

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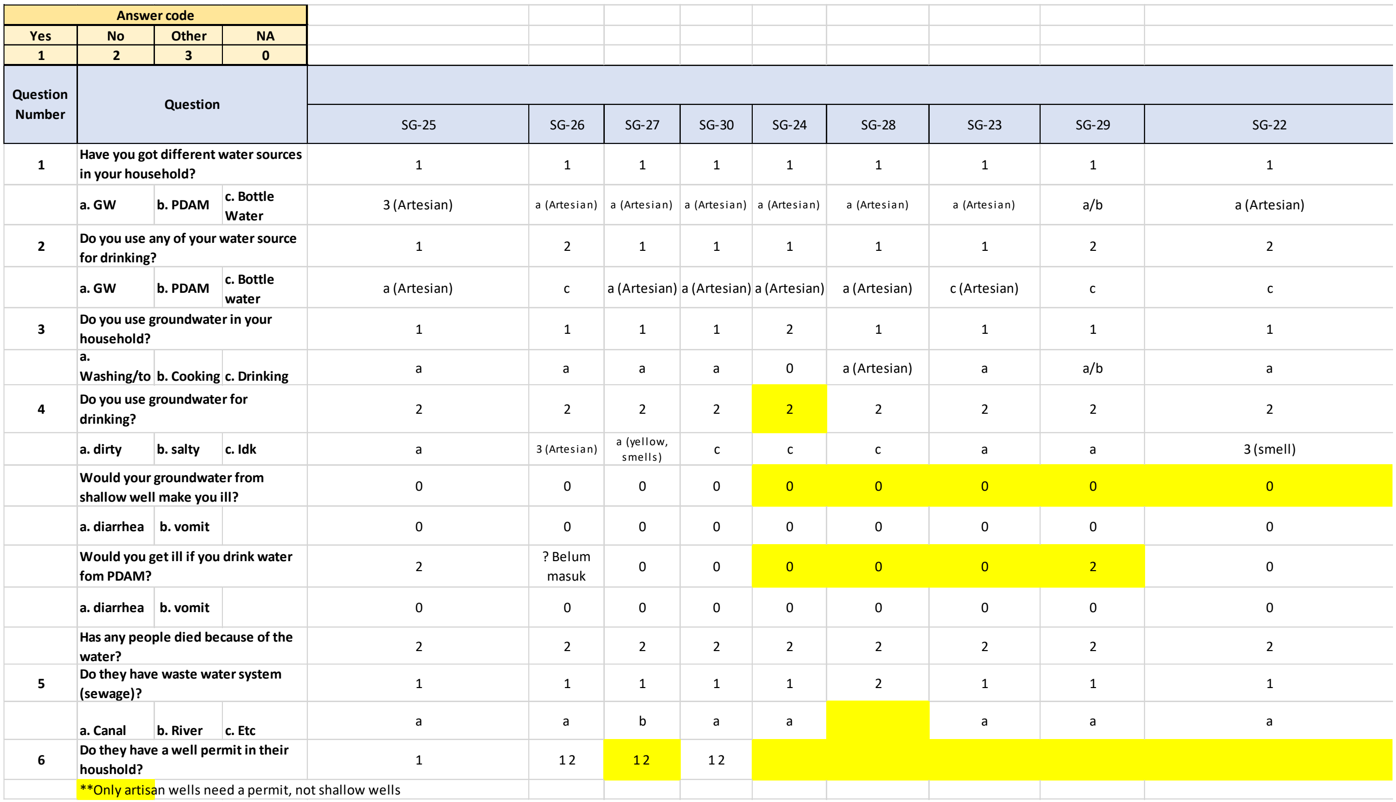
Annex I

This annex contains the results from the survey of the hydrosocial campaign carried out during May-June of 2019 in Semarang lowlands.

Figure Annex I-1 Hydrosocial questionnaire for the 30 dug well household owners of the study area, Semarang lowlands.



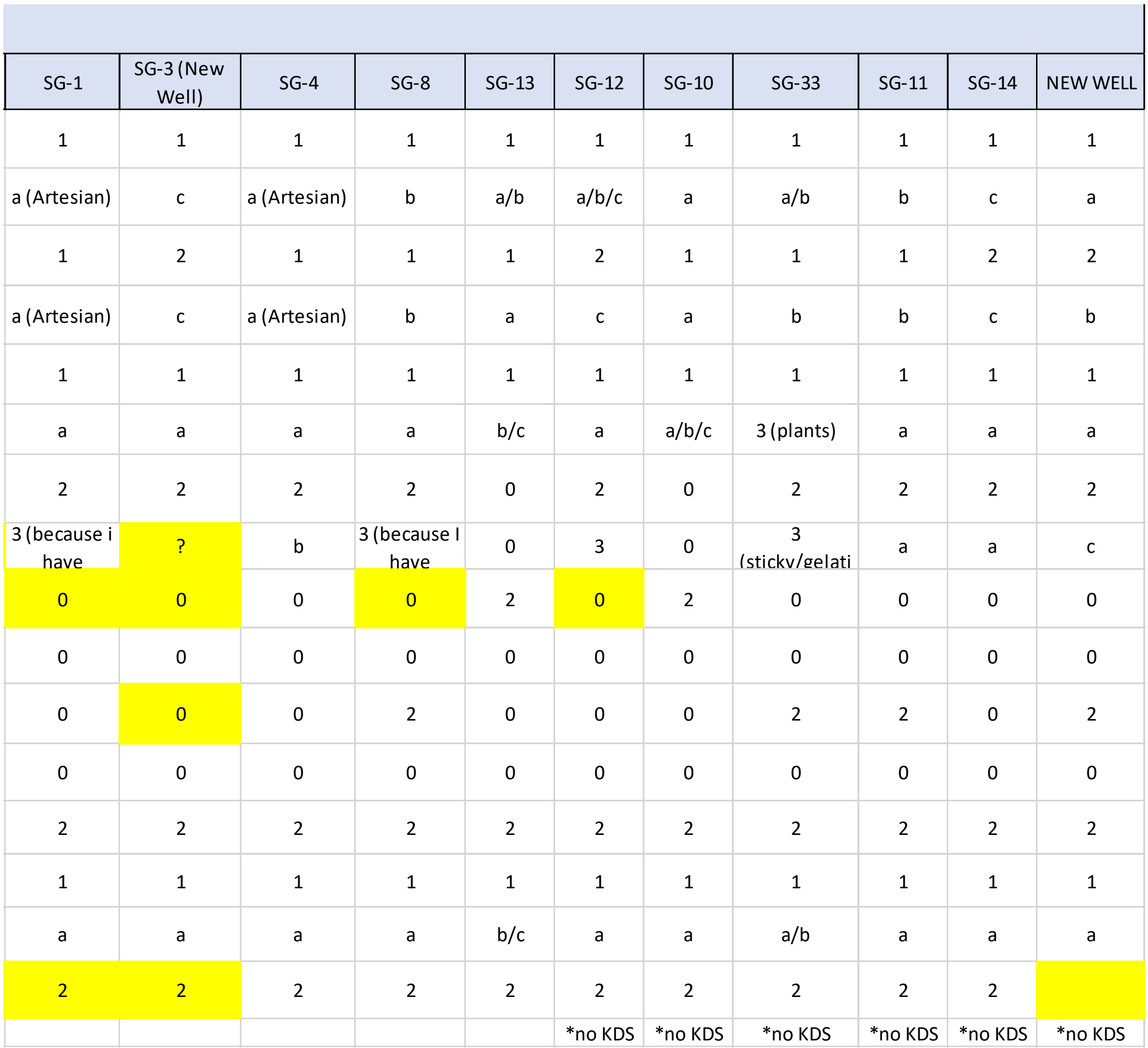
Answer code			
Yes	No	Other	NA
1	2	3	0

Question Number	Question			SG-25	SG-26	SG-27	SG-30	SG-24	SG-28	SG-23	SG-29	SG-22
1	Have you got different water sources in your household?			1	1	1	1	1	1	1	1	1
	a. GW	b. PDAM	c. Bottle Water	3 (Artesian)	a (Artesian)	a (Artesian)	a (Artesian)	a (Artesian)	a (Artesian)	a (Artesian)	a/b	a (Artesian)
2	Do you use any of your water source for drinking?			1	2	1	1	1	1	1	2	2
	a. GW	b. PDAM	c. Bottle water	a (Artesian)	c	a (Artesian)	a (Artesian)	a (Artesian)	a (Artesian)	c (Artesian)	c	c
3	Do you use groundwater in your household?			1	1	1	1	2	1	1	1	1
	a. Washing/to	b. Cooking	c. Drinking	a	a	a	a	0	a (Artesian)	a	a/b	a
4	Do you use groundwater for drinking?			2	2	2	2	2	2	2	2	2
	a. dirty	b. salty	c. Idk	a	3 (Artesian)	a (yellow, smells)	c	c	c	a	a	3 (smell)
	Would your groundwater from shallow well make you ill?			0	0	0	0	0	0	0	0	0
	a. diarrhea	b. vomit		0	0	0	0	0	0	0	0	0
	Would you get ill if you drink water fom PDAM?			2	? Belum masuk	0	0	0	0	0	2	0
	a. diarrhea	b. vomit		0	0	0	0	0	0	0	0	0
	Has any people died because of the water?			2	2	2	2	2	2	2	2	2
5	Do they have waste water system (sewage)?			1	1	1	1	1	2	1	1	1
	a. Canal	b. River	c. Etc	a	a	b	a	a		a	a	a
6	Do they have a well permit in their houshold?			1	1 2	1 2	1 2					
	**Only artisan wells need a permit, not shallow wells											

Figure Annex I-2 Hydrosocial questionnaire for the 30 dug well household owners of the study area, Semarang lowlands.

Well Code											
SG-19	SG-18	SG-20	SG-16	SG-17	SG-15	Artesian Well	SG-9	SG-7	SG-6	SG-5	SG-2
1	1	1	2	1	1	1	1	1	1	1	1
a/c	a	a (Artesian)	a		a/b	a (Artesian)/c	a	b	b/c	a	a/c
2	2	1		2	1	2	1	1	2	2	2
c	c	a (Artesian)		c	b	c	a	b	c	c	c
1	1	1	1	1	1	1	1	1	2	1	1
a	a	a	a	a	a	a	a/b/c	a	0	a/b	a
2	2	0	2	2	2	2	1	2	2	2	2
3 (old/gone off)	c	0	a	c	a	3 (calcium/ch	0	a	c	3 (bottled water)	?
0	0	0	0	0	1	1	2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	2	2	0	2	2	0	0
0	0	0	0	0	0	0	0	0	0	0	0
2	2	0	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1	1
a	a	a	a	b	a	a	b	a	a	a	a
						1	2				2

Figure Annex I-3 Hydrosocial questionnaire for the 30 dug well household owners of the study area, Semarang lowlands.

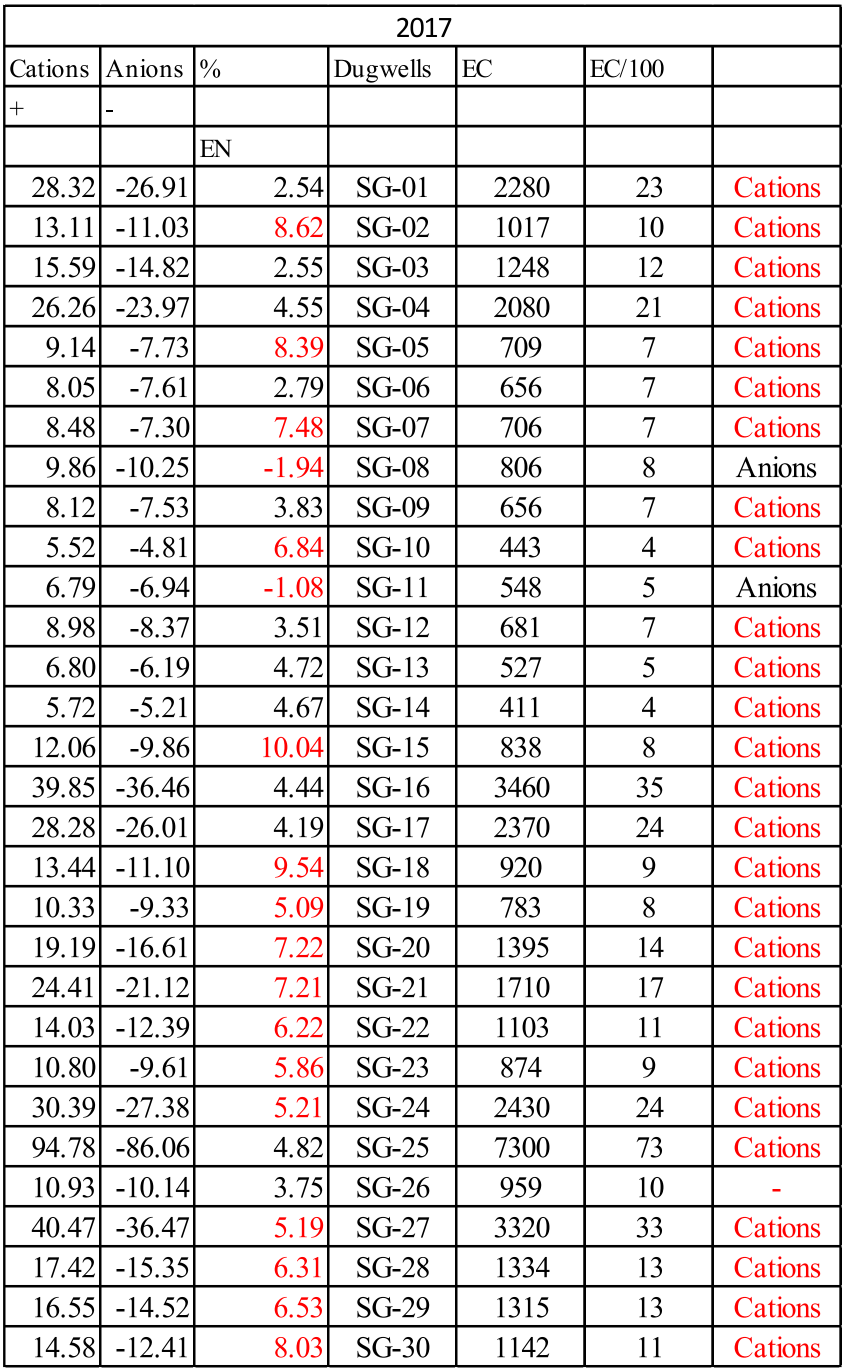


SG-1	SG-3 (New Well)	SG-4	SG-8	SG-13	SG-12	SG-10	SG-33	SG-11	SG-14	NEW WELL
1	1	1	1	1	1	1	1	1	1	1
a (Artesian)	c	a (Artesian)	b	a/b	a/b/c	a	a/b	b	c	a
1	2	1	1	1	2	1	1	1	2	2
a (Artesian)	c	a (Artesian)	b	a	c	a	b	b	c	b
1	1	1	1	1	1	1	1	1	1	1
a	a	a	a	b/c	a	a/b/c	3 (plants)	a	a	a
2	2	2	2	0	2	0	2	2	2	2
3 (because i have	?	b	3 (because I have	0	3	0	3 (sticky/gelati	a	a	c
0	0	0	0	2	0	2	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	2	0	0	0	2	2	0	2
0	0	0	0	0	0	0	0	0	0	0
2	2	2	2	2	2	2	2	2	2	2
1	1	1	1	1	1	1	1	1	1	1
a	a	a	a	b/c	a	a	a/b	a	a	a
2	2	2	2	2	2	2	2	2	2	
					*no KDS	*no KDS	*no KDS	*no KDS	*no KDS	*no KDS

Annex II

This Annex includes the results of the hydrogeological campaign carried out from May to June of 2017 and 2019 in Semarang lowlands.

Figure Annex II-1. 2017 Electronegativity analysis on cations and anions percentage.



2017						
Cations	Anions	%	Dugwells	EC	EC/100	
+	-					
		EN				
28.32	-26.91	2.54	SG-01	2280	23	Cations
13.11	-11.03	8.62	SG-02	1017	10	Cations
15.59	-14.82	2.55	SG-03	1248	12	Cations
26.26	-23.97	4.55	SG-04	2080	21	Cations
9.14	-7.73	8.39	SG-05	709	7	Cations
8.05	-7.61	2.79	SG-06	656	7	Cations
8.48	-7.30	7.48	SG-07	706	7	Cations
9.86	-10.25	-1.94	SG-08	806	8	Anions
8.12	-7.53	3.83	SG-09	656	7	Cations
5.52	-4.81	6.84	SG-10	443	4	Cations
6.79	-6.94	-1.08	SG-11	548	5	Anions
8.98	-8.37	3.51	SG-12	681	7	Cations
6.80	-6.19	4.72	SG-13	527	5	Cations
5.72	-5.21	4.67	SG-14	411	4	Cations
12.06	-9.86	10.04	SG-15	838	8	Cations
39.85	-36.46	4.44	SG-16	3460	35	Cations
28.28	-26.01	4.19	SG-17	2370	24	Cations
13.44	-11.10	9.54	SG-18	920	9	Cations
10.33	-9.33	5.09	SG-19	783	8	Cations
19.19	-16.61	7.22	SG-20	1395	14	Cations
24.41	-21.12	7.21	SG-21	1710	17	Cations
14.03	-12.39	6.22	SG-22	1103	11	Cations
10.80	-9.61	5.86	SG-23	874	9	Cations
30.39	-27.38	5.21	SG-24	2430	24	Cations
94.78	-86.06	4.82	SG-25	7300	73	Cations
10.93	-10.14	3.75	SG-26	959	10	-
40.47	-36.47	5.19	SG-27	3320	33	Cations
17.42	-15.35	6.31	SG-28	1334	13	Cations
16.55	-14.52	6.53	SG-29	1315	13	Cations
14.58	-12.41	8.03	SG-30	1142	11	Cations

Figure Annex II -2. Laboratory results for the 2017 sampling campaign (SNI standard) in Semarang lowlands carried out during May to June.

No.	Koordinat		Kode	Lokasi Pemercontohan	Keruh	Warna	Bau	Rasa	DHL	pH *Lab.*	Kes	Ca $^{2+}$	Mg^{2+}	Fe^{3+}	Mn^{2+}	K$^+$	Na$^+$	Li$^+$	NH$_4^+$	CO$_3^=$	HCO$_3^-$ *Lab.*	Cl$^-$	SO$_4^=$	NO$_2^-$	NO$_3^-$	TDS
Urut	X	Y	Contoh		NTU	TCU			µS/cm		mg/L CaCO$_3$	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	424587	9231339	SG-01	Jl. Mangkang Wetan 05/07	1.1	22.0	tb	anta	2280	7.20	416.2	83.8	49.6	0.011	2.662	53.1	387.3	0.0	0.8	0.0	826.1	452.5	6.3	0.31	6.3	1520
2	423116	9229306	SG-02	Jl. Mangunharjo 04/02	0.5	2.0	tb	tb	1017	6.81	373.4	96.8	31.5	0.000	0.012	22.1	91.3	0.0	0.0	0.0	469.5	99.8	14.5	0.00	8.3	680
3	424864	9229281	SG-03	Jl. Randugarut 02/01	1.7	42.0	tb	tb	1248	7.15	153.7	50.6	6.5	0.072	1.132	21.0	260.6	0.0	7.5	0.0	681.4	114.9	12.8	0.00	2.9	832
4	427684	9229475	SG-04	Jl. Tapak Tugu Rejo 2 04/06	11.6	10.0	tb	anta	2080	6.76	714.8	251.1	20.9	0.843	9.012	21.8	240.9	0.0	3.1	0.0	513.9	333.2	274.5	5.31	3.1	1388
5	425607	9228579	SG-05	Jl. Karangsari 2	0.3	1.0	tb	tb	709	6.80	311.5	84.0	24.3	0.000	0.015	11.3	40.7	0.0	0.0	0.0	270.1	87.8	22.0	0.00	18.3	476
6	425811	9226924	SG-06	Jl. Beringin 01/07	2.9	18.0	tb	tb	656	6.73	265.2	79.7	15.8	0.000	0.003	17.1	40.4	0.0	0.0	0.0	311.1	53.5	15.2	3.13	35.9	440
7	428692	9227928	SG-07	Jl. Arumanis Tengah 04/02, Ngaliyan	1.7	17.0	tb	tb	706	6.71	229.2	66.1	15.3	0.037	0.900	8.2	72.5	0.0	0.0	0.0	258.7	91.4	19.7	0.00	0.0	472
8	430156	9227699	SG-08	Jl. Subali II, Krapayak 02/04	0.5	0.0	tb	tb	806	6.93	177.5	49.2	13.1	0.000	0.003	18.7	123.5	0.0	0.0	0.0	430.7	87.4	24.1	0.00	9.2	540
9	430745	9225248	SG-09	Jl. Mutiara Timur 3 11/06	9.6	142.0	tb	tb	656	6.85	180.9	48.7	14.2	1.096	4.178	11.4	53.6	0.0	24.0	0.0	312.2	62.2	21.4	6.88	0.4	440
10	4332924	9227606	SG-10	Jl. Puspawarno Tengah Raya	0.4	1.0	tb	asam	443	6.34	146.9	40.5	10.9	0.021	0.582	8.4	43.5	0.0	1.6	0.0	161.8	45.5	17.5	0.28	29.0	296
11	433349	9229056	SG-11	Sambiroto	3.0	25.0	tb	tb	548	6.97	191.8	60.4	9.8	0.416	0.879	2.6	53.9	0.0	3.3	0.0	321.3	49.1	6.5	5.11	0.2	368
12	433668	9226375	SG-12	Jl. Simongan Gang V, Sampokong	1.2	26.0	tb	tb	681	6.85	339.4	102.5	19.9	0.002	0.121	3.7	32.1	0.0	0.1	0.0	414.8	29.5	17.8	0.54	20.5	456
13	435234	9226178	SG-13	Candisari	2.8	33.0	tb	tb	527	6.95	197.2	52.2	16.0	1.709	0.210	4.5	47.9	0.0	0.1	0.0	271.2	48.7	15.5	0.29	0.0	352
14	434568	9228631	SG-14	Jl. Sadena Utara	0.3	2.0	tb	tb	411	6.86	191.8	59.0	10.6	0.054	0.007	7.6	30.1	0.0	0.2	0.0	262.1	23.5	11.1	0.00	0.0	276
15	437039	9227641	SG-15	Brumbungan	0.4	5.0	tb	tb	838	7.11	313.5	47.1	47.0	3.644	0.436	12.2	83.4	0.0	0.0	0.0	449.0	67.0	19.8	5.17	2.0	560
16	438310	9230343	SG-16	Jl. Cimanuk VI	8.1	39.0	tb	asin	3460	7.07	398.5	84.3	45.0	0.478	1.320	57.9	653.5	0.0	6.6	0.0	520.7	933.7	37.3	2.21	0.3	2308
17	437834	9229105	SG-17	Mlatiharjo	1.6	3.0	tb	anta	2370	7.05	440.0	109.9	39.7	0.073	2.229	24.4	400.4	0.0	0.9	0.0	402.2	632.8	46.2	2.22	2.3	1580
18	439501	9226410	SG-18	Sambirejo	1.1	10.0	tb	tb	920	6.98	391.1	84.9	42.9	0.137	1.099	6.9	82.1	0.0	6.4	0.0	529.9	59.5	27.7	3.63	2.0	616
19	439164	9226849	SG-19	Gayamsari	0.3	8.0	tb	tb	783	6.99	317.6	96.8	18.1	0.000	0.899	11.1	70.3	0.0	0.1	0.0	460.3	40.7	23.6	4.89	0.2	524
20	439770	9229704	SG-20	Jl. Karanganyar 02/12	12.1	309.0	tb	tb	1395	7.15	301.3	68.5	31.2	0.537	3.215	28.6	155.6	0.0	82.0	0.0	780.5	116.9	19.5	0.19	0.9	932
21	440218	9227281	SG-21	Jl. Tlogotimur II/18	0.0	0.0	tb	tb	1710	7.43	327.1	37.0	56.3	0.000	0.018	20.3	353.1	0.0	0.0	0.0	948.0	175.6	22.5	0.00	1.4	1140
22	440963	9225772	SG-22	Jl. Palebon Tengah 01/02	2.7	64.0	tb	tb	1103	7.05	323.1	99.0	18.1	0.044	1.217	24.0	144.8	0.0	0.5	0.0	609.6	82.6	0.0	0.05	0.0	736
23	441752	9227959	SG-23	Jl. Kyai Syakir Raya 03/03	1.4	30.0	tb	tb	874	6.96	317.6	105.5	12.9	0.065	0.181	10.5	85.9	0.0	0.0	0.0	487.7	55.1	0.0	0.69	0.1	584
24	441498	9229755	SG-24	Jl. Widuri Raya 01/10	0.4	1.0	tb	anta	2430	7.74	338.7	59.0	45.9	0.006	0.104	27.9	489.4	0.0	0.0	0.0	725.8	533.5	0.0	0.00	0.2	1620
25	442661	9231953	SG-25	Jl. Karangasem Dalam VII 01/04	15.2	37.0	tb	asin	7300	7.27	984.8	168.1	135.5	1.582	1.938	63.5	1555.6	0.0	16.9	0.0	1041.5	2374.2	0.0	2.98	1.1	4868
26	442569	9230491	SG-26	Jl. Makam Ibrahim Fatah 04/04	2.0	33.0	tb	tb	959	7.66	122.4	46.2	1.6	0.000	0.353	8.8	188.7	0.0	0.0	0.0	524.2	53.5	0.0	0.00	0.1	640
27	443602	9230121	SG-27	Jl. Teratai RT 02	5.0	12.0	tb	asin	3320	7.26	299.2	57.9	37.0	0.289	0.708	25.6	747.0	0.0	0.2	0.0	907.0	701.1	57.9	2.36	0.2	2216
28	442535	9228163	SG-28	Jl. Woltermangonsidi Gg. Primadani 07/01	2.8	57.0	tb	tb	1334	7.00	378.1	112.6	23.2	0.098	0.650	46.3	178.1	0.0	2.0	0.0	745.2	84.2	32.3	1.02	0.0	892
29	442509	9227313	SG-29	Jl. Tegalrejo 05/02	0.3	0.0	tb	tb	1315	7.03	340.1	97.4	23.2	0.056	0.027	9.3	200.0	0.0	0.0	0.0	531.0	147.6	68.9	0.00	6.3	876
30	445092	9228797	SG-30	Jl. Kramat Raya 01/02, Kudu	0.4	6.0	tb	tb	1142	6.97	427.1	114.5	33.8	0.000	0.035	10.7	105.4	0.0	0.0	0.0	523.0	87.8	61.9	0.00	0.3	764

Figure Annex II -3. 2019 Electronegativity analysis on cations and anions percentage.

2019						
Cations	Anions	EN	Dugwells	EC	EC/100	
+	-	%	SG-1	1472	15	
16.00	-15.14	2.76	SG-2	1047	10	Cations
11.38	-11.22	0.71	SG-3	2980	30	Cations
30.96	-28.76	3.68	SG-4	2000	20	Cations
22.07	-20.39	3.96	SG-5	650	7	Cations
6.49	-6.62	-0.99	SG-6	329	3	Anions
3.42	-3.62	-2.88	SG-7	774	8	Anions
8.13	-7.87	1.63	SG-8	788	8	Cations
8.64	-8.13	2.99	SG-9	637	6	Cations
6.97	-6.93	0.28	SG-10	836	8	Cations
9.54	-9.68	-0.71	SG-11	825	8	Anions
8.62	-8.53	0.50	SG-12	668	7	Cations
7.41	-7.59	-1.23	SG-13	466	5	Anions
5.10	-5.39	-2.78	SG-14	430	4	Anions
4.87	-4.99	-1.23	SG-15	686	7	Anions
7.56	-7.55	0.03	SG-16	1564	16	Cations
17.23	-16.11	3.38	SG-17	1347	13	Cations
14.43	-13.89	1.92	SG-18	974	10	Cations
11.17	-10.89	1.30	SG-19	906	9	Cations
10.50	-10.20	1.49	SG-20	786	8	Cations
8.52	-8.30	1.31	SG-21	1167	12	Cations
13.31	-13.28	0.09	SG-22	1083	11	Cations
12.44	-11.83	2.54	SG-23	858	9	Cations
9.87	-9.25	3.26	SG-24	2320	23	Cations
25.59	-23.78	3.67	SG-25	8030	80	Cations
93.31	-87.73	3.08	SG-26	942	9	Cations
10.71	-10.05	3.15	SG-27	2660	27	Cations
28.89	-27.00	3.39	SG-28	1025	10	Cations
11.90	-11.03	3.82	SG-29	1071	11	Cations
12.27	-11.69	2.42	SG-30	988	10	Cations

Figure Annex II -4. Laboratory results for the 2019 sampling campaign (SNI standard) in Semarang lowlands carried out during May to June.

No.	Koordinat		Kode	Lokasi Pemercontohan	Keruh	Warna	Bau	Rasa	DHL	pH	Kes	Ca^{2+}	Mg^{2+}	Fe^{3+}	Mn^{2+}	K^+	Na^+	Li^+	NH_4^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_2^-	NO_3^-	TDS
Urut	X	Y	Contoh		NTU	TCU			µS/cm		mg/L $CaCO_3$	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	424618	9231297	SG-1	Ngebro, Mangkang Wetan, Tugu	7.2	5.0	tb	tb	1462	7.25	279.3	76.5	21.1	0.49	3.58	26.4	216.1	0.0	2.8	0.0	498.2	222.5	11.7	4.18	3.1	978
2	423118	9229335	SG-2	Mangun Harjo, Tugu	0.4	0.0	tb	tb	1046	6.93	353.7	107.5	20.4	0.00	0.00	29.9	80.9	0.0	0.0	0.0	373.9	61.0	74.7	0.03	103.1	700
3	424838	9229281	SG-3	Jl. Randu Garut 2/1, Tugu	0.8	9.0	tb	asin	3000	7.24	273.3	73.4	21.5	0.06	0.85	44.3	573.6	0.0	2.4	0.0	588.6	496.3	255.5	4.70	1.0	2000
4	427684	9229475	SG-4	Jl. Tapak, Tugu rejo	22.7	16.0	tb	anta	2010	7.04	563.4	145.5	47.9	2.37	8.14	20.9	236.8	0.0	1.9	0.0	494.8	284.2	222.0	1.37	0.0	1340
5	425607	9228579	SG-5	Jl. Karang Sari 2, Ngaliyan	0.3	0.0	tb	tb	627	6.72	243.6	68.5	17.4	0.09	0.00	9.9	27.5	0.0	0.0	0.0	224.8	53.4	41.1	0.10	34.7	420
6	425704	9226979	SG-6	Bringin kulon, Ngaliyan	0.0	0.0	tb	tb	330	7.09	124.0	32.5	10.3	0.00	0.00	7.9	17.3	0.0	0.0	0.0	158.2	23.1	1.8	0.20	18.9	220
7	428692	9227928	SG-7	Jl. Arum manis, Ngaliyan	1.6	12.0	tb	tb	777	6.64	238.1	68.3	16.2	0.05	0.63	7.6	72.5	0.0	0.3	0.0	255.3	97.4	37.5	0.00	4.0	520
8	430156	9227699	SG-8	Jl. Subali 2, Krapyak, Krapyak, Semaran	0.1	0.0	tb	tb	779	7.21	176.6	49.2	12.9	0.02	0.00	17.3	102.5	0.0	0.0	0.0	329.9	63.5	34.7	0.30	8.9	520
9	430713	9226199	SG-9	Jl. Mutiara Timur 3 11/06, Kembang Aru	0.2	1.0	tb	tb	640	6.70	212.0	54.7	18.0	0.00	5.47	3.9	57.0	0.3	3.2	0.0	327.6	41.5	18.2	3.52	0.0	428
10	433292	9227606	SG-10	Salaman Mloyo, Semarang Barat	0.0	0.0	tb	tb	842	7.04	380.4	112.3	23.9	0.93	0.04	5.3	48.1	0.0	0.0	0.0	463.2	38.2	33.2	0.01	10.5	564
11	433349	9229056	SG-11	Gang Pringgodani II, St 3, Rw 12, Semarang Barat	7.2	105.0	tb	tb	838	7.55	171.2	56.3	7.3	0.34	0.58	13.8	90.9	0.0	14.9	0.0	299.4	105.7	21.3	4.47	0.0	560
12	433668	9226375	SG-12	Simongan, Semarang Barat	0.0	0.0	tb	tb	660	7.18	321.9	101.3	16.5	0.01	0.05	2.6	23.7	0.4	0.1	0.0	334.4	19.8	31.2	0.04	32.1	444
13	435190	9226233	SG-13	Lempongsari, Gajahmungkur	0.5	0.0	tb	tb	464	8.07	181.0	47.1	15.2	0.27	0.01	1.9	38.5	0.0	0.0	0.0	197.7	35.3	33.1	0.01	11.3	312
14	434568	9228631	SG-14	Jl. Sadeweo , Semarang Tengah	1.4	9.0	tb	tb	423	7.56	187.1	61.7	7.9	0.50	0.61	7.3	21.8	0.0	0.0	0.0	261.0	15.9	10.4	0.00	0.0	284
15	437039	9227641	SG-15	Jl. Trengkil, Karang kidul, Semarang Ter	1.5	15.0	tb	tb	690	7.00	262.7	77.9	16.3	0.02	0.07	12.1	43.6	0.0	3.5	0.0	323.1	35.0	34.8	4.52	30.3	460
16	438310	9230343	SG-16	Cimanuk raya, Semarang Timur	3.9	68.0	tb	tb	1555	7.50	156.6	37.3	15.2	0.75	0.61	30.2	294.6	0.0	8.4	0.0	637.2	174.6	33.8	3.48	0.0	1040
17	437834	9229105	SG-17	Musi Raya Bugangan, Semarang Timur	0.7	29.0	tb	tb	1347	7.35	260.2	72.3	19.1	0.23	1.32	16.9	195.4	0.0	5.1	0.0	457.5	194.8	23.0	3.97	0.0	900
18	439501	9226410	SG-18	Beruang raya 9 RT 06/02	0.8	12.0	tb	tb	970	7.27	382.1	88.3	38.7	0.12	1.12	6.6	72.5	0.0	2.1	0.0	512.9	52.3	48.6	3.34	0.5	648
19	439164	9226849	SG-19	Gayamsari	1.5	9.0	tb	tb	909	7.20	368.7	84.7	37.7	0.21	1.51	11.7	63.2	0.0	1.7	0.0	481.3	42.9	57.6	2.84	0.0	608
20	439770	9229704	SG-20	Karanganyar	2.5	81.0	tb	tb	785	7.32	152.1	47.6	7.9	0.28	1.15	12.9	102.9	0.4	11.9	0.0	351.3	64.2	60.7	4.18	0.0	524
21	438412	9227224	SG-21	Bintoro, Gayamsari	0.4	0.0	tb	tb	1162	7.16	424.3	98.9	42.5	0.00	0.69	9.2	96.3	0.0	7.7	0.0	581.8	77.5	44.6	4.12	2.6	776
22	440963	9225772	SG-22	Palebon, Pedurungan	2.0	46.0	tb	tb	1073	7.17	307.3	98.4	14.7	0.26	1.07	21.5	116.2	0.4	6.5	0.0	535.5	67.8	27.6	4.06	0.0	716
23	441752	9227959	SG-23	Tlogosari Wetan, Pedurungan	1.2	13.0	tb	tb	856	7.09	279.7	90.9	12.6	0.00	0.10	9.7	91.7	0.0	0.0	0.0	424.8	46.9	40.6	0.13	2.9	572
24	441498	9229755	SG-24	Widuri Raya, Genuk	0.5	22.0	tb	anta	2320	7.94	253.0	36.4	38.9	0.02	1.16	25.4	446.5	0.0	4.4	0.0	651.8	398.6	61.0	1.87	0.7	1548
25	442661	9231953	SG-25	Trimulyo, Genuk	7.1	32.0	tb	asin	8200	7.35	887.9	170.2	111.0	0.98	1.42	55.5	1638.4	0.0	10.9	0.0	843.9	2366.1	200.0	3.91	2.8	5468
26	442569	9230491	SG-26	Banjardowo, Genuk	2.6	65.0	tb	tb	942	7.64	133.0	45.0	4.9	0.11	0.89	6.6	180.2	0.0	1.5	0.0	436.1	47.6	67.4	0.05	1.1	628
27	443602	9230121	SG-27	Banjardowo, Genuk	5.4	24.0	tb	anta	2680	7.16	312.2	79.1	27.5	0.83	0.60	19.5	508.2	0.0	3.1	0.0	716.2	456.6	85.0	2.74	9.3	1788
28	442535	9228163	SG-28	Banget Ayu Wetan	11.0	40.0	tb	tb	1016	7.16	297.9	93.3	15.5	0.46	0.52	35.8	116.4	0.3	1.2	0.0	546.8	46.5	36.8	0.82	0.2	680
29	442509	9227313	SG-29	Tlogo Mulyo, Pedurungan	0.1	0.0	tb	tb	1080	7.25	259.9	78.6	15.2	0.00	0.01	11.2	152.8	0.0	0.0	0.0	455.3	83.0	73.4	0.05	0.1	720
30	445092	9228787	SG-30	Kudu, Genuk	1.7	22.0	tb	tb	998	7.23	307.1	87.0	21.5	0.04	0.27	9.8	103.9	0.0	0.0	0.0	437.2	40.4	93.1	0.01	12.8	668

Figure Annex II -5. Laboratory results for the 2019 sampling campaign (IAEA standard) in Semarang lowlands carried out during May to June.

No.	Koordinat		Kode	Lokasi Pemercontohan	Warna	Bau	Rasa	DHL	pH	Kes	Ca^{2+}	Mg^{2+}	Fe^{3+}	Mn^{2+}	K^+	Na^+	Li^+	NH_4^+	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	NO_2^-	NO_3^-	TDS
Urut	X	Y	Contoh		TCU			µS/cm		mg/L $CaCO_3$	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	424618	9231297	SG-1	Ngebro, Mangkang Wetan, Tugu	0.0	tb	tb	1472	7.34	279.5	75.7	21.7	0.09	3.60	26.6	218.9	0.0	1.8	0.0	505.0	219.7	20.3	0.07	3.8	984
2	423118	9229335	SG-2	Mangun Harjo, Tugu	0.0	tb	tb	1047	6.96	354.8	107.4	20.7	0.00	0.02	30.6	81.2	0.0	0.1	0.0	376.2	62.0	78.0	0.02	101.2	700
3	424838	9229281	SG-3	Jl. Randu Garut 2/1, Tugu	9.0	tb	asin	2980	7.39	263.4	71.4	20.4	0.00	0.85	43.3	562.6	0.0	1.9	0.0	621.3	502.4	190.0	0.05	2.2	1988
4	427684	9229475	SG-4	Jl. Tapak, Tugu rejo	0.0	tb	anta	2000	7.16	547.2	143.6	45.2	0.00	8.52	19.1	234.4	0.0	3.4	0.0	480.1	284.9	203.0	0.04	1.2	1336
5	425607	9228579	SG-5	Jl. Karang Sari 2, Ngaliyan	0.0	tb	tb	650	6.79	252.6	71.0	18.0	0.00	0.03	10.2	27.7	0.0	0.0	0.0	220.3	54.5	42.7	0.03	33.7	436
6	425704	9226979	SG-6	Bringin kulon, Ngaliyan	0.0	tb	tb	329	7.12	122.4	31.4	10.6	0.00	0.00	8.2	17.8	0.0	0.0	0.0	161.5	19.8	0.9	0.04	23.4	220
7	428692	9227928	SG-7	Jl. Arum manis, Ngaliyan	0.0	tb	tb	774	6.69	237.0	68.1	16.0	0.00	0.72	7.8	73.3	0.0	0.1	0.0	259.8	97.4	33.3	0.09	5.8	516
8	430156	9227699	SG-8	Jl. Subali 2, Krapyak, Krapyak, Semarar	0.0	tb	tb	788	7.57	180.5	50.2	13.2	0.00	0.00	18.0	105.3	0.0	0.1	0.0	326.5	63.1	36.8	0.09	11.4	528
9	430713	9226199	SG-9	Jl. Mutiara Timur 3 11/06, Kembang Ar	0.0	tb	tb	637	6.73	206.7	53.3	17.6	0.00	5.14	3.6	57.3	0.0	1.6	0.0	329.9	41.1	15.0	0.02	1.3	428
10	433292	9227606	SG-10	Salaman Mloyo, Semarang Barat	0.0	tb	tb	836	7.30	366.1	108.3	22.9	0.00	0.03	5.0	47.3	0.4	0.1	0.0	459.8	36.8	43.7	0.03	10.1	560
11	433349	9229056	SG-11	Gang Pringgodani II, St 3, Rw 12, Semarang Barat	60.0	tb	tb	825	7.83	169.6	56.3	6.9	0.00	0.59	14.1	91.6	0.0	15.7	0.0	309.5	104.6	16.2	3.86	0.0	552
12	433668	9226375	SG-12	Simongan, Semarang Barat	0.0	tb	tb	668	7.45	316.7	99.9	16.1	0.00	0.06	2.3	23.9	0.0	0.0	0.0	337.8	18.0	37.9	0.09	46.0	448
13	435190	9226233	SG-13	Lempongsari, Gajahmungkur	0.0	tb	tb	466	8.07	172.9	44.0	15.1	0.00	0.00	1.7	37.0	0.0	0.1	0.0	196.6	34.6	43.3	0.02	16.0	312
14	434568	9228631	SG-14	Jl. Sadeweo , Semarang Tengah	0.0	tb	tb	430	7.78	185.3	61.9	7.4	0.00	0.58	7.5	22.1	0.0	0.0	0.0	254.2	15.1	18.4	0.03	0.0	288
15	437039	9227641	SG-15	Jl. Trengkil, Karang kidul, Semarang Te	16.0	tb	tb	686	7.33	261.1	77.7	16.0	0.00	0.09	11.9	42.6	0.4	2.6	0.0	318.6	33.9	35.6	3.64	32.8	460
16	438310	9230343	SG-16	Cimanuk raya, Semarang Timur	82.0	tb	tb	1564	7.59	147.8	33.8	15.2	0.00	0.69	30.6	301.7	0.0	6.6	0.0	643.9	173.8	23.9	0.09	0.5	1044
17	437834	9229105	SG-17	Musi Raya Bugangan, Semarang Timur	6.0	tb	tb	1347	7.54	257.4	71.5	18.9	0.00	1.39	17.0	198.3	0.0	3.6	0.0	471.1	196.6	22.1	0.03	0.0	900
18	439501	9226410	SG-18	Beruang raya 9 RT 06/02	0.0	tb	tb	974	7.34	383.2	89.9	38.0	0.00	1.08	6.2	75.3	0.0	1.6	0.0	514.0	52.7	43.4	0.02	1.9	652
19	439164	9226849	SG-19	Gayamsari	21.0	tb	tb	906	7.30	363.9	82.8	37.7	0.00	1.62	11.7	65.7	0.0	1.0	0.0	484.6	42.2	48.4	0.05	1.2	604
20	439770	9229704	SG-20	Karanganyar	66.0	tb	tb	786	7.42	147.4	46.3	7.6	0.00	1.23	13.0	105.6	0.0	11.0	0.0	354.7	59.2	36.7	0.03	0.0	524
21	438412	9227224	SG-21	Bintoro, Gayamsari	2.0	tb	tb	1167	7.30	422.9	99.0	42.1	0.03	1.76	9.2	97.0	0.3	6.2	0.0	587.5	76.8	64.1	3.33	1.2	780
22	440963	9225772	SG-22	Palebon, Pedurungan	21.0	tb	tb	1083	7.42	315.5	100.5	15.4	0.02	1.18	23.0	118.8	0.3	5.6	0.0	546.8	66.4	43.6	1.10	0.6	724
23	441752	9227959	SG-23	Tlogosari Wetan, Pedurungan	4.0	tb	tb	858	7.21	276.7	89.9	12.5	0.00	0.10	9.8	93.2	0.4	0.0	0.0	433.8	46.2	35.3	0.05	4.0	572
24	441498	9229755	SG-24	Widuri Raya, Genuk	1.0	tb	anta	2320	8.23	245.8	32.7	39.4	0.00	1.09	25.6	459.9	0.0	0.4	0.0	674.4	396.7	55.3	1.82	1.3	1548
25	442661	9231953	SG-25	Trimulyo, Genuk	25.0	tb	asin	8030	7.45	988.6	110.1	171.2	0.00	1.45	55.9	1649.5	0.0	9.0	0.0	858.6	2403.9	185.0	0.26	1.7	5356
26	442569	9230491	SG-26	Banjardowo, Genuk	14.0	tb	tb	942	7.84	114.9	36.3	5.8	0.00	0.82	7.7	188.4	0.0	0.0	0.0	449.6	50.1	58.8	0.06	0.3	628
27	443602	9230121	SG-27	Banjardowo, Genuk	24.0	tb	anta	2660	7.27	284.2	69.7	26.4	0.00	1.01	16.1	520.9	0.0	2.5	0.0	709.5	458.4	90.4	1.36	9.4	1776
28	442535	9228163	SG-28	Banget Ayu Wetan	18.0	tb	tb	1025	7.26	292.3	91.8	15.1	0.00	0.66	36.5	116.7	0.0	0.8	0.0	537.7	44.4	44.2	0.03	0.2	684
29	442509	9227313	SG-29	Tlogo Mulyo, Pedurungan	0.0	tb	tb	1071	7.37	265.5	78.1	16.9	0.00	0.03	11.2	154.0	0.0	0.0	0.0	448.5	81.2	84.4	0.03	14.0	716
30	445092	9228787	SG-30	Kudu, Genuk	0.0	tb	tb	988	7.32	328.2	96.8	20.7	0.00	0.27	9.2	104.6	0.0	0.0	0.0	448.5	41.5	93.3	0.17	1.3	660

Figure Annex II -6. Laboratory results for the 2019 sampling campaign of *Escherichia coli* (E. coli) in Semarang lowlands carried out during May to June.

Collection date:	16/05/2019
Samples:	E. Coli
Area:	Semarang (lowlands)

Code Well	**Location**				**Code**	**MPN/100mL**	**MPN/1L**	**Index MPN/100**	**Identification of E.Coli (Media Mac Conkey)**
		10mL	**1mL**	**0.1mL**					
SG-1	Ngebro, Mangkang wetan, Tugu	5	1	1	5-1-1	50	500	>240	+
SG-2	Mangun harjo, Tugu	5	1	1	5-1-1	50	500	>240	+
SG-3	Jl. Randu garut 2/1, Tugu	5	1	1	5-1-1	50	500	>240	+
SG-4	Jl. Tapak, Tugu	5	1	1	5-1-1	50	500	>240	+
SG-5	Jl. Karang sari 2 Ngaliyan	4	0	0	4-0-0	13	130	15	-
SG-6	Biringin Kulon Ngaliyan	4	1	1	4-1-1	21	210	27	-
SG-7	Jl. Arum manis, Ngaliyan	5	1	1	5-1-1	50	500	>240	+
SG-8	Jl. Subali 2, Krapyak, Krapyak, Semarang Barat	5	1	1	5-1-1	50	500	>240	+
SG-9	Jl. Mutiara Timur 3 11/06, Kembang Arum, Semarang Barat	4	1	1	4-1-1	21	210	27	+
SG-10	Salaman Mloyo, Smg barat	5	1	1	5-1-1	50	500	>240	+
SG-11	Gg Pringgodani II Rt2 Rw12 Smg barat	5	1	1	5-1-1	50	500	>240	+
SG-12	Simongan, Semarang barat	5	1	1	5-1-1	50	500	>240	+
SG-13	Lempongsari, Gajahmungkur	5	1	1	5-1-1	50	500	>240	+
SG-14	Jl. Sadewo Utara, Semarang Tengah	5	1	0	5-1-0	30	300	240	+
SG-15	Jl. Trengkil, Karang kidul, Semarang Tengah	5	1	1	5-1-1	50	500	>240	+
SG-16	Cimanuk raya, Semarang Timur (14.40)	5	1	1	5-1-1	50	500	>240	+
SG-17	Musi Raya Bungangan, Semarang Timur (14.29)	5	1	1	5-1-1	50	500	>240	+
SG-18	Beruang raya, 9RT 06/02, Gayamsari (09.39)	5	1	1	5-1-1	50	500	>240	+
SG-19	Gayamsari (10.20)	5	0	1	5-0-1	30	300	96	+
SG-20	Jl. Karanganyar 02/12	5	1	1	5-1-1	50	500	>240	+
SG-21	Jl. Tlogotimur II/18	5	1	1	5-1-1	50	500	>240	+
SG-22	Bintoro, Gayamsari	3	1	1	3-1-1	14	140	16	-
SG-23	Tiogosari wetan, Pedurungan	1	1	1	1-1-1	6	60	6.7	-
SG-24	Widuri raya, Genuk	5	1	1	5-1-1	50	500	>240	+
SG-25	Trimulyo, Genuk	5	1	1	5-1-1	50	500	>240	+
SG-26	Banjardowo, Genuk	4	1	1	4-1-1	21	210	27	+
SG-27	Banjardowo, Genuk	5	1	1	5-1-1	50	500	>240	+
SG-28	Bangetayu Wetan	4	1	0	4-1-0	17	170	21	+
SG-29	Trlogo mulyo, Pedurungan	5	1	1	5-1-1	50	500	>240	+
SG-30	Kudu, Genuk	4	1	1	4-1-1	21	210	27	+