Hydrogeological and economic analysis of a groundwater-based water supply system in rural Nepal

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Cover picture: Baikunth lake in Madi in Nepal. Photo: Hedayat, Hamon

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Hydrogeologisk och ekonomisk analys av ett grundvattenförsörjningssystem i rurala Nepal

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Preface

This degree project aims to examine an under-construction groundwater supply system in Madi, a rural area in Nepal, regarding three aspects. First a water quality assessment is carried out by collecting samples at site and evaluating the results. Next, a hydraulic test is conducted to determine aquifer characteristics and the performance of the well. Finally, an economic analysis is carried out to study the project's financial viability.

I want to thank and send my best regards to all the people supporting me during my journey. Special thanks to:

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Hamon Hedayat, 2023-04-24

Abstract

Access to safe drinking water and sanitation is a given standard and considered as basic human rights in urban areas and industrialized countries. However, 40 % of the world's population living in rural areas in developing countries lack access to safe drinking water. Many ongoing projects are focused on providing safe drinking water and sanitation in rural areas, including Hamro Paani. Hamro Paani is a pilot project that aims to establish an efficient and sustainable water system in Madi, Nepal, by constructing a new pumping well.

The goal of this degree project is to carry out hydrogeological and economic analyses of the water supply system in Madi. The hydrogeological analysis aims to evaluate groundwater quality, aquifer characteristics, and well performance through water sample collection and conducting a hydraulic test. The economic analysis aims to present costs and incomes for the water system and generates an economic model for rural water supply systems based on Hamro Paani. It also examines whether similar projects can be implemented without 100% charity-based funding by determining total project costs, monthly water tariffs, and forming different investment alternatives with varying interest rates.

The hydrogeological analysis indicates that the groundwater in Madi meets national and international standards. The major processes controlling the quality and chemistry of the groundwater are silicate weathering, carbonate dissolution, cation-exchange, and rock-water interaction. It is also evident that the aquifer of interest is unconfined with high permeability and storativity, making it suitable for groundwater extraction. However, regular monitoring is necessary to prevent contamination and overexploitation.

The economic analysis reveals that the water supply system in Madi costs 7.8 million nepali rupees (NPR) ($1=132.53 NPR), with households paying 214 NPR/month for maintenance and operation. However, if funded by loans, the water tariff would become too high for Nepal at 1044-1438 NPR/month. Additionally, the low Return On Equity (ROE) makes the water supply project unattractive from an investment point of view. Yet, parameters such as poverty impact and health benefits that are not included in this analysis could add economic value. It's challenging to determine whether the project is financially viable or not. Nonetheless, the challenge of providing safe drinking water to people in developing countries is not only due to a lack of funds or low ROE, but also a lack of political will and interest

Keywords: Groundwater quality and hydrochemistry, hydrogeology, hydraulic test, economic analysis, and financial viability

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Abbreviations

CAPEX	Total investment cost
DS	Dissolved Solids
K	Hydraulic conductivity
LCOE	Levelized Cost Of Energy
NPR	Nepali rupees
NPV	Net Present Value
OPEX	Operation and maintenance costs
OW	Observation Well
ROE	Return On Equity
SS	Suspended Solids
T	Transmissivity
TDS	Total Dissolved Solids
TS	Total Solids
S	Storativity
WHO	World Health Organisation
WW	Water Well

1 Introduction and background

1.1 Freshwater usage and resource

Freshwater is the most essential resource on the planet and is widely used in everyday life of humans and in industries. Water plays an important role in:

- Drinking and household needs
- Recreation
- Industry and commerce
- Agriculture
- Energy production by using hydropower

Freshwater stands for less than 3 % of earth's water and can mainly be found in excavated dams, ponds, glaciers, rivers, lakes and underground (known as groundwater) (Beth. et al. n.d). Groundwater accounts for one-quarter of all water used by humans (Pointet, 2022) and has a vital role in meeting the water demand. In 2010 the world's groundwater extraction rate was 1000 km^3/year and 67 % was used for irrigation, 22 % for domestic purposes and 11 % in industry (I.G.R.A.C, n.d).

Groundwater is found in aquifers which are geological units that can store and transmit water at rates high enough to supply a reasonable amount of water to wells. There are different types of aquifers and the most common ones are explained in chapter 2. First water wells were constructed during the Neolithic period in parts of Asia, the Middle East and Ethiopia to depths of up to 50 meters. One of the events leading to major advances in water well drilling and pumping technology was the *Grenelle* borehole in Paris that was drilled in 1841 (Pointet, 2022). The most common way to access groundwater today is by using pumps. Pumping rate is an important factor in groundwater extraction and overexploitation can lead to depletion of a finite resource and also lowering of the water table which results in higher energy costs for pumping water to the surface. It is therefore vital to study the potential of the aquifer and this can be done by different hydraulic tests. Section 2.4 in chapter 2 is dedicated to hydraulic tests.

In addition to quantity, quality of groundwater is an important aspect. There are many sources of geogenic and anthropogenic groundwater pollution. Anthropogenic refers to pollution caused by humans and can originate from agriculture, households, sewerage and industries etc (Pointet, 2022). Geogenic refers to contamination of groundwater from natural hazardous elements such as arsenic. There are guidelines and regulations regarding the acceptable amount of natural elements that human bodies can be exposed to. Both geogenic and anthropogenic contamination can lead to severe health problems. Thus, assessment of groundwater quality to provide safe drinking water is of great value (see chapter 2).

1.2 An international perspective to safe drinking water

Access to safe drinking water and sanitation is considered a basic human right in urban areas and industrialized countries. However, the situation is different in rural areas of developing countries, where 43% of the world's population resides (World Bank, 2018), mainly in Asia and Africa. Access to safe drinking water is a major issue, and unsafe water causes 829,000 deaths per year (WHO, 2022), affecting education levels, poverty, and the economy. In rural areas of developing countries, women and children are often responsible for fetching water for the household, which limits their opportunities for education. This results in a cost of $92 billion per year for less-developed nations (Drop in the Bucket, n.d). It can be stated that access to safe drinking water for the population is closely linked to a country's economic capacity. It is shown that access to safe drinking water and sanitation has a significant impact on eradicating poverty and boosting economic growth. In one of the studies on the economic benefits of improved water, it is stated that an annual average economic growth of 3.7 % is reached with improved water and sanitation (SIWI, n.d.). Two important aspects in water supply projects are people's willingness to pay and the cost of the system. Therefore, it is essential to carry out an economic analysis to determine a project's feasibility and financial viability. Chapter 3 is dedicated to economic analysis on water supply projects.

Economy may seem to be the biggest obstacle to providing safe drinking water to everyone. However, while the economy is an important factor, it is not the primary issue. To put it in perspective, the estimated total cost of providing safe water and sanitation to the world in 2030 is $1140 billion, whereas in June 2021, the estimated cost for Covid-19 exceeded $80 000 billion (Jonsson, 2022). Hence it can be argued that there is enough money but lack of political interest for investment. There are also other challenges in providing safe drinking water in rural areas, such as (Unesco, 2015):

- The population is mainly unskilled and elderly
- Lack of resources in rural areas
- Difficulties to access the areas due to geographical conditions

There are many ongoing projects with focus on either improving or constructing new water supply systems in rural areas. One such project was initiated by the World Bank and financed in 2019 with the aim of providing access to clean drinking water to over 400,000 people in rural Tajikistan (World bank, 2019). Another project, which this degree project uses as a case study, is *Hamro Paani* in Nepal.

1.3 Hamro Paani project

Hamro Paani is a pilot project that began in 2020 with the aim of establishing an efficient and sustainable safe drinking water system in Madi, a rural area in Nepal, by constructing a new water well. The project is fully funded and takes a significant step towards improving water supply systems in rural areas by utilizing modern technologies. More information about the hydrogeology of the area, well construction, and the project's economic components is presented in Chapter 2, Section 2.3, and Chapter 3, Section 3.3.1.

1.4 Purpose and research goals

This degree project aims to carry out a hydrogeological and economic analysis on the water supply system in Madi. The purpose of the hydrogeological analysis is to:

- Evaluate groundwater quality
- Analyze the groundwater chemistry and identify major processes
- Determine the characteristics of the aquifer from which water is withdrawn
- Study the well's performance

The economic analysis aims to:

- Present the costs of the water supply system in Madi and calculate the monthly water tariff that each household should pay
- Generate an economic model for water supply systems in rural areas based on the *Hamro Paani* project, and examine whether similar projects can be implemented without relying solely on charity-based funding
- Investigate the financial sustainability of the project by determining the net present value and return on equity for different investment options

1.5 Delimitations and assumptions

Looking at the lithology of the water well drilling in Madi, it appears that the aquifer to which the well is connected is unconfined. Thus, this report will primarily focus on unconfined aquifers. However, this assumption may be incorrect after analyzing the data from the hydraulic test, and if that is the case, the focus on the type of aquifer will be adjusted accordingly.

Ideally samples to analyze the groundwater quality should be collected continuously during pumping to observe any changes that may occur during water withdrawal. This could not be done due to practical difficulties such as the time required to send the samples to the laboratory.

When it comes to determining the aquifer characteristics in the area, the preferred hydraulic test is a pump test. This is due to the fact that pump tests provide more detailed information about aquifer properties compared to other methods. However, several sources in the literature have noted that pump tests are also the most expensive of all available methods. The impact of these costs on the overall project will be discussed in chapter 6. Although studying the sensitivity of aquifers to contamination and exploring the expansion of the project area (into urban areas) that could lead to other human activities affecting groundwater chemistry is interesting, it is outside the scope of this study. Possible sources of contamination in the project area are presented in chapter 2, section 2.1.4.

One important delimitation in this degree project is the scope of the economic analysis. The economic model is created based on the cost of the components used in the Madi project. As a result, a study on different components with the aim of minimizing the total cost will not be done. However, a sensitivity analysis where the total cost, interest rate and number of households range, will be carried out. It is also assumed that an economic analysis to choose the least cost alternative has been performed during the planning phase and the focus will be on the under-construction water supply system. In the economic analysis, the annual operation and maintenance cost of the entire system is assumed to be 1.135% of the total investment cost. The operation and maintenance cost of the solar panels, along with the electricity grid, is assumed to be 5% of the investment cost. Other assumptions used in the economic analysis are presented in Chapter 4, Section 4.5.

1.6 Disposition

Chapter 1 will provide an introduction and background to present the relevance of this degree project, and it will give a comprehensive overview of the topics that will be explained in detail in Chapters 2 and 3. Additionally, the purpose and limitations of this project will be presented in this chapter, and the structure of the report (the disposition) will be described.

Chapter 2 will provide a thorough explanation of the necessary theory to conduct a complete groundwater assessment and carry out a hydraulic test. The first part of this chapter is dedicated to groundwater quality and chemistry, where groundwater quality is defined, and methods to evaluate the quality and analyze the chemistry are explained. The second part of this chapter is dedicated to aquifers and the pump test, which is one of the most commonly used hydraulic tests. Additionally, the hydrology and hydrogeology of the project area will be described in this chapter, and more detailed information about the newly constructed well will be provided.

Chapter 3 covers the important parameters in an economic analysis of water supply systems, specifically in groundwater based supply systems with the project in Madi as reference. Further, the economy of this particular project with regards to its components and associated costs, will be presented. This information will be used to create an economic model for future projects in rural areas.

Chapter 4 provides a brief overview of the components and software used in this project. Additionally, the chapter explains both the theoretical and practical measurements carried out in the field during this degree project. Finally, this chapter presents the assumptions and loan layouts used to determine the financial feasibility and viability of the project.

Chapter 5 presents the results of groundwater quality and chemistry analysis and the hydraulic test. Furthermore the cost of the project in Madi and results from the economic model are presented.

Chapter 6 contains a discussion of the results presented in chapter 5 and explains uncertainties in measurements and analysis. Another aspect that is discussed in this chapter is reliability of the obtained results.

Chapter 7 summarizes the most essential parts of chapter 5 and 6 and gives conclusions with regards to the purpose of this project. Last but not least, interesting future studies that are in line with the topic of this project (water supply systems in rural areas) are brought up at the end of this chapter.

2 Theory & literature review

2.1 Groundwater quality

The ground has a certain filtration capacity, and precipitation gets purified from particulate matter as it travels horizontally and vertically through geological material. However, water is an excellent solvent, which means it can dissolve substances as it moves through the ground. Therefore, having a well that yields water does not necessarily mean that the water is safe to drink. It could contain dissolved chemicals and gasses in concentrations high enough to cause health problems.

Groundwater quality can be defined by three main categories and each category contains several parameters that must be studied to do a complete quality evaluation:

- Physical parameters
- Chemical parameters
- Biological parameters

Physical parameters

Physical parameters of water quality include turbidity, color, taste, odor, temperature, Total Dissolved Solids (TDS), and electrical conductivity. Turbidity is a measurement of how easily light can pass through the water. High turbidity can occur if the concentration of silt, clay, and organic matter in the water is high (Sensorex, 2021). The color, taste, and odor of water are referred to as aesthetic qualities and are therefore important for consumers, as nobody wants to drink water that tastes or looks strange. TDS is a measure of the suspended solids and solids that are in solution. A high TDS value is an indication that the water is highly mineralized (Meride and Ayenew, 2016). One important physical parameter is electrical conductivity, which is directly connected to the amount of ions in the water and measures saltiness. Electrical conductivity refers to the water's ability to transmit an electrical current over a distance (Lenntech, n.d.). The range of electrical conductivity can vary from 0 to 50,000 µS/cm. Freshwater usually has a conductivity value between 0 and 1500 µS/cm (Water quality standards, n.d.).

Chemical parameters

Chemical parameters of water quality include pH, alkalinity, hardness, dissolved oxygen, and chloride ions etc. Next section, 2.1.1, provides detailed information about groundwater chemistry. pH is an indication of how acidic or basic the water is, and its value is connected to the amount of hydrogen ions present. A higher amount of hydrogen ion will result in an acidic solution, and vice versa. For water to be regarded as safe to drink, the pH range should be between 6.5 and 8.5 (Sensorex, 2021). Alkalinity refers to the water's acid-neutralizing capacity and is connected to the concentration of bicarbonate ions, carbonate ions, and hydroxide ions. High alkalinity is a sign of contamination in the water. Hardness is a measure of the amount of magnesium and calcium ions in the water. These ions can enter the water from rock and soil, and groundwater has more hardness than surface water. Table 1 shows the classification of water based on the hardness value expressed in mg/L as $CaCO_3$ (Wang et al., 2005).

Table 1: Presents the classification of water based on ranges of hardness.

Hardness description	Hardness range (mg/L as $CaCO_3$)
Soft	0–75
Moderately hard	76–150
Hard	151–300
Very hard	>300

One parameter that is of great importance in water quality is Dissolved Oxygen (DO), which occurs due to the solubility of oxygen. The amount of DO in a water body is influenced by temperature and biological and chemical processes in the distribution system. If the amount of DO is low, microbial reduction of nitrate to nitrite, sulfate to sulfide, and concentration of ferrous iron are increased (WHO, 2011). Dissolved oxygen eliminates the risk of hydrogen sulfide, which is toxic and imparts a bad odor (Fetter, 1994). However, too high concentration of DO will increase the corrosion of metal pipes. Last but not least, it is important to maintain a balance in chloride concentration in the water. A small amount of chloride has a positive impact as it kills harmful bacteria and prevents the spread of waterborne diseases. Too high concentration of chloride can result in an unpleasant taste and odor and react with organic matter to produce disinfectant byproducts like trihalomethanes that can increase the risk of cancer (Environmental Protection Agency, 2021). Chloride is normally present in most disinfected waters at concentrations of 0.2-1 mg/L, and 5 mg/L is the maximum allowable concentration (WHO, 2011).

Biological parameters

Biological parameters of water quality include bacteria, algae and viruses. If the condition in the water (pH, dissolved oxygen and food supply etc) is ideal, bacteria can grow rapidly. High amounts of bacteria like cholera, tularemia and typhoid can cause serious health problems in humans. Algae are microscopic plants that consume carbon dioxide and release oxygen with the sun's energy. Presence of algae in drinking water causes strange odor and taste problems. Viruses are of course harmful for humans and due to their small size, they are able to pass through filters. There are several diseases like hepatitis that can originate from intake of viruses. Consequently, controlling biological parameters is an essential step in evaluating groundwater quality.

2.1.1 Groundwater chemistry

There are several geochemical reactions taking place continuously when water is in contact with the atmosphere and minerals. If the groundwater is in contact with the atmosphere, one of the most important geochemical reactions is dissolution of atmospheric carbon dioxide in water (Fetter, 1994, p.355). Carbon dioxide reacts with water and builds a weak acid, carbonic acid (H_2CO_3) which then undergoes chemical reactions that give rise to hydrogen ions and as a result the pH value of water decreases.

Groundwater chemistry is directly connected to the groundwater quality and varies in different regions and different types of aquifers due to processes like chemical weathering, redox and hold back processes and circulation time. Weathering of minerals such as feldspars, calcite, dolomite and gypsum in the ground play an important role in formation of major ions in the groundwater. Sodium, magnesium, calcium, bicarbonate, sulfate and chloride are the 6 major ions existing in groundwater at concentrations higher than 1 mg/L. There are also other ions like iron, strontium, potassium, carbonate, nitrate and fluoride that normally exist at low concentrations.

Feldspars stand for 50-60 % of earth's crust and are present in the majority of magmatic and metamorphic rocks but only in a small amount in sedimentary rocks. The chemical composition of feldspars includes both monovalent and divalent cations which makes the structure complicated. Feldspars can be divided into three groups. Plagioclase feldspar contain sodium (Na) and calcium (Ca), alkalic feldspar contain potassium (K) and sodium and barium feldspar contain barium (Ba) (Buřival, 2018). When it comes to sedimentary minerals, calcite is the most widespread and contains a significant amount of magnesium (Mg), iron (Fe), barium (Ba), strontium (Sr) and small amounts of cobalt (Co), manganese (Mn), lead (Pb) and zink (Zn) (Buřival, 2018). Dolomite is calcium and magnesium carbonate and when dissolved in water, ions Ca^{2+} and Mg^{2+} are released. It is clear that the groundwater chemistry and composition are directly related to the geological condition of the area. The geology and hydrogeological conditions in Nepal and more specifically in the project area are presented in section 2.3.

One important parameter in groundwater chemistry is the concentration of nitrate (NO_3^-). A high concentration of nitrate is an indication of groundwater pollution caused by anthropogenic sources (Esmaeili et al., 2014). Nitrate is present naturally in groundwater in concentrations lower than 10 mg/L and if the concentration exceeds this limit, the water is regarded as polluted (Karagüzel and Irlayici, 1998).

Common units to express concentration of components and ions in water are *mg/L* and *meq/L*. The unit *mg/L* is usually used to present and compare chemical composition of the water with national and international standards and guidelines. The unit *meq/l* is usually used to evaluate the chemical groundwater composition and get a better understanding of the chemical reactions and dominating processes that occur under the ground. *mg/L* can easily be converted to *meq/l* by dividing it with the equivalent weight of the ion.

2.1.2 Guidelines for drinking water quality

Standards and guidelines for drinking water quality are essential since there are many groundwater consumers that use untreated water directly from a well. There are different organizations worldwide that work with guidelines, regulations and recommendations for safe drinking water. What is considered as safe drinking water and the accepted amount of different ions and particles can vary depending on the country. This is due to socioeconomic and geographical variations in different countries. One of the organizations that work with water quality standards is the *World Health Organisation* (WHO). WHO is the United Nation agency dedicated to the well-being of all people and guided by science. WHO leads global efforts to expand universal health coverage and safe drinking water is an important vision. In this report two standards are used to evaluate the groundwater quality from the water well in

Madi. The first one is WHO (WHO, 2011) and the second one is *National Drinking Water Quality Standards* in Kathmandu, Nepal (Government of Nepal, 2005).

2.1.3 Methods to evaluate groundwater quality and illustrate groundwater chemistry

There are several graphical methods to evaluate the chemical groundwater composition and identify important processes governing the hydrochemical quality of groundwater. Some examples are Bar Chart, Piper Diagram and Gibbs Diagram.

Piper diagram analysis

A piper diagram is a useful tool for understanding the groundwater chemistry and classifying hydrochemical facies that describe the bodies of groundwater (Back, 1960). Piper diagrams illustrate results of major ion charge balance in the water in unit *meq/l* (Piper, 1944). Expressing the ion concentration in *meq/l* enables controlling the accuracy of the quality analysis by comparing the amounts of cations and anions. Piper diagram analysis consists of two triangles for cations and anions respectively and a diamond that summarizes the triangles and shows the composition of water with respect to ions. The left triangle presents the cations magnesium, calcium, sodium and potassium and the right triangle presents sulfate, chloride, carbonate and bicarbonate. The first step in designing a piper diagram is converting the ion concentrations to *meq/l* and plotting them on the according triangle. Once the concentrations are plotted a perpendicular line from each triangle goes to the diamond and a point is drawn at the intersection point. When the samples are plotted in the diamond, interpretation of the hydrochemical facies can be done according to figures 1 and 2 (Piper, 1944). Figure 1 illustrates the hydrochemical facies in groundwater and can be used to determine the type of water. Figure 2 can be used to study the acidity and alkalinity characteristics of groundwater samples.

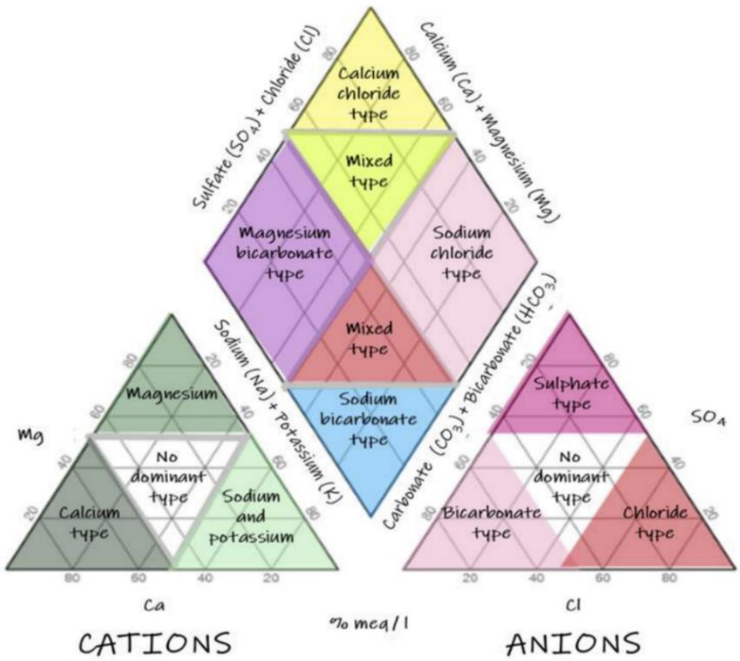

Figure 1: Illustration of hydrochemical facies in the cation and anion triangle and the diamond (Santiago de Surco, 2023).

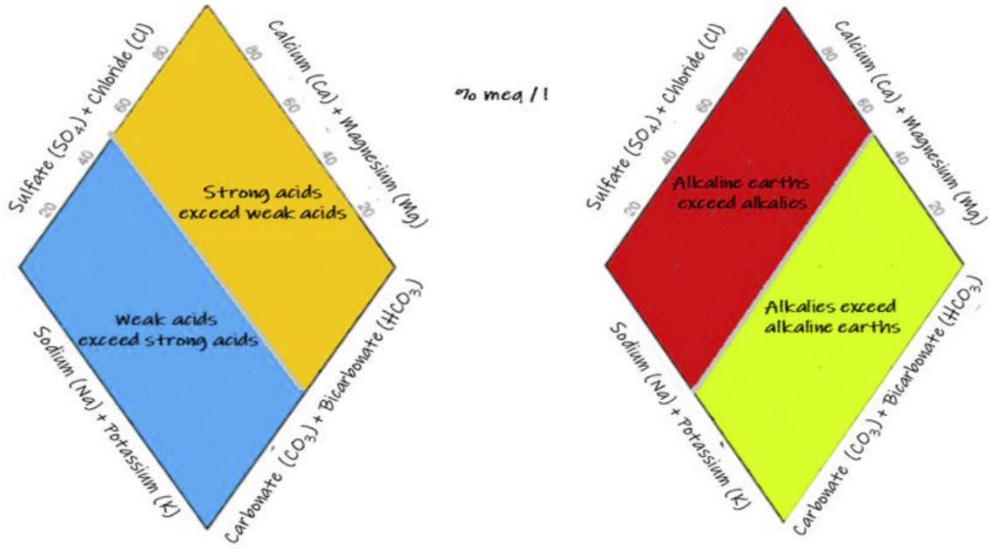

Figure 2: Illustrating different zones of the diamond to determine acidity and alkalinity characteristics (Santiago de Surco, 2023).

Bar chart

Bar charts enable visual comparison of major ion concentrations in the water. If there is data about the secondary ions, they should also be included in the analysis. The first step in constructing a bar chart for water analysis is to convert concentration to *meq/l*. This can be done, as explained above, by dividing the concentration in *mg/L* by the equivalent weight of the component. The equivalent weight is determined by dividing the molar mass by charge of the ion. A bar chart presenting the sum of cations and anions respectively can then be constructed. Ideally, the sum of cations and anions should be equal since the charge balance of water should be 0. In order to check the accuracy of the chemical analysis, a charge balance error (CBE) according to equation 1 can be calculated.

$$CBE = 10 * \frac{\sum cations - \sum anions}{\sum \text{anions} + \sum \text{cations}} \qquad \text{Equation 1}$$

CBE can have both negative and positive values. If the calculated value is positive there are more cations than anions. Absolute CBE values less than ± 5 % are acceptable.

Gibbs diagrams

Gibbs diagrams show major processes such as precipitation, rock-water interaction, evaporation and crystallization that control groundwater chemistry. Gibbs diagram analysis can be carried out by plotting ratios of for example $Na^+/(Na^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO_3^-)$ versus TDS (Gibbs, 1970). Once the ratios are plotted, the dominating process can be identified according to figure 3.

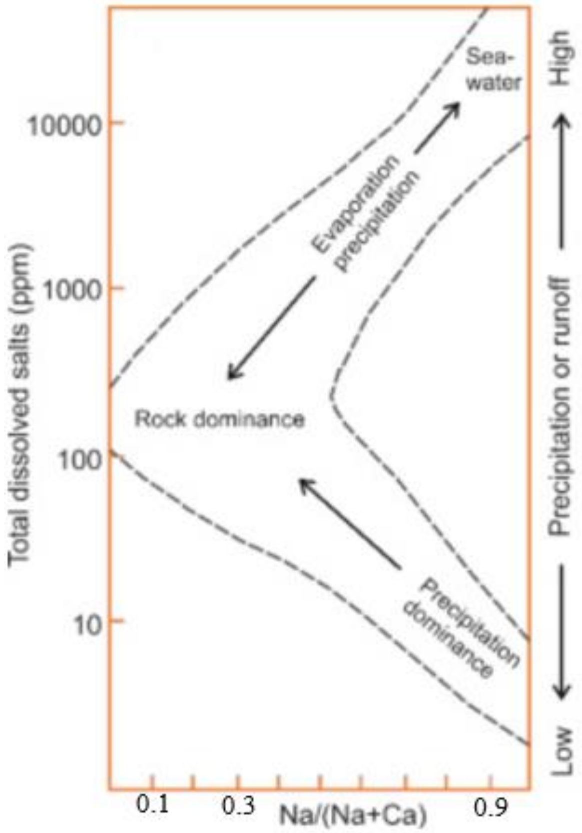

Figure 3: Gibbs diagram illustrating the dominating processes controlling the groundwater chemistry (Marandy and Shand, 2018).

In addition to the ratios mentioned above, there are other molar ratios that can provide a deeper understanding of chemical processes. The molar ratio of Na^+/Cl^- determines whether Na^+ originates from the halite dissolution ($Na^+/Cl^- = 1$) or silicate weathering ($Na^+/Cl^- >1$) or anthropogenic sources ($Na^+/Cl^- <1$) (Kanagaraj and Elango, 2016). Another useful ratio is between $Ca^{2+} + Mg^{2+}$ and HCO_3^- which reveals the source of Mg and Ca in the groundwater (Nematollahi et al., 2015). If the molar ratio is about 0.5, then calcium and magnesium derive from dissolution of carbonate and if the ratio is higher than 0.5, there are additional sources of magnesium and calcium (Yu et al., 2016). Dissolution of carbonate and sulfate minerals (such as gypsum and anhydrite) and mineralization processes (such as cation exchange and reverse cation exchange) can be studied by calculating the molar ratio of $(Ca^{2+} + Mg^{2+})/(HCO_3^- + SO_4^{2-})$. If the ratio is close to 1, weathering of carbonate and sulfate minerals are the dominating processes and if the ratio is higher or less than 1, cation exchange processes are dominating. In deep groundwater the ratio is usually less than 1 and the cation-exchange takes place. In shallow groundwater the ratio can be both less and higher than 1 and the reverse cation exchange process is more likely to take place (Xiao et al., 2017).

2.1.4 Sources of contamination in the project area

Analyzing the impact of human activities on groundwater chemistry is a complex and often uncertain process (Yu et al., 2014). High concentrations (>10 mg/L) of nitrate and chloride are typically indicative of anthropogenic sources and suggest that human activity is affecting groundwater chemistry (Abdesselem et al., 2015). In rural areas, due to less human activity and industry, anthropogenic sources are generally minimal. However, one of the main sources of groundwater pollution in rural areas is bacterial contamination from the sewage system (USGS, 2019). The most common method of treating sewage in rural areas is through septic tanks, but overflow and leakage from these tanks can percolate through the ground and contaminate the water.

2.2 Hydrology and Hydrogeology

Movement, distribution and occurrence of waters both on and below the earth's surface is referred to as hydrology. Hydrogeology or sometimes referred to as geohydrology is the study of groundwater and its interrelationship with geologic materials and processes. Analyzing the hydrology and hydrogeology of an area is essential when:

- Designing and constructing a water well for drinking water supply
- Doing an investigation of water quality
- Dealing with groundwater pollution

2.2.1 Groundwater recharge

Groundwater formation can be analyzed by studying the hydrologic cycle (the water cycle) which is a continuous process where water is purified by evaporation and transported to the atmosphere and back to the land and oceans. The hydrologic cycle describes where water is on Earth and how it moves (USGS, 2022). One of the most important processes in groundwater formation is precipitation. The water from precipitation reaches the ground and percolates through the soil to groundwater reservoirs (aquifers). However, all the water from precipitation will not form groundwater. At first the water enters the zone of aeration (below land surface where the soil pores contain both air and water). Roots of plants reach to the upper part of the aeration zone and use the water. Water can also go up from the zone of aeration and get back to the land surface to evaporate. Evapotranspiration refers to the amount of water that leaves the zone of aeration due to plant transpiration and evaporation. When the amount of water in the zone of aeration exceeds the field capacity, the water is transferred downward due to gravity drainage and at a certain depth the geological formation under the ground is saturated with water, commonly known as groundwater. Besides precipitation and evapotranspiration, infiltration capacity of the geological formation is an important aspect in determining the groundwater formation. A high infiltration rate leads to a larger amount of water infiltrating through the soil and forming groundwater. Flat areas of coarse soils, well-vegetated land, low soil moisture and a top soil layer made porous by insects and animals provide optimal conditions for high infiltration (Fetter, 1994).

2.2.2 Aquifers and aquifer properties

As described in chapter 1, section 1.1, aquifers are geological units that can store and transmit water and are mainly divided into two categories, unconfined and confined aquifers. The classification of an aquifer is based on its geometry, relation to topography and the subsurface geology. Unconfined aquifers or commonly known as water table aquifers, are formed near the ground surface and are in contact with the atmosphere. Confined aquifers are formed between two confining layers (such as clay and unfractured rocks. The water in a confined aquifer is under pressure and will rise to a level above the top of the aquifer once a well is installed to the aquifer. The newly constructed well in Madi is highly likely installed to an unconfined aquifer. Therefore, unconfined aquifers are described in detail in the next section. The lithology and hydrogeology of the study area is presented in section 2.3.

There are specific geological terms that are used to describe the ability of an aquifer to store and transmit water. The first important term to know is the **porosity** which is the percentage of void spaces in a material. Water can be stored in the void spaces and transmitted through them. Cracks, voids and pore spaces in geological soils and rocks are of great importance in studying hydrogeology. A high total porosity means that the aquifer is able to store large volumes of water. Nevertheless, the total porosity is not an indication of high ability to transmit water. For the water to be conveyed within an aquifer, the void spaces need to be connected. The volume of the connected void spaces is called **effective porosity**. One important term in hydrogeology is **intrinsic permeability,** which is the material's general ability to allow liquid to pass through it. Materials with high intrinsic permeability are usually good aquifers. Another important parameter is **hydraulic conductivity** or coefficient of permeability which is a material property for both the porous media and fluid and reflects the ease of liquid flow through porous media (Shackelford, 2003). Hydraulic conductivity can be determined by equation 2, commonly known as Darcy's law. A (L^2) is the cross-sectional area, *dh/dl* is the hydraulic gradient where *dh* is the change in head between two points and *dl* is the distance between them and *K* is the hydraulic conductivity (L/T). Q is the flow rate (L^3/T).

$$Q = \mathrm{KA}\frac{\mathrm{dh}}{\mathrm{dl}} \qquad \text{Equation 2}$$

Aquifers are formed from many different types of sediments and rocks such as sandstone, gravel, conglomerates and fractured limestones. Both permeability and hydraulic conductivity vary for different sediments and are affected by several parameters such as grain size, packing arrangement and pore shape. Table 2 presents values for permeability and hydraulic conductivity for some unconsolidated sediments.

Table 2: Presents ranges of permeability and hydraulic conductivity of sediments (Fetter 1994; Freeze and Cherry, 1979; Domenico and Schwartz, 1990).

Material	Intrinsic permeability (darcys)	Hydraulic conductivity (cm/s)
Clay **Silt, sandy silts**	$10^{-6} - 10^{-3}$	$10^{-11} - 10^{-8}$
Clayey sands, till	$10^{-3} - 10^{-1}$	$10^{-8} - 10^{-6}$
Silty sands, fine sands **Well-sorted sands**	$10^{-2} - 1$	$10^{-7} - 10^{-5}$
Glacial outwash	$1 - 10^{2}$	$10^{-5} - 10^{-3}$
Well-sorted gravel	$10 - 10^{3}$	$10^{-4} - 10^{-3}$

Other important parameters that can be used to describe the characteristics of aquifers and analyze the performance of a water well are **Storativity** and **Transmissivity.** Storativity (S) refers to the volume of water that can be withdrawn from the aquifer per unit area and change in hydraulic head. Equations to calculate storativity for an unconfined aquifer are presented in the next section. Transmissivity (T) describes the aquifer's ability to transmit water through a unit width under a hydraulic gradient of 1 (Fetter, 1994). Transmissivity is assumed to be lateral movement of groundwater throughout the entire saturated thickness of an aquifer. Transmissivity can be determined by multiplying the hydraulic conductivity with the saturated thickness of the aquifer.

2.2.3 Unconfined aquifers

Unconfined aquifers are in contact with the atmosphere and have the water table as the upper boundary. Unconfined aquifers are fully saturated as all aquifers. Above the water table, there is a capillary fringe and an unsaturated zone. Figure 4 shows an illustrative image of the different zones and varying pressure and also the division of the zones in connection to an unconfined aquifer. The unsaturated zone contains water in both gas phase (under atmospheric pressure) and liquid phase (less than atmospheric pressure). The saturated zone is found under the water table at pressures greater than atmospheric. Due to the fact that the pressure is greater, if a water well is sunk into the aquifer, the water will rise up and stand at the level of the water table where the pressure is atmospheric (Hubbert, 1940). If the well is installed deeper, the level of water in the well will be either above or below the water table depending on whether the well is located in the discharge or recharge area (Lohman, 1972). One important division in unconfined aquifers is the capillary fringe. The lower part of this region is totally saturated, however the pressure is less than atmospheric, thus under static conditions, water from this region will not enter the well. Capillary fringe rises and declines with fluctuation of the water table. This means that when water is withdrawn from the well, the body of the capillary fringe is lowered and moves towards the water table and enters the well.

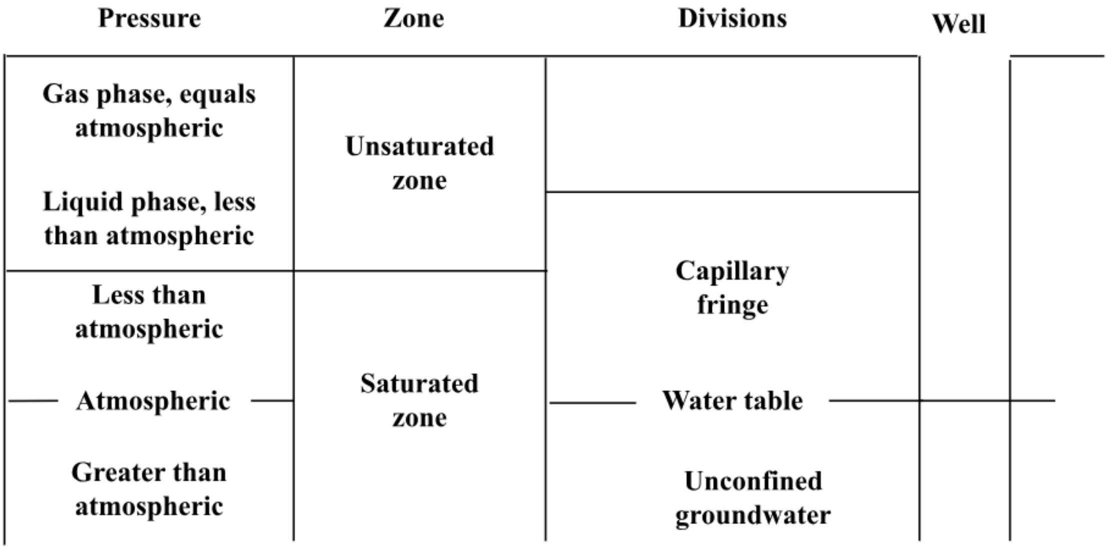

Figure 4: Illustration of divisions of subsurface water in connection to unconfined aquifers, inspired by (Hubbert, 1940).

In an unconfined aquifer, storativity is a function of **Specific yield, S_y** which is a gravity drainage term and **Specific storage, S_s**. S_y refers to the change in volume caused by lowering or rising of the water table in the aquifer and S_s refers to the volume of water that is either added or released to storage per unit volume of saturated material due to elastic storage and release of water (Rackley, 2017). Storativity of an unconfined aquifer can be determined by equation 3 and b is the average saturated thickness. Specific storage can be determined by equation 4 where α is the compressibility of the aquifer skeleton, η is the effective porosity and β is the compressibility of water, and ρ and g are density and gravitation constant respectively. However, values of α (m^2/N) and β (m^2/N) are often very small ($10^{-11}<\alpha<10^{-6}$ m^2/N and $\beta=4.4*10^{-10}$ m^2/N), thus the contribution of specific storage can be neglected and the storativity of an unconfined aquifer is equal to the specific yield (equation 5) (Woessner and Poeter, 2020). Nevertheless, if the storativity is determined by conduction of a pump test with observation wells and the data is analyzed in a software, the contribution of the specific storage term is built into the interpreted specific yield (Lohman, 1972). Once the storativity is determined, the volume of water drained from the aquifer can be calculated by equation 6 where A is the surface area and Δh is the change in head.

$$S_{Unconfined} = S_y + S_s b \qquad \text{Equation 3}$$

$$S_s = \rho g(\alpha + \eta\beta) \qquad \text{Equation 4}$$

$$S_{Unconfined} = S_y \qquad \text{Equation 5}$$

$$V = SA\Delta h \qquad \text{Equation 6}$$

According to Lohman (1972) and Freeze and Cherry (1979, chapter 2), the values for specific yield in unconfined aquifers are generally higher than the values for storativity in confined aquifers, ranging from 0.01 to 0.3. This suggests that extracting water from unconfined aquifers is typically more efficient for water supply than extracting water from confined aquifers.

As mentioned above, transmissivity is the product of hydraulic conductivity and the saturated thickness. In an unconfined aquifer the water is derived from storage by vertical drainage and therefore the water table slopes in the direction of flow, thus the saturated thickness varies with space and T obtains different values with distance from a given location. Depending on the change in hydraulic head, the value of T can be calculated by either taking a single value for the saturated thickness or a mean value from different parts of the aquifer (Woessner and Poeter, 2020). In order to get a better understanding of the variation in water level throughout an unconfined aquifer, a hydrogeological interpretation of an area can be done by constructing a water table map.

2.2.4 Water table map

A water table map is a fundamental tool in hydrogeological interpretation and can be created by measuring the water level elevation at static conditions (when the water is not pumped) in a series of wells that are in contact with the aquifer of interest. It is important to measure the water levels simultaneously during a short interval of time since the groundwater level can vary. The water level readings should be referenced to a common point, such as mean sea level, to ensure consistency. When constructing a water table map, it is essential to consider the presence of nearby rivers, lakes, and streams since they can interact with the aquifer and affect the groundwater level (Keith, 2021).

The first step in designing a water table map is to prepare a base map showing the surface topography and location of surface water bodies. The location of wells, together with their elevation, can then be plotted on the base map. Contours of groundwater elevation can be drawn with reasonable intervals and proper interpolation. The contour interval can be determined by identifying the highest and lowest hydraulic head and dividing it into a 5-10 range of intervals. For example, if the highest point is at 100 m and the lowest at 0, then an interval of 10 or 20 is reasonable. There are some general rules that need to be followed when creating a water table map (Keith, 2021):

- groundwater contours can not be higher than the surface topography
- when crossing a gaining stream, contours form a V pointing upstream
- when crossing a losing stream, contours bend downward
- groundwater contours should be spaced well apart where the water table has a small gradient and close together when the gradient is steep

The properties of aquifers can vary with the geology, substrate structure, and topography of the area in which they occur. Therefore, it is crucial to study the geology and hydrogeology of the specific area of interest and the next section is dedicated to the project area. A more general description of the geology and hydrogeology of Nepal can be found in Appendix 1.

2.3 Geology and hydrogeology of the project area

The project area is located in Madi Municipality, Chitwan District, which is situated in the Quaternary deposits consisting of unconsolidated sediments from the dun basins and dun gravel deposits. The basement rocks of the Chitwan area are part of the lower, middle, and upper siwalik formations, which occur continuously throughout the Himalayas. The Chitwan Dun Valley is located within the Sub-Himalayan zone (Siwaliks), and the Upper Siwaliks occur intermittently in some areas. Sediment sizes increase upwards, becoming conglomerated in the Upper Siwaliks. Figure 5 shows the geological map of the Chitwan's dun valley and the project area is also marked with a red dot in the figure.

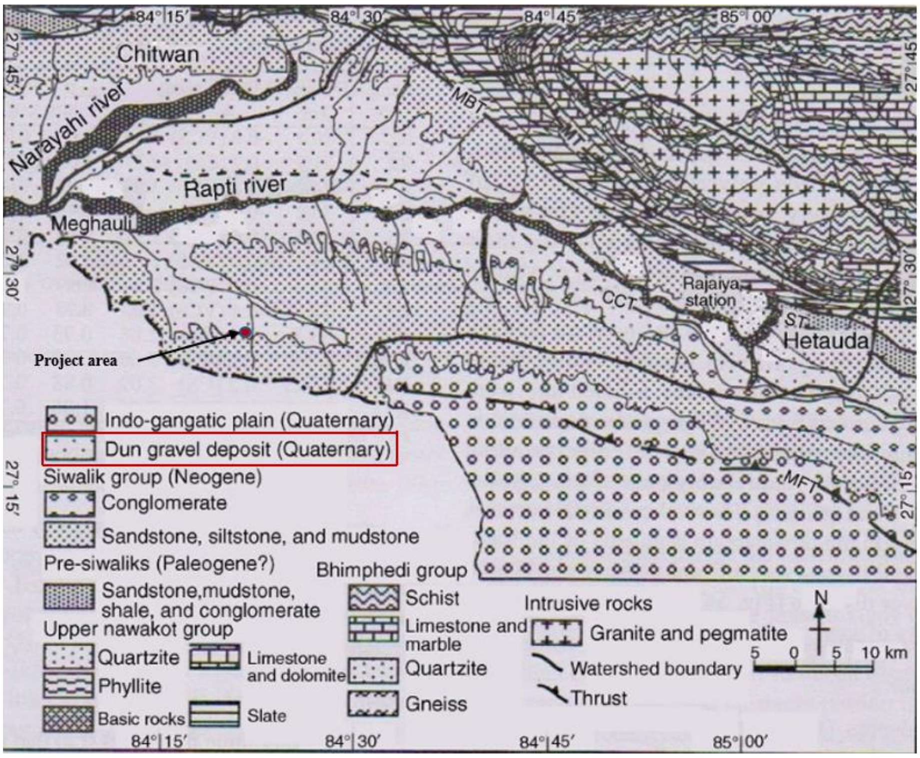

Figure 5: Geological map of Chitwan's dun valley (Malla and Karki, 2016).

The large aquifer system underlying Chitwan's dun valley is predominantly filled with highly porous, permeable, and unconsolidated to poorly consolidated alluvial or fan deposits. These unconsolidated valley fill deposits consist of thick bedded conglomerates with pebble to boulder clasts in a fine-grained matrix. They are locally called dun fan gravels or dun gravels. The sediments are finer toward the confluence of two rivers called, the Rapti and Narayani rivers. The study area is drained by several rivers: Rewa Khola, Baghai Khola, Aireni Khola, Dumre Khola. They all meet at the Rapti River and finally join the Narayani River.

As mentioned in chapter 1, a new well is constructed in Madi with the purpose of providing safe drinking water. Drilling of the water well is carried out to the depth of 100 meters by direct rotary drilling method. The tube well is developed by inner washing, water jetting, backwashing and a suitable air compressor to make water sand free. Figure 6 illustrates the lithology of the water well. Well screens are installed at depths 75-81 m and 85-94 m and that is where the water from the aquifer is entering the well. This means that the saturated thickness of the aquifer is 15 meters. Furthermore, this indicates that the well is partially penetrating the aquifer.

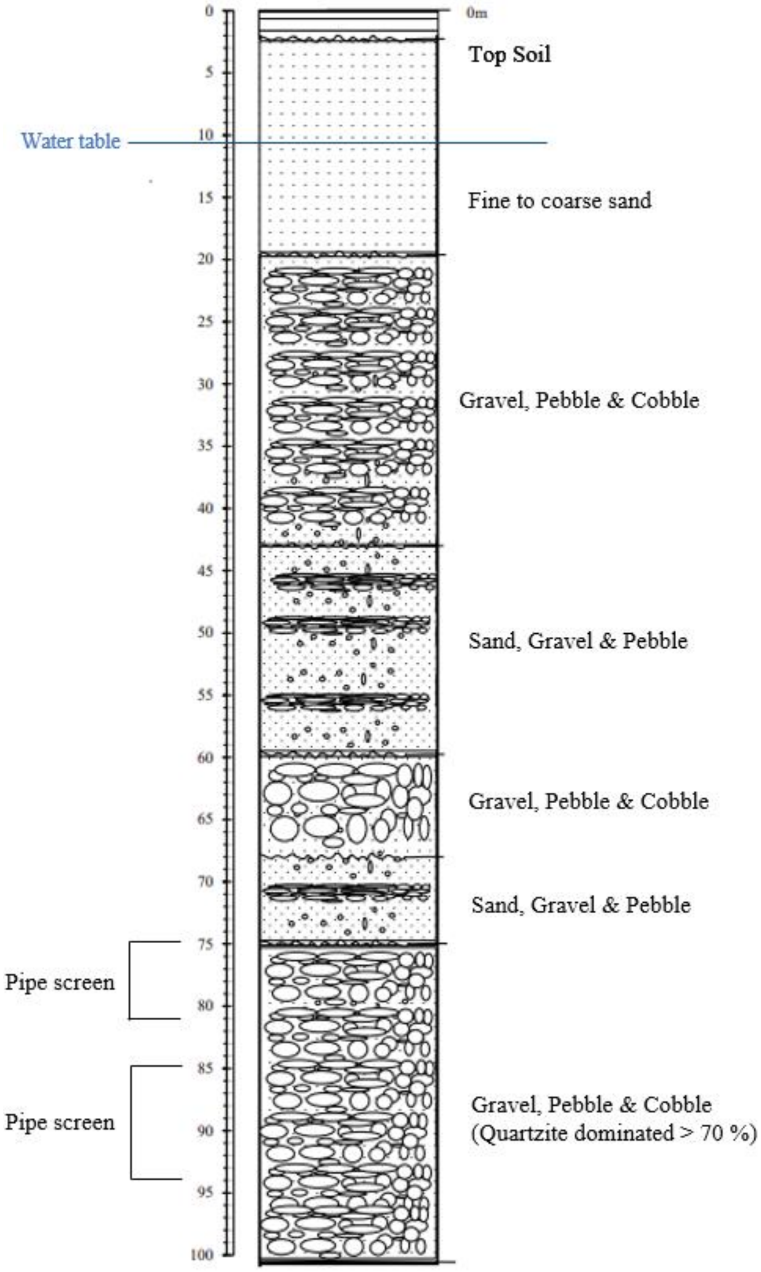

Figure 6: Lithology illustration of the water well drilling in Madi

Looking at the lithology, there are no confining layers and therefore it can be assumed that the aquifer that the WW is connected to is an unconfined aquifer. The aquifer consists of sand, gravel, pebble and cobble which has high permeability indicating that the location at which the well is drilled has good potential for extracting groundwater. Even though the lithological log of the well shows good potential for groundwater extraction, it is important to determine aquifer characteristics and analyze the performance of the well. This is widely done by conducting hydraulic tests.

2.4 Hydraulic tests

There are three main hydraulic tests. A **pumping test** is carried out by withdrawing water from a well and measuring the water level in the water well and surrounding observation wells that are connected to the same aquifer. Pumping tests can last from several hours to several weeks depending on the size of the aquifer and purpose of the test (Triad Engineering, 2019). If the need of determining aquifer properties is on a smaller scale a **slug test** can be used. A slug test is carried out by causing a rapid change in the volume of water in the well (either adding or taking out) and measuring the water level and the time it takes for it to get back to the static condition. The third hydraulic test is the **constant head test** in which the drawdown is held constant, and the discharge rate is recorded over time.

A pumping test is carried out in this project and therefore a detailed literature review on pumping tests is done. However, if one is interested in detailed information about slug test, it can be found in chapter 5, section 5.6 in *Applied Hydrogeology book* by Fetter (Fetter, 1994). A brief overview of carrying out a constant head test and evaluation of the results can be found in a doctoral thesis by Jan-Erik Rosberg (Rosberg, 2010).

2.4.1 Pumping test

The main source of information in this section is the handbook, *Analysis and Evaluation of Pumping test data* by Kruseman et al. (2000). Therefore, a reference notation is not added each time this source is used.

Pumping test is an effective method used over a century to evaluate how an aquifer will respond to groundwater exploration (Butler, 2009). The purpose of a pumping test can be to determine hydraulic properties such as transmissivity and storativity, to evaluate the aquifer capacity and also identify existing boundaries (spatial limitations of an aquifer) (Mauro, 2020). There are two main types of pumping test depending on the purpose of the analysis. The first one is aquifer testing with the aim of studying the hydrogeological characteristics and determining the aquifer properties. This type of test usually involves at least one observation well and is carried out for a longer period of time. The second one is a production test which is typically conducted in newly constructed wells to study the well flow and efficiency. The test is carried out in shorter periods of time with different withdrawal rates.

The principle of conducting a pumping test is rather simple. Water is withdrawn from a well and the displacement of water (known as drawdown) in surrounding observation wells and the pump well is measured over time. In spite of that, there are several parameters that need to be taken into account in conducting a pump test and analyzing the obtained results.

Discharge of water
Monitoring the discharge rate is an important parameter in pumping tests. The flow should ideally be held at a constant rate. This can be done by either installing a valve to control the flow or having the pump running at a constant speed. There are different methods such as using a container, an orifice weir or jet-stream method to measure the discharge rate. Another aspect related to discharge of water is the place that the discharged water is released to. In cases of longer pumping tests, it is essential that the discharged water is hindered from

returning to the aquifer and affecting the results. Information about methods to measure the discharge rate and hinder the discharged water from infiltrating back to the aquifer can be found in the handbook (Kruseman et al., 2000).

Duration of pumping test

Duration of a pumping test can vary from several hours to several days or even weeks. This depends on the type of the aquifer and the degree of accuracy desired. At the beginning of the test, water is derived from the aquifer storage around the well and this causes the cone of depression to develop rapidly. The development of the cone of depression is slowed down as the test continues and at one point, the recharge rate of the aquifer equals the pumping rate. At this point, steady state condition is reached in the aquifer. It is of value to continue the pump test until a steady state is reached and there are several advantages to doing so. One is that accurate information on the aquifer characteristics can be obtained by simpler equations which enables reliable results. Another benefit of reaching a steady state condition is being able to reveal the presence of boundary conditions. For an unconfined aquifer it is recommended to continue pumping for at least 3 days (Kruseman et al., 2000).

Data correction

In order to obtain sufficient results from a long pumping test, the data need to be corrected. Common corrections include adjustments for barometric pressure and rain events. A practical measure that can be done in the field to reveal the external influences on the groundwater level is, measuring the water level manually with a water table meter some days prior to the test and some days after the test (known as recovery time and is explained in section 2.4.2). If the water level after the test is stopped, returns back to the same static level as before the test was started, it can be concluded that there are no external influences on the aquifer. If the water does not return to its static level in the well, there might be external parameters such as rain falls and seasonal variation, influencing the aquifer. Further detailed information about fluctuations and how the data can be corrected can be found in chapter 2, section 2.8 in the handbook.

Data interpretation

Interpreting the data obtained from a pumping test involves choosing a theoretical model that describes the behavior of the aquifer under withdrawal conditions. During a pumping test (as the cone of depression develops) the type of aquifer and boundary conditions dominate at different times and affect the drawdown. It is therefore important to comprise these parameters when analyzing the pumping test data and this can be done by a theoretical model. Analyzing pumping test data starts by constructing diagnostic plots (log-log plots of drawdown versus time) and specialized plots (semi-log plots of drawdown versus time or versus radial distance to the well). The plotted data on a diagnostic and specialized graph are commonly known as a data curve. The data curve is then compared to a type curve which shows the theoretical drawdown that would be observed based on a set of assumptions. By matching the data curve with a type curve an analytical solution can be obtained and aquifer parameters can be determined. There are various type curves that can be used depending on the type of the aquifer. As presented in section 2.3, the aquifer of interest is most likely an unconfined aquifer and theoretical models such as Neuman, Theis, Cooper Jacob and Boulton can be used to find the best fitting type curve.

There are several softwares that can be used to interpret the data of a pumping test. Regardless of the type of the analytical solution and the software that is used to interpret the date, there are some main assumptions made (Mauro, 2020; Kruseman et al., 2000):

- Aquifer is horizontal, homogeneous, isotropic, infinite and has constant thickness
- Horizontal flow in the aquifer
- Recharge to the aquifer is not considered
- In most cases the pumping well is fully penetrating the aquifer

The assumption that the aquifer is homogeneous and isotropic means that the hydraulic conductivity is the same throughout the geological formation and in all directions. However, this is almost never the case in reality but for simplifying the analysis, this assumption can be made.

The shape of the cone of depression reveals some important hydraulic characters of the aquifer. An indication of the transmissivity can be made by observing the cone of depression. If the shape is wide and flat, the transmissivity of the aquifer is high and vice versa. Another important conclusion that can be made by looking at the cone of depression is the existence of boundary conditions. Next section goes through common boundary conditions and how the shape of the cone of depression can give an indication of the type of boundary.

Boundary conditions

Derivation of data curves from type curves is usually an implication of existing boundaries. Main boundary conditions are recharge boundaries (constant head boundary) and impermeable boundaries (no-flow boundary). A recharge boundary condition occurs when an aquifer is in contact with a recharge zone which is typically a water body like a river or a dam. When a recharge boundary is reached in the aquifer, the drawdown (data curve) stabilizes (steady state is reached) and moves almost horizontally whereas the type curve continues to increase. A no-flow boundary condition occurs when an aquifer is in contact with impermeable units like clay or unfractured rocks. Water can not infiltrate through a no-flow boundary and as a result, the drawdown will double and the data curve steepens.

Limitations of pumping tests

As mentioned earlier, estimates of transmissivity and storativity can be obtained by conducting a pump test. The estimated average value of T can be reasonable and representative for the entire aquifer. The estimated S value can be problematic because spatial variation in T can affect the S value (Sanchez-Vila et al., 1999). There are two possible explanations for this uncertainty in the obtained storativity value. Firstly, the hydraulic diffusivity (T/S) is a direct estimation where T is obtained from the drawdown data in absence of boundary effects. Second, is the fact that the estimated T value represents an average over a large area whereas diffusivity is a function of material between the WW and OWs (Schad and Teutsch, 1994). Consequently, it is therefore not uncommon that the estimated T value is near constant and the S value differs from analysis of drawdown at different OWs. However, a representative value of S can be obtained if the distance between the pumping well and the observation well is long (Schad and Teutsch, 1994).

One important parameter that can not be obtained by a pumping test is spatial variation in hydraulic conductivity. Knowing the spatial variation in hydraulic conductivity can be useful for predicting contaminant movement and analyzing the aquifer's sensitivity to contaminants (Butler, 2009). There are other methods rather than a pumping test to obtain this information and one such method is the hydraulic tomography (HT) that can be studied and carried out on field. This is however outside the scope of this study.

Pumping test in unconfined aquifers and partially penetrating wells
Analyzing drawdown data obtained from a pump test conducted in an unconfined aquifer is rather complicated as the drawdown curve displays three segments in response to pumping if the OW is close to the WW. The first segment occurs at early pumping time and the drawdown increases rapidly as water is released from the wellbore storage instantaneously. An unconfined aquifer reacts like a confined aquifer and the shape of the drawdown curve is similar to Theis type curve. During the second segment, drainage of the porous matrix takes place due to formation of vertical gradients near the water table. As a result, the increase in drawdown is either slowed down (deviates from Theis curve) or remains constant. During the last segment, the drawdown curve is almost horizontal and water is supplied from specific yield, S_Y (Yeh and Huang, 2009). The time-drawdown curve at this stage confirms to Theis type curve. There are different analytical methods to analyze the drawdown data. One common curve-fitting method for unconfined aquifers is the Neuman method which is based on delayed water table response. However, flow in the saturated capillary fringe above the water table is neglected in this method which gives an estimation of specific yield that can be unreasonably low. Each curve-fitting method implies a set of assumptions that need to be considered. However, this report does not focus on curve-fitting methods, as various methods have been tested using software to analyze and determine the aquifer properties. Curve-fitting methods, assumptions related to each method and equations that can be used to numerically calculate the aquifer parameters are presented in the handbook (Kruseman et al., 2000).

In some cases a well is partially penetrating the aquifer and this can be due to various reasons. When an aquifer is partially penetrated by a well, the general assumption that the well receives water from horizontal flow is not valid anymore. Partial penetration causes vertical flow components and a higher velocity in the vicinity of the well. This effect is reduced as the distance from the pumping well gets longer and at a distance that is 1.5-2 times greater than the saturated thickness, it is completely negligible. There are two main curve-fitting methods for partially penetrating wells in unconfined aquifers. Streltsova and Neuman curve-fitting method and the latter is more commonly used in both numerical and analytical analysis.

2.4.2 Recovery test

The results of a pumping test can be verified by carrying out a recovery test (collecting the change in water level after the pump is stopped). Analyzing the recovery test data gives an estimation of T value which can then be used to check the validity of the results obtained from the pumping test. Results obtained from a recovery test are more reliable than ones obtained from a pumping test since the rate at which recovery occurs is constant whereas it is difficult to maintain a constant discharge rate during a pumping test. The main methodology to analyze recovery data is Theis recovery method. Although this method is mainly used for confined aquifers, Neuman (1975) (Kruseman et al. 2000) demonstrated that it can also be used to analyze late time recovery data in unconfined aquifers and partially penetrating wells. At late time the effects of elastic storage have dissipated and if the residual drawdown is plotted against $(t_p - t)/t$ in a semilog plot, the residual drawdown data fall on a straight line.

The duration of the recovery test should ideally be as long as the pumping test or until 80-90 % of the static water level is reached. If the water level in the well is not restored to 90-95 % of its static value within a week, it can be an indication that the pumping rate was too high for the well's capacity or there are some external influences on the aquifer, like seasonal variation in groundwater level.

2.4.3 Well performance tests

Performance of a well during discharge of water can be described by two components which are aquifer losses and well losses. Aquifer losses are referred to as head losses and are time-dependent and vary linearly with discharge rate. Aquifer losses can for instance be connected to the well partially penetrating the aquifer. Well losses consist of linear and non-linear losses. Linear head losses in a well are a result of damage to the aquifer during construction (drilling, plugging and compaction etc.) and non-linear head losses are related to friction losses inside the well screen and in the suction pipe. Both aquifer and well losses induce a much greater drawdown than expected theoretically. It is therefore important to evaluate the performance of a well and this can be done by step-drawdown test and recovery test. During a step-drawdown test, water is discharged at a slower rate and drawdown data is noted until it stabilizes. The discharge rate is then increased gradually and drawdown is noted at each step. Step-drawdown test is carried out for a single pumping well and the duration of the test is short. By performing a step-drawdown test, a value of T can be obtained and the specific capacity of the well can be determined by dividing the discharge by the drawdown observed during the test. However, it should be noted that the method for determining well losses may vary depending on the type of well and its construction, and it is important to consider these factors when evaluating the performance of a well. Detailed information about analyzing a step-drawdown test is in chapter 14 in the handbook. Recovery test in unconfined aquifers is explained in the previous section, 2.4.2.

3 Economic analysis on Groundwater supply system

Previous chapter was dedicated to the groundwater quality and the aquifer characteristics and the performance of the well. These three mentioned factors are important in creating a sustainable water supply system but for a system to sustain it needs to be financially viable too. Therefore, this chapter focuses on economic analysis of water supply systems and presents the water supply system in Madi.

3.1 Value of water

One important parameter in the economy of water systems is the value of water. Water in itself is free. The payment is for services people receive, the infrastructure, labor and maintenance of the system. Water is an asset and its economic value is connected to its contribution in different areas (drinking, industry and recreational etc) (National Research Council, 1997). Pricing of water is essential in order to get the water to be used more efficiently and effectively. One way to price the water used for domestic purposes is by introducing water tariffs. Water tariffs are usually set below the average economic cost of the system which hinders a sustainable delivery of water services. Hence, carrying out an economic analysis of water supply system is of significant value.

Water withdrawn from different sources has different economic values due to quality and quantity that can be delivered during a period of time. The economic value of groundwater has seen an increase during recent years due to high pollution levels of surface water and an increase in population rate (Suman et al., n.d). In cases where the groundwater is directly used for drinking, the quality of water is connected to the economic value of that water. Poor quality of water reduces the value since the consumer's willingness to pay reduces (National Research Council, 1997). It is therefore essential to carry out a quality assessment of the groundwater and results from the quality assessment of the groundwater in Madi are presented in chapter 5, section 5.1. From an economic point of view the price of water (assumed of high quality) should be expressed as the quantity of water per capita of consumption. The price model for the water supply project in Madi is presented in section 3.3.1. Nevertheless, determining an economic value of groundwater is rather difficult and includes many parameters such as welfare impact and different services that groundwater offers. Estimating a value for groundwater is outside the scope of this project but more detailed information regarding different studies and the obtained results can be found in the book, *Valuing Groundwater, Economic Concepts and Approaches,* in chapter 3 and 4 (National Research Council, 1997).

3.2 Economic analysis

The main source of information provided in this section is, *Handbook for the Economic Analysis of Water Supply Projects* by Asian Development bank (World Bank, 1999). Hence a reference notation is not added each time this source is used.

An economic analysis of a water supply system comes into play at different stages such as project identification, preparation and project appraisal. A standard procedure to carry out an economic analysis of water supply systems can be done according to the flow chart presented in the *Handbook* on page 8. However, the presented procedure is more accurate in the planning and designing phase of a project. In this case the system is already built. Thus, the economic analysis in this project is focused on the components and financing. A simplification of the mentioned flowchart leads to the following procedure to carry out the economic analysis (note that the last point is added for this specific project):

A. Identification of project objectives, such as the target population and effective demand (quantity of water demanded of a given quality at a specified price)
B. Determination of components and construction cost
C. Calculation of the economic indicators such as net present value (NPV), internal rate of return (IRR) and return on equity (ROE).
D. Conduction of a sensitivity analysis to identify the key parameters that perceptibly impact the economy of the system
E. Comparing different types of financing since the price of water is directly connected to how the water supply system is financed

One important parameter that must be considered in all economic analysis is the assessment of sustainability. Economic sustainability can be achieved if the project can continue to produce economic benefits throughout its lifetime and if the government or municipality can afford to pay the level of financial subsidies (if needed) for the project to survive.

3.2.1 Financial benefit-cost calculation

Financial benefit-cost analysis follows above mentioned steps (A-E) and evaluates the financial viability of a water supply project. In order to carry out a financial benefits-cost analysis following parameters need to be determined:

1. Investment costs (CAPEX)
2. Operation and maintenance costs (OPEX)
3. Reinvestments
4. Residual values
5. Revenues
6. Net Financial Benefits/Net Present Value (NPV)
7. Internal rate of return (IRR)
8. Return on equity (ROE)

Parameters 1-3 are referred to as project costs and need to be determined on an annual basis. Operation and maintenance costs can be estimated as a percentage of the total investment cost (CAPEX) or in cases where the system is already in operation, real data can be collected and used in the analysis. Reinvestments are related to components that need to be changed, i.e components that have shorter lifetime than the water supply system. Residual value is the value of components at the end of their lifetime and is usually included in the analysis as a benefit. Project revenues include user charges and connection fees. After identifying cost and revenues the NPV can be determined by calculating the difference between the project revenues and costs. Last but not least the project's profitability can be calculated by means of an internal rate of return (IRR). IRR can be calculated as a discount rate at which the value of NPV is equal to zero. However, IRR is usually used to compare different projects and choose the most profitable one. A better measurement to analyze if the project is interesting from an investment point of view is return on equity. This is explained in the next section.

In addition to economic and financial benefits, there are other benefits related to a water supply project. Two important benefits are health and time cost saving benefits. It is however difficult and complicated to determine the monetary value of these benefits. There are many parameters that play a role in improving health conditions and it is difficult to find out a precise value of time (especially in rural areas). A considerable amount of research and data is required to be able to include these benefits in the cost calculations and this is outside the scope of this study.

3.2.2 Financial sustainability

To achieve sustainable development, the water supply project needs to be financially viable. There are three main aspects in analyzing the financial sustainability of a water supply project. First, funding of the project and if the amount is sufficient to cover all the costs (during construction, implementation and operation). Second, partial or full cost recovery from project beneficiaries. This is done by implementing user charges. In cases when full cost recovery is not possible (mainly in rural areas), subsidy from the government is needed. Thirdly, financial incentives to engage all the stakeholders in the water supply project. This means generating enough income to pay back the lenders and their interest rate and paying staff working with the water supply system. One essential parameter in cost recovery from project beneficiaries is the user's willingness to pay. Users should be satisfied with the quality and quantity of the water so they are willing to pay for it or otherwise the system can not be maintained and the water supply system will not sustain.

One important parameter in financial sustainability analysis which is connected to project funding and creating financial incentives for investors is the return on equity (ROE) which shows the profitability of the investment. ROE can be calculated by dividing net income (revenue minus expenses) with total investment made by shareholders. The value of ROE is interesting from an investor perspective and different investors have different requirements for the ROE value. In case of foreign investors, returns of 16-20 % is preferable and in case of investment from the government returns of 10-12 % is desired.

3.2.3 Sensitivity & risk analysis

Economic and financial cost-benefit analysis are based on assumptions of parameters such as demand, cost, water availability and benefits. These parameters are subject to change over time and the actual value may deviate from the assumptions. Thus, carrying out a sensitivity and risk analysis is of great importance. Sensitivity analysis illustrates to what extent the viability of the project changes by variation in major costly processes/components and risk analysis determines the probability that changes in cost calculations occur. Both sensitivity and risk analysis, analyze the project's IRR and NPV which are the two most widely used measures of economic worth. Since the construction of the water supply system in Madi is almost done, this project focuses on sensitivity analysis and the process to carry out a risk analysis is not considered hereafter.

Required steps to carry out a sensitivity analysis are as follows:

1. Identification of key variables that affect the project costs and benefits. In a water supply system key variables that affect the economic viability usually include water demand, investment cost (CAPEX), operation and maintenance costs (OPEX), financial revenues, financial and economic benefits, discount rates and tariffs.
2. Determining the effects of changing parameters by recalculating IRR and NPV with help of sensitivity indicators and switching values.

Sensitivity indicators and switching values consist each of 2 values, towards the net present value and towards the internal rate of return. Sensitivity indicators show the percentage change in NPV and IRR with percent change of project variables. Calculating the net present value as a switching value shows the percentage change in a variable that reduces the NPV of the whole project to 0 and towards the internal rate of return shows the percentage change of a variable that reduces the IRR to cut-off rate (discount rate). Equations 7-10 show the calculation of indicator and switching values. SI1 and SI2 are sensitivity indicators to determine "towards net present value" and "internal rate of return" respectively and SV1 and SV2 are switching values.

$$Sl1 = \frac{\mathrm{NPV}_b - NPV_1}{\mathrm{NPV}_b} * \frac{X_b - X_1}{X_b} \quad \text{Equation 7}$$

$$Sl2 = \frac{\mathrm{IRR}_b - IRR_1}{\mathrm{IRR}_b - d} * \frac{X_b - X_1}{X_b} \quad \text{Equation 8}$$

$$SV1 = \frac{100 * \mathrm{NPV}_b}{\mathrm{NPV}_b - NPV_1} * \frac{X_b - X_1}{X_b} \quad \text{Equation 9}$$

$$SV2 = \frac{100 * (\mathrm{IRR}_b - d)}{\mathrm{IRR}_b - IRR_1} * \frac{X_b - X_1}{X_b} \quad \text{Equation 10}$$

Where:
X_b= value of variable in the base case
X_1= value of the variable in the sensitivity test
NPV_b= value of NPV in the base case
NPV_1= value of the variable in the sensitivity test
IRR_b= value of IRR in the base case
IRR_1 = value of the variable in the sensitivity test
d = discount rate

Note: Described steps above to carry out an economic analysis is simplified to suit the specific project *Hamro Paani.* A full economic analysis can be carried out in different ways and contain different information depending on the specific water supply system and the phase of the project. To get a better understanding of economic and financial analysis of water supply projects, reading the handbook provided by the World Bank is recommended.

3.3 Water supply systems

Water demand is increasing while water sources are depleting. This leads to water utilities shifting to water sources further away from the consumers (as the water sources are depleting regionally). At the same time the standard of drinking water quality is getting higher. All mentioned results in higher cost of water supply systems.

A water supply system consists of many parameters such as source of supply, collection system, treatment system and distribution system. Figure 7 (Ajami, 2015) illustrates the water distribution and use cycle and shows the different parameters in a water supply system. There are economic aspects related to each area in a water supply system and a complete economic analysis should ideally be carried out for all the parameters in the cycle. Figure 7 shows the general parameters included in all water supply systems, thus a modification of this model is needed to present the important parameters in the water supply system in Madi.

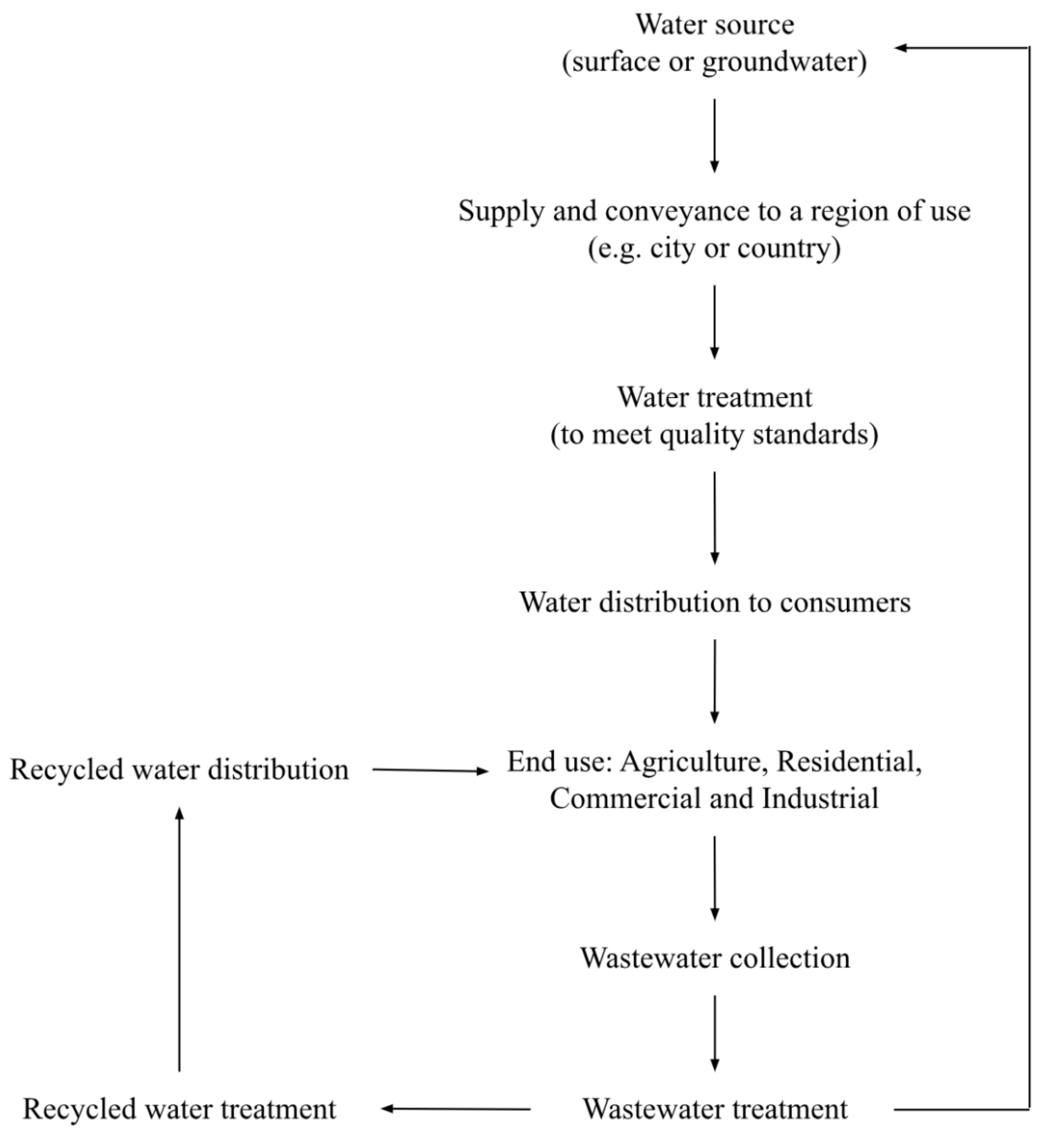

Figure 7: Illustration of water supply and use cycle for water supply systems. Inspired by a Webinar on *Economic of Water* (Ajami, 2015)

3.3.1 Water supply system in Madi and component review

The information provided in this section of the report is based on field observations, meetings with the project manager and interview with Surya Prajapati who is the engineer in charge of the project. Relevant documentation on the project has also been a source of information to this section.

There are currently 2000 people living in Madi and they get their drinking water from different sources. Some households use public water supply systems built by the government, some use wells constructed by the municipality and others collect water from shallow wells and ponds. There are in total 19 wells in the area of which 15 are irrigation wells. The government has allocated budget and resources to improve the irrigation situation in Madi by drilling many wells. However almost all of the wells are completely welded, making it difficult to control the water level and water quality. There have been several water supply projects in the area of Madi with the purpose of providing safe drinking water but they have not been successful for various reasons. Some of the main problems in the previous projects have been:

- Under-designed distribution system
- Poor execution of pipe laying and jointing and lack of technical skills
- Poor management leading to the failure of the system and not being able to generate income to maintain the system
- Lack of water awareness

Hamro Paani is a 100 % charity funded project. The project is a collaboration between *Jysk Landsbyutveckling, Grundfos, AVK holding A/S, Kamstrup* and the engineering company in charge of the project is Envidan which contributes with expertise and experience in water resource management and takes care of design, supervision and implementation of the water supply system. As mentioned in chapter 1 the project aims to provide safe drinking water for families in Madi. The system is designed for 4000 people in case of an increase in consumption and population and the designed quantity of water is 350 m^3/day.

The water supply system is a gravity flow system with pressure pumps and an overhead water tank. A borehole is constructed and water is withdrawn by a pump (information regarding the borehole and the geology in the area is presented in chapter 2, section 2.3) and stored in the overhead water tank. The water is then distributed to consumers via a 16 km long pipeline and each household gets an individual water tap. This is one of the main advantages compared to previous projects where everyone had to collect water from one common tap. The system is simpler than the general water supply system illustrated in figure 7 since there is no treatment of water and the wastewater is handled by the old system in the area. Most common sewage systems in rural areas are presented in chapter 2, section 2.1.4. Further, the water supply system is in the same area as the consumers are which simplifies the model even more. One additional parameter that is included in this specific water supply system is solar panels that are installed to provide the energy needed to run both a booster pump alongside the distribution pipeline and the pump installed in the borehole to withdraw water. Figure 8 shows the simplified version of figure 7 and presents the parameters of the groundwater supply system in Madi.

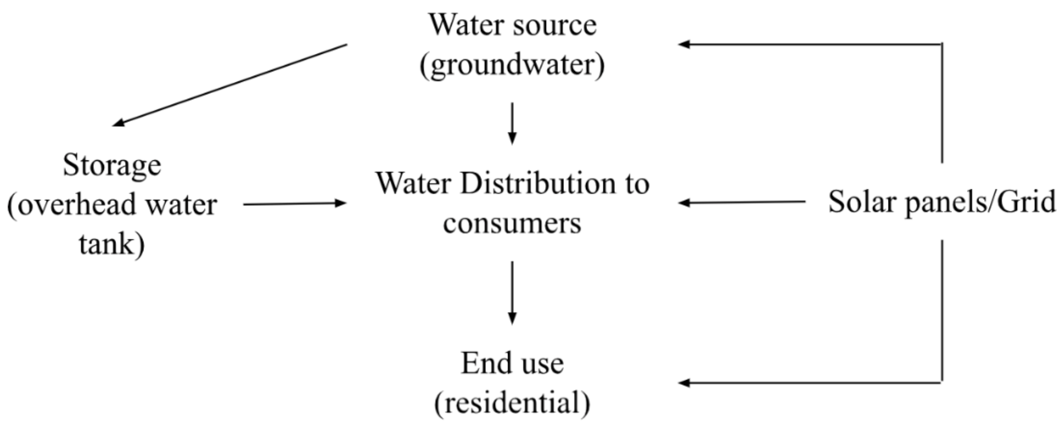

Figure 8: Illustration of the parameters included in water supply system in Madi.

There are two pumps from *Grundfos* used in this water supply system. The first one is a submersible pump which is installed in the borehole and will be operating during daytime and the second one is a multistage centrifugal surface pump that is used to maintain the pressure in the pipeline. The surface pump will be operating all the time but the capacity varies depending on the demand. Both the submersible and surface pump are driven by a combination of solar panels and electricity grid. Valves that are used in the system are provided by *AVK holding A/S* and there are smart water meters from *Kamstrup* installed to detect leakages in the system. Table 3 presents the components that are used in the system. The costs are presented in nepali rupees (NPR). The total cost of the system with the value added tax of 13 %, the economic analysis and the sensitivity analysis are presented in chapter 5, section 5.4.

Table 3: Main components and other related costs to the project.

Component	**Specification**	**Cost (million NPR)**
Overhead water tank	100 m^3	15
Pipeline	16 km	16
Number of household connection	420 pcs	5
Submersible pump	9.2 kW	0.7
Surface pump	4 kW	1
Solar PV module for submersible pump	275 W_{peak}, 90 panels	4.7
Solar PV module for surface pump	275 W_{peak}, 34 panels	1.8
Inverters	15 kW	1.4
Valves	450 pcs	7.7
Smart meters	450 pcs	6.7
Construction, staff and administration etc	-	10.5

The energy used for the system (pumps) is provided by solar panels and the electricity grid. Solar systems have seen a huge cost cut during recent years. It is however important to evaluate when a solar energy system is worth the investment. In order to carry out this valuation the total production from the solar system and the electricity cost that it saves, need to be determined. When the cost of the provided/replaced energy is calculated, the profitability of the system can be determined by comparing the cost saving with the investment cost. Another method to calculate the cost efficiency of a solar cell system is levelized cost of energy (LCOE). A simple method to calculate the LCOE is the investment cost divided by the total energy production. The calculated value can then be compared to how much a kWh electricity costs in that region of the country. However, this simplified calculation does not consider the fact that the energy output from a solar system decreases over time. This is mainly due to degradation of the system. A more accurate value of the LCOE can be calculated by equation 11, where n is the lifetime of the system and R is the discount rate. Values of discount rate and degradation of the system depend on many factors and can be project specific. Going through literature, values of 6-10 % for discount rate (BLACK and VEATCH, n.d), (I.R.E.N.A, 2021) and 0.3-0.8 % for annual degradation (N.R.E.L, n.d), (Pascual et al., 2021) seem to be reasonable.

$$LCOE = \frac{Investment\ cost + \sum_{t=1}^{n}\left(\frac{Maintenance\ cost_t}{(1+R)^t}\right) - \frac{Residual\ value}{(1+R)^t}}{\sum_{t=1}^{n}\frac{Initial\ energy\ production * (1-annual\ degradtion)^{t-1}}{(1+R)^t}} \quad \text{Equation 11}$$

As mentioned earlier in this section, one of the problems in the way of providing sustainable water supply system in Madi, has been, not generating enough income to operate the system. In this project each household pays 7000 NPR to connect to the system. 71 % of the connection fee goes to building individual water stands and 29 % is used for operation costs. In addition to the connection fee, each household pays a standard tariff for using a certain amount of water each month. The tariff is fixed and households are obligated to pay even if they use less water. If the consumption exceeds the decided amount, the tariff gets higher exponentially. Since the money is donated in this project, user chargers are set to cover only the operation and maintenance cost. User chargers (tariffs) have two main economic effects in this case. First, they provide money to operate the system and ensure optimal use of the facility. Second, they theoretically ensure optimal use of water (not overuse and not underuse by poor families) and this is valuable since overuse of water leads to wastage contributing to operational deficits and underuse results in loss of welfare to the community. In order to ensure that people pay the tariff, the water supply system is handed over to the municipality and an office (called ward office) that provides services to people will require a receipt of the latest payment to the water supply system in relation to provision of services.

4 Devices, Softwares & Methodology

4.1 TD-Diver

The TD-Diver (data logger) is a compact, groundwater monitoring instrument for continuously measuring level and temperature in groundwater, surface water and industrial waters. The collected data can be used to manage water resources, estimate hydraulic conductivity and other aquifer conditions. Some advantages of a TD-Diver are:

- A life span of 10 years, depending on use
- A working memory and a backup memory to store 72 000 measurements
- No need for the user to calibrate and test the divers since they already have been calibrated for life time

The TD-Diver is equipped with a pressure sensor, a temperature sensor and a battery that powers the electronics that take and store measurements. Once the diver is submerged at a fixed level under the water, the pressure sensor measures the absolute pressure. This means that both the water pressure at the fixed depth and the atmospheric pressure (ρ_{baro}) acting on the water surface are measured. Thus, it is necessary to know the barometric pressure at measuring points and this can be done by a barometer or downloading online data. The diver data can be extracted by a software called diver-office. Section 4.1.1 will give an insight to the diver-office. Note that if pressure obtained by the diver and the barometric pressure are not measured at the same time, then the measurements need to be interpolated. This is automatically done by the diver-office. The barometrically adjusted water values can then be related to a reference point such as the top of the monitoring well or Mean Sea Level (MSL) or any other vertical reference datum.

4.1.1 The diver-office and TD-Divers in this project

The diver-office is a software that enables connection with the divers and extracting diver data. The diver can be programmed by placing it in the USB reading unit and connecting it to a computer. After creating a new project and setting up the project properties, the diver can be programmed by clicking on the diver icon. Figure 9 illustrates the diver programming page where one can choose the sample method, time interval and monitoring point. Last step in programming the diver is to decide the time that the diver should start measuring the absolute pressure.

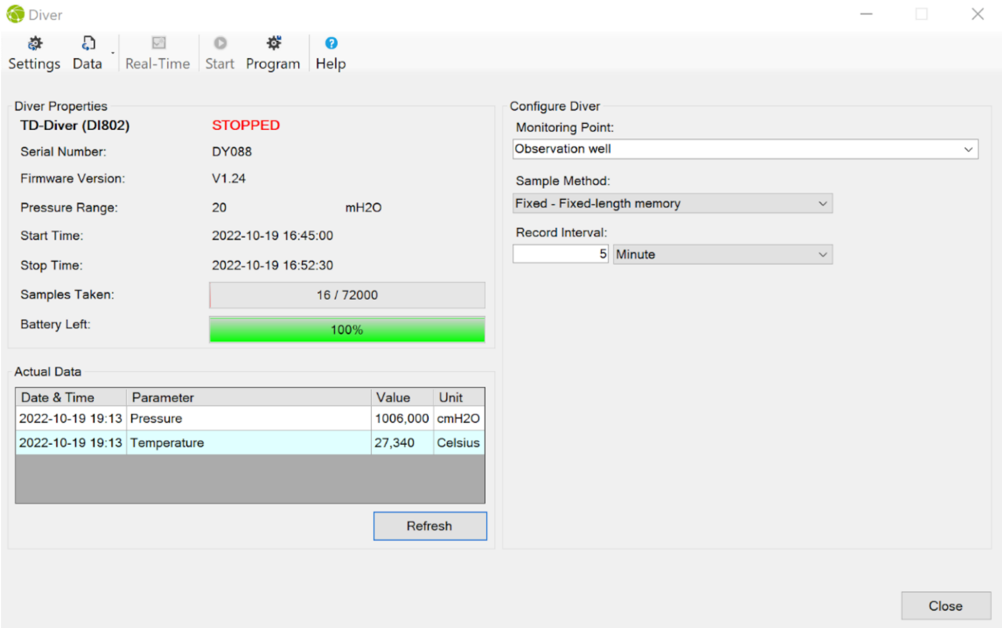

Figure 9: Showing the diver-office setup dialog. A screen shot taken from the software diver-office (Van Essen, n.d)

There are two TD-divers from VanEssen used in this project. One D1801 for the WW and one D1802 for an OW. Table 4 presents important specifications of the two divers.

Table 4: Presenting the specifications of the two divers used in this project.

Diver/ parameter	WC measurement range (mH_2O)	Pressure accuracy (cmH_2O)	Temperature accuracy (°C)	Temperature range (°C)	Display resolution (cmH_2O)	Overload pressure (mH_2O)
D1801	10	±0.5	±0.1	-20 ..+80	0.058	15
D1802	20	±1	±0.1	-20 ..+80	0.09	30

In order to use the Diver-Office software correctly, one needs to understand the relevant input data since there are many parameters that can be put into the software. Reading the user manual and looking at a short youtube video about the software can be a good idea.

4.1.2 Interpretation of data

The software that is used to analyze the data from the pumping test is *Aquifertest.* Featuring the most comprehensive set of solution methods for porous confined, unconfined and fractured aquifers, makes *Aquifertest* a favorable option for pumping test data analysis. Relevant parameters for the aquifer and the wells and the drawdown data are put into the software and a data curve is created. By choosing different solution methods, a good match with a type curve can usually be found. Once the matching type curve is found, the type of aquifer can be assessed and the characteristics are determined by the software. Different graphs such as displacement-time and distance-drawdown can be illustrated by simply choosing the type of graph from view options. *Aquifertest* is also useful for evaluation of results from other hydraulic tests like slug test and constant-head tests.

4.2 Water table meter

A water table meter is a rather simple instrument for mobile measurements of water level in groundwater wells and groundwater sites. The water meter in this project is ordered from *ROTEK A/S* and consists of a measuring probe, a measuring tape and 4*1.5 V batteries for visual signaling when the probe is in contact with water. The electronics and the visual display are compactly integrated into the cable drum and are protected against ingress of water. There is a sequential brake to regulate the speed at which the cable is lowered in wells. This feature makes the instrument practical to use in the field. The water sensor works fine even after many measurements and relatively precise readings of the water level in the wells can be done. The display resolution of the water meter is 1 cm.

4.3 Groundwater quality and chemistry

A literature study with the purpose of identifying different parameters that define groundwater quality was done before travel to Nepal. This made the communication with the laboratory easier. Sterile water samples, syringe and filters were ordered from *EUROFINS* and taken to site to collect samples of the groundwater. Both filtered and unfiltered samples were taken and analyzed to observe whether the filtration has a significant impact on the amount of for example iron and TDS or not. Samples were collected at different times during the pump test to see if any changes in groundwater composition occur.

In this case the water in the well had not been used after the construction and standing water in contact with the atmosphere and the well construction can possibly contain contamination. Therefore it is usually recommended to remove 3 or more well volumes of standing water before collecting samples for groundwater quality evaluation. Prior to pumping, the outlet of the pipe that was used to lead water downstream from the well was cleaned by alcohol wipes. A water bucket was cleaned with alcohol and water samples were collected at a certain depth in the water bucket. This was done to avoid longer contact time with the atmosphere which can affect the concentration of for example iron that can oxidize. When the pump was started, the water had a dark yellow/brownish color and this was most likely due to water standing still for a long time. It took almost 3 hours until the discharged water looked clean. Samples were then taken and sent to the nearest laboratory which lies within 50 km from the project site and it took 3 hours to drive.

To carry out a full groundwater quality assessment, the results from the laboratory analysis were compared to national drinking water standards in Nepal (Government of Nepal, 2005) and Word Health Organisation (WHO, 2011) standards. There are results from water quality evaluation (on samples collected from the same water well) done in Denmark and Kathmandu in 2020. These documents are presented in appendix 2 and are used to compare the groundwater quality with the samples collected in 2022. If there are concentrations that exceed the maximum allowable limits, the impact of these chemicals on human health will be further investigated. The comparison of groundwater analysis from the newly constructed well in Madi and safe drinking water standards is presented in chapter 5, section 5.1.

With the purpose of analyzing the groundwater chemistry and understanding the dominating chemical processes, graphical analysis such as a Piper diagram, a Gibbs diagram and a bar chart (to study the ion charge balance) were designed. Furthermore molar ratios of major ions were calculated to determine the main sources (chemical reactions) to existing minerals in the groundwater in the project area. Chapter 2, section 2.1.3 is dedicated to these methods. To study the groundwater chemistry, observed values from the sample sent to Danmark are used since the concentration of all the major ions are determined unlike the samples analyzed in Nepal.

4.4 Hydraulic test

The hydraulic test carried out in this project was a pump test with a constant discharge rate at 12.4 l/s. In order to get a better understanding of the natural water level change in the area, the water level in the WW and 4 OWs at different directions and distances from the WW was measured some days prior to the pump test. This was done by the water table meter and the groundwater level in the wells together with the time of the measurements was noted. Figure 10 illustrates the position of the water well and the observation wells in the project area. The blue mark shows the WW and the red marks are the OWs. The elevation (above sea level) is shown next to each well. Table 5 presents information about all the wells in this study. People who use the located OWs in the area were notified about the pumping test and were asked to not pump water. This was done since pumping at near wells can affect the water level in the WW.

Table 5: Information about the wells in this study.

Well/Parameter	Diameter (cm)	Distance to WW (m)	Elevation (m, a.s.l)	Depth of well (m)	Height of well (Above ground level, cm)
WW	25.4	-	223.32	100	82
OW01	15.24	180	224.55	unknown	44
OW02	21.2	500	216	unknown	81
OW03	22.86	230	229.5	80	119.5
OW04	30.48	670	213.55	unknown	29

Figure 10: The position of the water well and observation wells. North is upwards in the figure. This figure was created on Google Earth.

The pump was installed at the depth of 30 m in the WW and the diver was placed at 25.5 m (about 5 m above the pump to prevent the diver from getting affected by the turbulence created by the pump). Prior to starting the pump, a pipe was installed to lead the discharged water away from the WW. The discharged water was led approximately 200 m away from the WW to prevent it from infiltrating back into the ground and entering the aquifer. The discharge rate was measured by filling a bucket with known volume and noting the time it took to fill up the bucket. The determined discharge rate was assumed to be constant throughout the entire test. The pumping test was carried out for 10 days with a constant discharge rate. The time interval for measurements in the WW was set to 5 seconds for the first 4 hours and then 10 minutes for the rest of the period. The second diver was placed in the closest observation well from the WW at a depth of 26.4 m, OW01 in figure 10. The time interval for the first 4 hours was set to 2 minutes and then was changed to 15 minutes. The reason to have a short time interval in the beginning of a pumping test is the rapid development of the cone of depression. During the pump test, the water level in all the wells were measured manually. The observation well (OW 04) farthest from the WW was used irregularly for another water project in the area. This made it difficult to predict whether the change in the water level was due to pumping in the WW or pumping in the OW 04 itself. Thus the OW 04 was excluded from this study.

After 10 days the pump was shut down and the recovery period was started. After 5 days, the water level was stable and manual measurements with the water table meter were done for another 5 day-period. During the pumping - and recovery test the divers were pulled up to change the time interval for measurements and the data were downloaded using the Diver-Office. The downloaded data from both the WW and OW 01 showed sudden jumps in the hydraulic head at different times during the days. Most likely the sudden increase in hydraulic head was a result of power outage in the area. The data was then manipulated to minimize the effect of power outages.

The software *Aquifertest* was used to analyze the drawdown data from all the wells (the water well and 3 observation wells). A time-drawdown graph was created and the data curve was matched with different type curves to find the best fitting-method. After the best fitting-method was identified the aquifer characteristics were determined. Transmissivity was determined by analyzing the late drawdown data from the WW and storativity was determined by analyzing the drawdown and recovery at observation wells. A graph with the drawdown and recovery data for all the wells were plotted against time to double check that the wells are connected to the same aquifer and the determined parameters are valid and representative for the entire aquifer.

A step-drawdown test had already been performed when the borehole was constructed. The results from the pump test were then compared with the results obtained from the step-drawdown test and the performance of the well was analyzed. The data obtained from the step-drawdown test are presented in appendix 3.

4.5 Economic analysis

Last but not least, an economic analysis of the water supply project in Madi was done to check the financial viability of the project. First a literature review on economic analysis of water supply systems was done and then the water supply system in Madi was analyzed. The literature review is described in chapter 3. After going through documents regarding the components and costs of the project, the total investment cost (CAPEX) was put together. The operation and maintenance cost (OPEX) of the system was determined as a percentage of the CAPEX. Based on the calculated OPEX, a monthly water tariff that covers the OPEX was calculated. As mentioned in section 3.3.1 the water tariff in this case (base case) is meant to cover only the operation costs related to the system and the investment cost is a donation.

It can not be assumed that investment costs for future water supply projects in rural areas will be in the form of a donation and therefore two cases (A and B) where the project needs a loan and one scenario (C) where the population is increased were formed. There are a set of assumptions that are included in cases A and B, which are following:

- Calculated CAPEX for the base case is used.
- OPEX is determined on the basis of 1.135 % of the calculated CAPEX. To calculate the total OPEX per month, physical contingency of 8 % and taxes and duties of 7 % are added. These percentage rates are provided as reasonable value for groundwater water supply system in the handbook of economic analysis used in chapter 3.
- The lifetime of the water supply system is set to 50 years.

- Number of households in Madi are 450 and the numbers connected to the system are 400.
- Return term for the loans are: 20 years with monthly payments.
- The inflation rate is set to 2 % per year.
- Connection fee that each household must pay is 7 000 NPR.

Case A
In case A, 80 % of the CAPEX is a loan from a national bank and 20 % is a donation. This case is divided into two alternatives depending on the interest rate. In the first alternative (A1), the interest rate is at 4 % and in the second alternative (A2) the interest rate is 6 %. Results from this case study are presented in table 14 in section 5.4 and include, the net present value, return on equity and the water tariff that each household should pay.

Case B
In case B, 80 % of the CAPEX is a loan from a national bank and 20 % is a loan from a private investor. Since private investors usually loan money with a higher interest rate, two alternatives B1 and B2 with interest rates of 10 % and 12 % respectively are formed. For the loan from the bank 4 % interest rate is used in this case. Results are shown in table 15 in section 5.4 and include total net present value, return on equity for the 20 % borrowed money from a private investor and the 80 % from a national bank and the total water tariff.

Case C
In case C, main assumptions listed above are used but the number of households that are connected to the system is increased to 900. This is done since the water supply system in Madi is designed for double the population that are currently living in the area. Further the investment cost is increased by 5 million NPR to build individual connections for all the households. This case is divided into three alternatives. In the first alternative (C1), 80 % of the CAPEX is a loan from a national bank with 4 % interest rate and the rest is a loan from a private investor with 12 % interest rate. In the second and third alternatives (C2 and C3), the total investment cost is covered by a loan from the government with an interest rate of 6 % and the number of households is 400 and 900 respectively. Results from this case are presented in two separate tables in section 5.4.

In the last part of the economic analysis, the economic value of the installed solar panels will be analyzed in two aspects. The first aspect is related to the investment cost of the solar panels. This analysis is done by comparing two options. The costs to operate the system with a combination of solar panels and electricity will be compared to costs for operation by electricity grid alone. This will be done by accumulating the costs for the two options over the lifetime of the solar panels which is considered to be 20 years in this case. From this analysis it can be concluded whether investment in solar panels is economically beneficial or not. The second aspect is related to the LCOE. LCOE of the solar system is calculated with both the simple and complicated equation presented in chapter 3, section 3.3.1. The discount rate is set to 6 % and the annual degradation of the system is set to 0.5 %. The calculated LCOE is compared to the energy fee in Madi which is 7.2 NPR/kWh.

Note: All calculations for the economic analysis with input data are in an excel file that will be handed in along with the report.

5 Results

5.1 Groundwater Quality assessment

Table 6 presents the observed values for physical, chemical and biological parameters of 4 groundwater samples collected from the WW and analyzed in 2022 in the laboratory in a city (Bharatpur) close to the project area. The observed values from all the samples (Filtered and unfiltered) are similar to each other, thus a mean value is calculated and presented in this table. Observed values for each sample are shown in table A4 in appendix 4. Safe drinking water standards according to the Nepal standard (NDWQS, 2062 BS) and WHO are also presented in table 6. Table 7 presents the results from water quality analysis in Denmark and Kathmandu which were carried out by collecting samples from the same WW in 2020 and the latest analysis done in 2022 is also repeated in this table for easier comparison.

Table 6: Mean observed values from the water quality evaluation done in 2022 and drinking water standards in Nepal and Europa.

Parameter	Observed values (Bharatpur, 2022)	NDWQS, 2062 BS	World Health Organisation (WHO)
Turbidity (NTU)	0.2	5	5
pH	7.57	6.5-8.5	6.5-8.5
TDS (mg/L)	333	1000	1000
Electrical conductivity (µS/cm)	501	1500	400
Iron (mg/L)	<0.2	0.3	0.3
Manganese (mg/L)	<0.1	0.2	0.08
Arsenic (mg/L)	<0.01	0.05	0.01
Ammonia (mg/L)	<0.1	1.5	1.5
Nitrate (mg/L)	3	50	10

Calcium (mg/L)	40.4	-	200
Magnesium (mg/L)	22.94	-	150
Total Hardness (mg/L as $CaCO_3$)	195	500	300
Calcium Hardness (mg/L)	101	200	
Residual Chlorine (mg/L)	-	0.1-0.2	
Fecal coliform E.coli	0	0	0

Table 7: Observed values from the quality analysis done in Denmark, Kathmandu and Bharatpur.

Parameter/Result from laboratory	**Denmark (2020)**	**Kathmandu (2020)**	**Bharatpur (2022)**
Ammonium (mg/L)	0.062	<0.1	<0.1
Nitrite (mg/L)	0.019	-	-
Nitrate (mg/L)	4.8	5.8	3
Total phosphorus (mg/L)	<0.01	-	-
Chloride (mg/L)	3	-	-
Fluoride (mg/L)	0.28	-	-
Sulfate (mg/L)	6.2	-	-
Arsenic (mg/L)	0.0004	<0.01	<0.01
Barium (µg/L)	12	-	-
Bor (µg/L)	1.7	-	-
Calcium (mg/L)	79	44	40.4
Cobolt (µg/L)	0.61	-	-
Iron (mg/L)	0.25	<0.2	<0.2
Potassium (mg/L)	1.3	-	-
Magnesium (mg/L)	16	12.7	22.9
Manganese (mg/L)	0.058	<0.1	<0.1

Sodium (mg/L)	6.2	-	-
Nickel (µg/L)	0.99	-	-
Bicarbonate (mg/L)	304	-	-

In accordance with table 6, turbidity, TDS, iron, arsenic, ammonia, nitrate, calcium, magnesium, total hardness and calcium hardness values are lower than the maximum limit from NDWQS and WHO. According to table 1 in section 2.1, the water is moderately hard. The pH value lies within the acceptable range for drinking water (see chapter 2, section 2.1, *chemical parameters*). Electrical conductivity is a bit higher than WHO standard. However values up to 800 µS/cm are acceptable for human consumption (Water quality standards, n.d.). One explanation for WHO having a limit as low as 300 µS/cm can be that they have taken irrigation into account. Salt sensitive plants can be harmed by conductivity values higher than 400 µS/cm. According to the classification of groundwater based on electrical conductivity value (fresh: <1500µS/cm; brackish: 1500–3000µS/cm; saline: >3000µS/cm) (Saxena et al., 2003), all the samples show an indication of fresh groundwater. The detection limit of manganese is 0.1 mg/L which is ok for NDWQS standard. The recommended value according to WHO is 0.08 mg/L which is lower than the detection limit and this makes it hard to determine whether the manganese concentration is in line with WHO standard or not. In drinking water guidelines from *Minnesota Department Of Health* (MDH) the acceptable amount of manganese for children younger than 1 year is less than 0.1 mg/L and 0.3 mg/L for older people (Minnesota Department of Health, 2021).

Almost all of the observed values in 2020 from quality analysis in Denmark and Kathmandu (presented in table 7) are in the same range of intervals as the newly collected samples. Concentrations that differ are calcium and iron. The observed value for calcium concentration in the sample tested in Denmark is 79 mg/L compared to 40-44 mg/L that was observed in the other two laboratories. However 79 mg/L is still lower than the NDWQS standard. According to the Swedish drinking water standard for 2022 (Livsmedelsverket, 2022) the maximum allowable amount of calcium should not exceed 100 mg/L which indicates that the concentration of calcium in the groundwater in Madi lies within the limits of European standards. Detected iron concentration in the laboratory in Denmark is 0.25 mg/L compared to <0.2 mg/L that has been observed in the other two laboratories. This value exists within NDWQS and WHO standard but is higher than the standard in Sweden (accepted value is 0.2 mg/L). Having said that, a higher amount of iron ions at this level does not have any effect on human health at all. High amounts of iron can lead to corrosion in the pipes and affect the aesthetic values, changing the color of the water. Nevertheless the water does not taste or smell iron (Based on drinking the water in the field).

5.2 Groundwater chemistry

Figure 11 together with table 8 below show the results of ion charge balance analysis. As it can be seen, the sum of anions is lower than the cations. This can be due to inaccurate measurements in the laboratory or that some anion has been left out from the analysis. However, the charge balance error is 2.63 % which indicates that the result from the laboratory analysis is reliable. The positive sign of the calculated charge balance error shows that the sum of cations is higher in the analyzed sample.

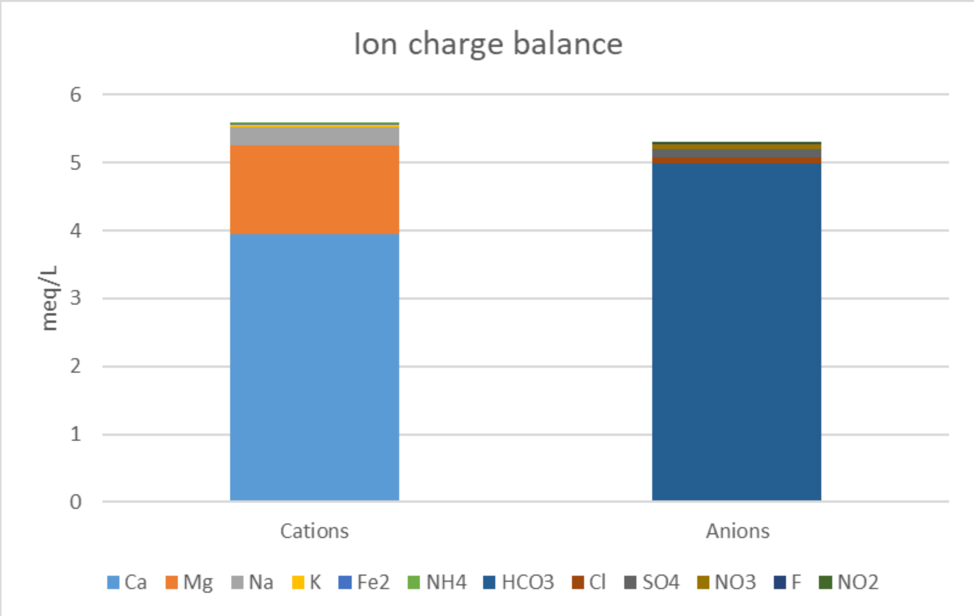

Figure 11: A bar chart of the ion charge balance of the sample from 2020 analyzed in Denmark.

Table 8: Result of bar chart analysis in a table with calculated charge balance error.

Sum of cations (meq/L)	**Sum of anions (meq/L)**	**Total dissolved solids (mg/L)**	**Charge balance error %**
5.6	5.3	421	2.63

Figure 12 shows the piper diagram regarding the samples taken in 2020 and analyzed in Denmark. The blue circle presents the sample. Looking at the figure 1 and 2 in chapter 2, section 2.1.3 it can be concluded that the character of the facies of the water is in region Mg/Ca-HCO_3 which is typical for shallow and fresh groundwater. Further the results suggest that the analyzed water is alkaline in nature. The concentrations in mg/L are presented at the top left of the figure.

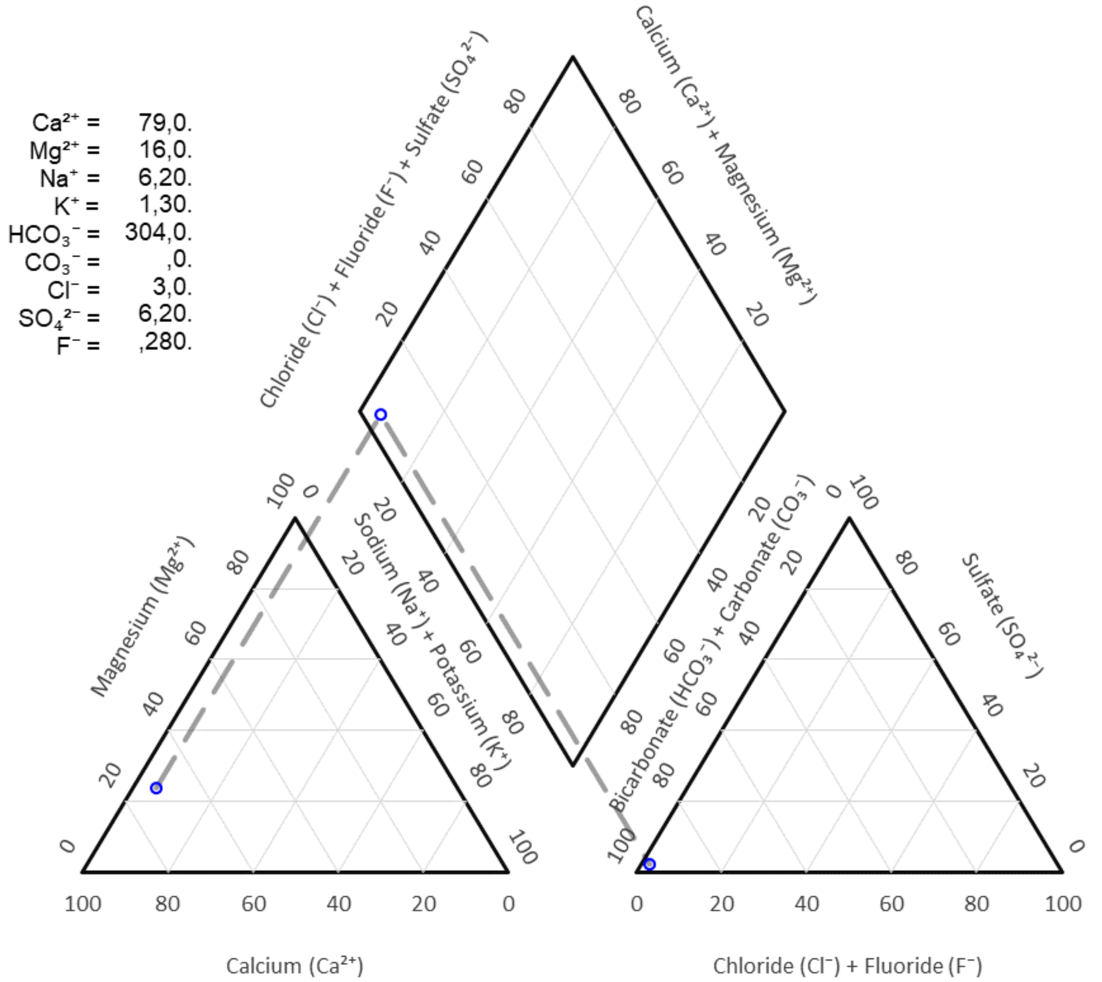

Figure 12: Piper plot for samples collected in 2020 and analyzed in Denmark. The blue circle presents the sample.

Figure 13 illustrates Gibbs diagram. As it can be seen the major process controlling the groundwater chemistry is mostly rock-water interaction but evaporation has also an impact.

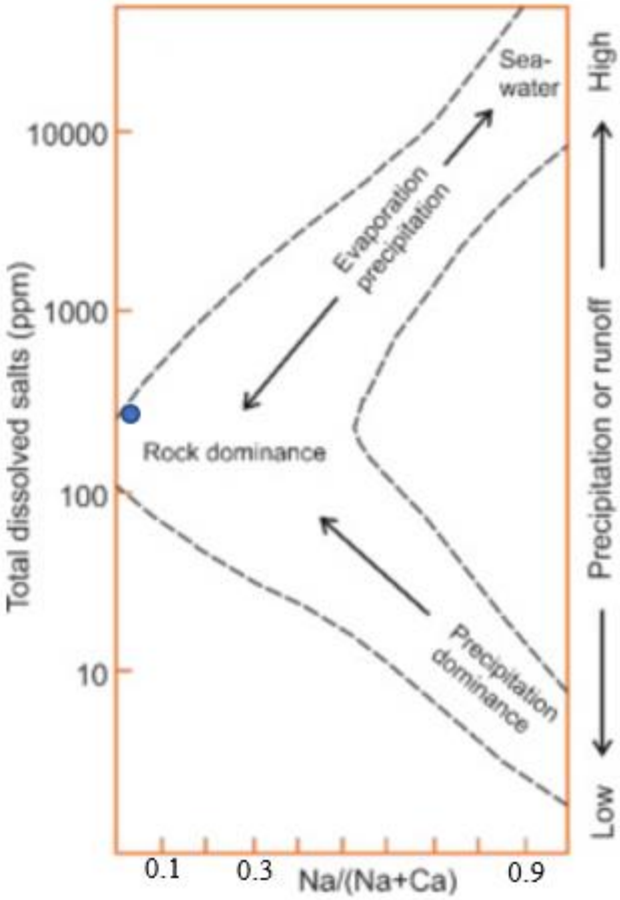

Figure 13: Gibbs diagram for samples collected in the WW in 2020 and analyzed in Denmark.

Tabel 9 presents molar ratios of major ions that can be used to determine the major controlling processes of groundwater quality. The ratio of Na^+/Cl^- is greater than 1 which indicates that the sodium is mainly contributed by silicate weathering. This is reasonable since an important source of sodium in deep groundwater is weathering of silicate minerals. The molar ratio of $(Ca^{2+} + Mg^{2+})/ HCO_3^-$ is close to 0.5 which makes it likely that dissolution of carbonate is contributing to calcium and magnesium content. The ratio of $(Ca^{2+} + Mg^{2+})/(HCO_3^- + SO_4^{2-})$ is less than 1 indicating that the mineralization process, cation-exchange is occurring in the groundwater.

Table 9: Molar ratios of major ions in groundwater chemistry in the WW.

Molar ratio	Na^+/Cl^-	$(Ca^{2+} + Mg^{2+})/ HCO_3^-$	$(Ca^{2+} + Mg^{2+})/ (HCO_3^- + SO_4^{2-})$
Calculated value	2.07	0.31	0.31

5.3 Hydrology and hydrogeology

Figure 14 displays drawdown and recovery data obtained from manual measurement using the water table meter in all wells. The y-axis is logarithmic to facilitate comparison between the wells. Figure 15 illustrates raw drawdown and recovery data obtained by divers in the WW and OW01 and manual measurement in the other wells.

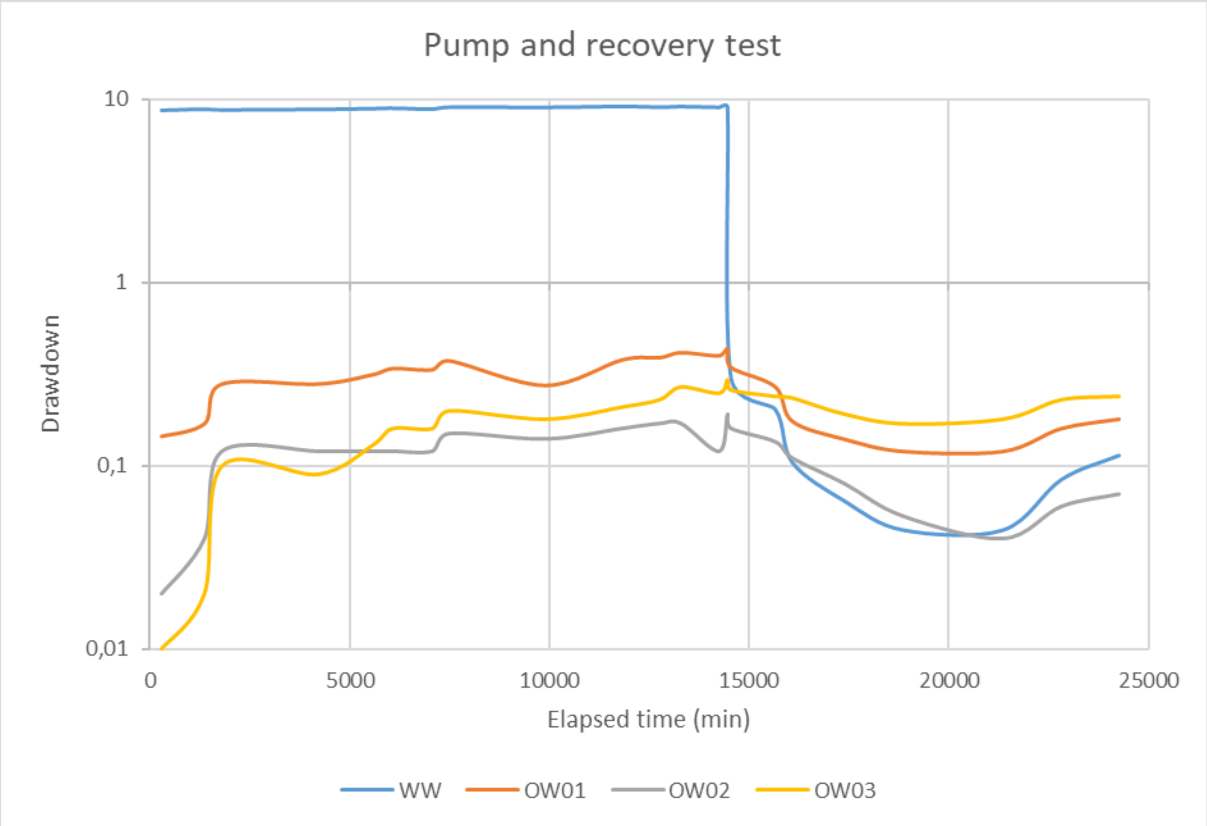

Figure 14: Drawdown and recovery data from manual measurements in all the wells. The pump is stopped before 14600 minutes of operation.

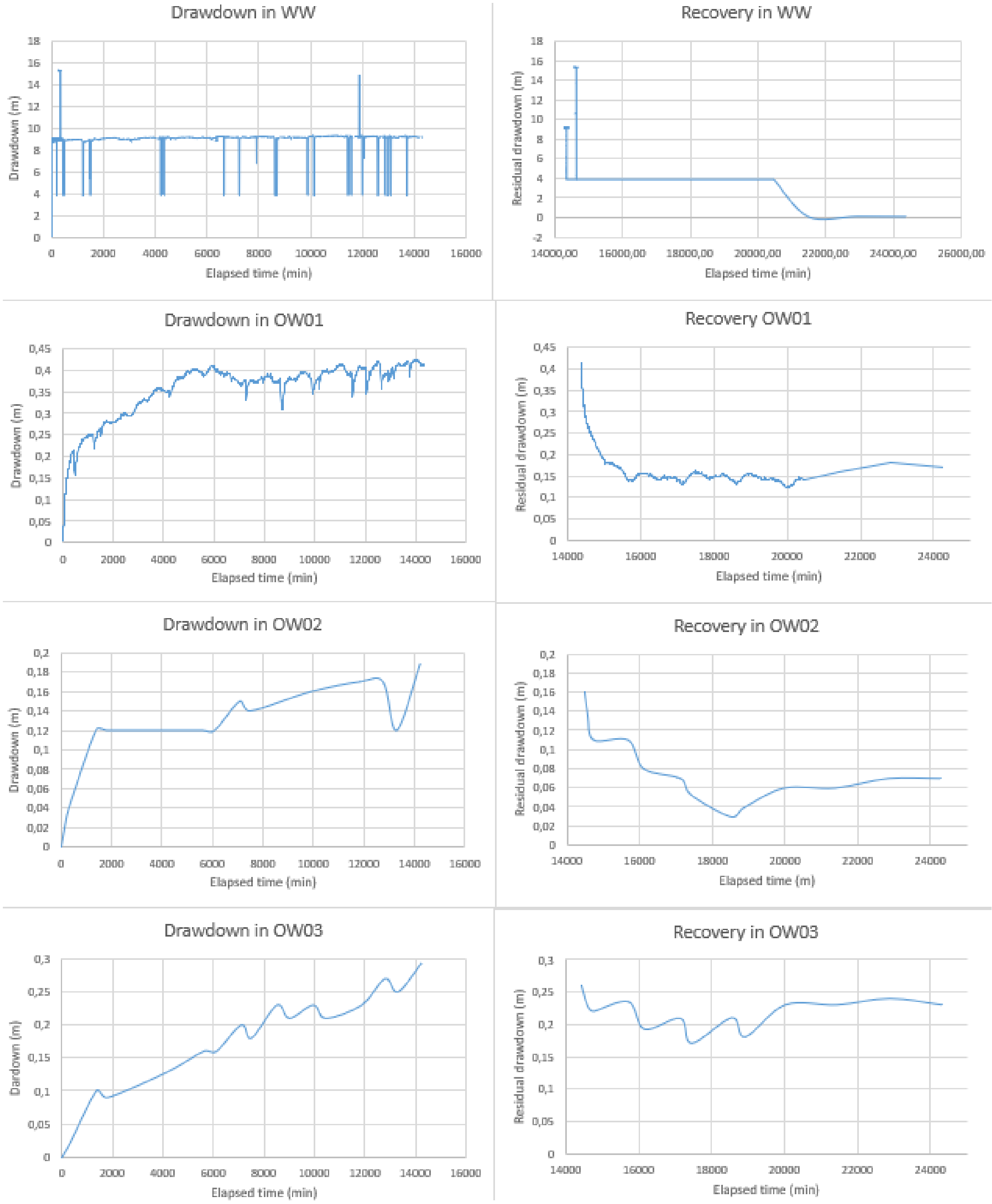

Figure 15: Drawdown and recovery data in all the wells. The raw data for WW and OW01 is obtained by divers.

Table 10 presents the results of the step-drawdown test conducted in 2020 during the construction of the WW. Table 11 presents the aquifer characteristics determined from the pump test carried out in 2022. The Neuman type curve was used as the best curve-fitting method to evaluate the pump test data in AquiferTest. Type-curve matching done in AquiferTest is shown in appendix 6. Lastly, table 12 presents the storativity values obtained from analyzing the drawdown and recovery data in the observation wells.

Table 10: Results from the step-drawdown test performed in 2020 in the WW, before the rainy season in Nepal.

Parameter	**Static water level** (m below ground surface)	**Dynamic water level** (m below ground surface)	**T** (m^2/s)	**K** (m/s)
Value	15.10	25.32	$1.83 * 10^{-3}$	$1.2 * 10^{-4}$

Table 11: Aquifer characteristics determined by analyzing the pump test data conducted in 2022 in the WW, after the rainy season in Nepal.

Parameter	**Static water level** (m below ground surface)	**Dynamic water level** (m below ground surface)	**T** (m^2/s)	**K** (m/s)
Value	10.05	19.3	$6.12 * 10^{-3}$	$4.1 * 10^{-4}$

Table 12: Obtained values for storativity by analyzing drawdown and recovery data in observation wells.

Well/value	**Storativity**
OW01	$7.9 * 10^{-2}$
OWO2	$1.15 * 10^{-3}$
OW03	$1.67 * 10^{-1}$

5.4 Economic analysis

Table 13 presents the total investment cost (CAPEX) and operation and maintenance cost (OPEX) for the water supply system in Madi. The calculated water tariff to cover the operation cost of the system is also presented in the following table.

Table 13: Total investment cost, operation cost and water tariff that each household should pay per month.

Total investment (M NPR)	Operation and maintenance (M NPR/year)	Water tariff (NPR/month)
7.8	1	214

Table 14-17 present the results for Cases A, B and C. Relevant assumptions and what each case represents is described in chapter 4, section 4.5.

Table 14: Financial parameters in case A with 80 % loan from a national bank.

Case/Financial parameter	Net present value (NPR/month)	Return on equity (%)	Water tariff (NPR/month)
Case A1 **4 % interest rate**	321 000	3.1	1044
Case A2 **6 % interest rate**	383 000	3.7	1201

Table 15: Financial parameters in case B with 80 % loan from a national bank with 4 % interest rate and 20 % loan from private investors.

Case/Financial parameter	Net present value (NPR/month)	Return on equity Private loan (%)	Return on equity Bank loan (%)	Water tariff (NPR/month)
Case B1 **10 % interest rate**	451 000	5.2	3.1	1371
Case B2 **12 % interest rate**	472 000	6	3.1	1421

Table 16: Financial parameters in the first alternative of case C with doubled population and increase in CAPEX. The interest rate for the bank and private loan are 4 % and 12 % respectively.

Case/Financial parameter	Net present value (NPR/month)	Return on equity Bank loan (%)	Return on equity Private loan (%)	Water tariff (NPR/month)
Case C1 **900 households**	502 000	3.1	6.2	672

Table 17: Financial parameters in the two last alternatives of case C with a loan from the government with 6 % interest rate.

Case/Financial parameter	Net present value (NPR/month)	Return on equity (%)	Water tariff (NPR/month)
Case C2 400 households	478 000	3.67	1438
Caes C3 900 households	484 000	3.72	639

5.4.1 Energy calculation

Figures 16 and 17 illustrate the accumulative cost of running the system with solar panels together with grid versus grid only. Figure 16 shows the cost comparison for the solar system that is used to provide energy for the surface pump and figure 17 shows the cost comparison for the solar system providing energy for the submersible pump in the borehole. The green line represents the cost for the solar system each year and the blue line represents the grid system. As it can be seen it takes 15 years and 17 years for the solar system that provides electricity for the surface and submersible pump respectively to be cost competitive compared to the electricity grid.

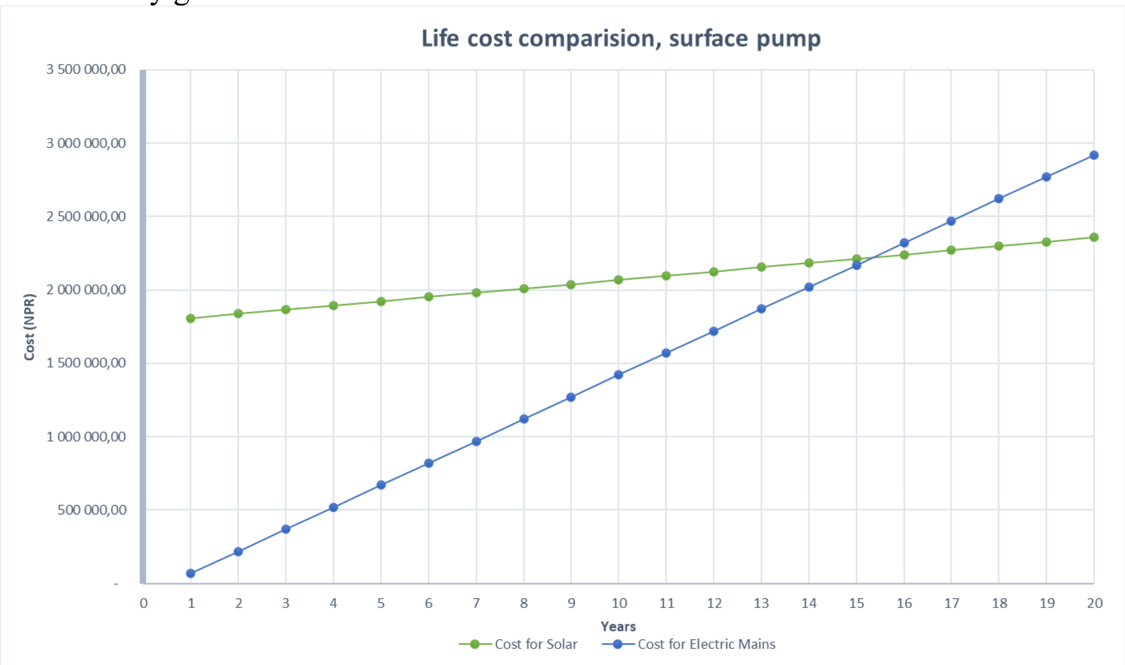

Figure 16: Accumulative cost for the solar system versus grid over the lifetime of the solar system.

Figure 17: Accumulative cost for the solar system versus grid over the lifetime of the solar system.

Table 18 presents the energy fee in Madi and levelized cost of energy for the solar system in two aspects: neglecting and taking the degradation of the system into account.

Table 18: Levelized cost of the solar systems and the energy fee in Madi.

Energy fee (NPR/kWh)	**LCOE (NPR/kWh) Surface, Degradation neglected**	**LCOE (NPR/kWh) Submersible, Degradation neglected**	**LCOE (NPR/kWh) Surface pump, Degradation**	**LCOE (NPR/kWh) Submersible, Degradation**
7.2	5.4	5.8	10.5	11.2

6 Discussion

6.1 groundwater quality and chemistry

Based on the all laboratory analysis on groundwater quality from the same water well, 4 samples analyzed in Bharatpur in 2022, 2 samples analyzed in 2020 in Denmark and Kathmandu respectively, the water pumped from the aquifer in the project area in Madi, is safe to drink and there is no need for water treatment. There are however many parameters such as transportation time, procedure of sample collection and analysis and exposure to the atmosphere that might have affected the collected water samples.

Transportation time is one of the important factors that can have an impact on water composition. The time gap between collection of samples, taken in 2020 and reaching the laboratory in Kathmandu and Denmark was 36 hours and two weeks respectively. Samples collected in 2022 reached the laboratory in Bharatpur within 4 hours. Concentration of components such as iron and nitrite can change during time. Contact with air leads to oxidation of iron and reduction of nitrite. Another parameter that can be affected by the time gap is alkalinity and given enough time, the bicarbonate concentration can change due to precipitation of carbonate materials. Other parameters that can change the composition in the samples are pressure change and exposure to atmospheric oxygen and carbon dioxide. The pressure can change while the water is withdrawn from the aquifer by the pump and the water can be exposed to atmospheric oxygen and carbon dioxide. This will change pH, Eh and the chemical equilibrium conditions of the water. pH should ideally be measured directly after taking the sample in the field. Letting the sample be in contact with the atmosphere will result in a lower pH value. This is described in chapter 2. Section 2.1.1. All being said, it is always better to analyze the samples quickly after collecting them and if there is delay in analysis, the samples can be preserved in preservatives and kept at an appropriate temperature. There were no preservatives in this case and the samples were stored in a refrigerator until they were transported to the laboratory.

One point worth discussing is the fact that the detected iron concentration in the laboratory in Denmark was higher than the one detected in Nepal. Two possible explanations can be the fact that the samples in 2020 were collected during cleaning of the newly constructed well and they were not filtered. The compressor that was used during drilling caused strong aeration which might have loosen particles from inside of the well. Though, it would have been expected that the results from analysis in Kathmandu showed similar results and this is not the case. The detected amount of iron concentration is lower in all the samples analyzed in Nepal compared to Denmark. Since the difference is small and iron at that concentration can not cause any health problems to humans, there is no need for further investigation at the writing moment.

The charge balance error of the ions is less than 5 % but there can still be errors in evaluating the concentration of ions in the laboratory. Anionic errors can cancel out cationic errors. The carried out methods for determination of physical, chemical and biological parameters of the collected samples are known but the accuracy of the procedures is unknown.

All the aforesaid parameters lead to the question whether the obtained results in the groundwater quality assessment are reliable or not. The answer is yes. Because, in addition to six results being analyzed in this report, the groundwater quality from other wells in the area that are most likely connected to the same aquifer had been analyzed before and all the samples have shown similar results.

6.2 Hydrology & hydrogeology

Observing Figures 14 and 15 in Chapter 5, it can be observed that all the wells are interconnected to the same aquifer as the water level in all of them changes due to pumping in the WW. The first two graphs in Figure 15 show the raw data for drawdown and recovery in the WW. It can be seen that the drawdown in the WW changes rapidly once the pump is started; however, there are sudden jumps in the data. Sudden increase in the drawdown occurred when the diver was pulled out to upload the data and change the time step. Additionally, there are many instantaneous decreases in the graph, which are due to blackouts in the grid that occurred almost every day. These blackouts influenced the drawdown in OW01, which can be seen in the drawdown OW01 graph in Figure 15. However, this effect can not be observed in OW02 and OW03, which is reasonable since they are further away from the WW (500 m and 230 m, respectively). The recovery data of the WW appears unusual since it reaches steady state quickly and maintains a constant value for an extended period. During the recovery test, the well was utilized periodically during the day to fill up tanks for both construction work and people residing at the construction site. The adjustment of the pipe to withdraw water might have affected the diver in some way. Due to the anomalous appearance of the WW's recovery data, it was not used to establish the aquifer's characteristics. It's worth noting that the second decrease in the WW's recovery data was obtained through manual measurements and not from the diver's data.

Figure 14 illustrates the drawdown and recovery data obtained from manual measurements, indicating that all the observation wells respond to pumping in the WW. Nevertheless, the drawdown in the OWs is considerably smaller in comparison to that in the WW. This supports the assumption, based on lithology, that the aquifer of interest is unconfined. In unconfined aquifers, wells farther away from the pumping well do usually not exhibit a significant decrease and increase in drawdown during pumping and recovery. Conversely, if the aquifer was confined, the change in the OWs would be more prominent since water is under relatively high pressure and released from elastic storage in the aquifer, and the cone of depression develops more quickly laterally in a confined aquifer. Moreover, it is evident that the water level in the WW and OWs did not return to the static level. Tables 10 and 11 indicate a 5 m difference in the static water level in the WW before and after the rainy season (known as the Monsoon period). Therefore, not reaching the original static level in the observation wells may be attributable to natural seasonal variation in the water level in the aquifer.

Table 10 and 11 in section 5.3 shows the hydraulic properties of the aquifer. Obtained values of T and K from the step-drawdown and pump test are in the same order of magnitude which shows the reliability of the results. High values of hydraulic conductivity and permeability prove that there is a good potential for groundwater extraction in that location. When it comes to determining the storativity of the aquifer, OW02 displays a value that is very low for an unconfined aquifer (see table 12 in section 5.3). The storativity values obtained from OW01 and OW03 are 0.079 and 0.2, respectively, which fall within the normal range of storativity values (0.01-0.3) for unconfined aquifers mentioned in chapter 2, section 2.2.3. It is common to observe variation in storativity and transmissivity for large, unconfined aquifers. OW02 shows a lower storativity value, most likely due to the well being located 500 m away from the WW and having limited data on drawdown and recovery. Therefore, it can be concluded that the most representative values for storativity of the aquifer are the ones obtained from OW01 and OW03.

There are several parameters that may have affected the characteristics of the aquifer obtained from the pump test. Firstly, the discharge rate was measured by filling a bucket with a known volume and taking time, which is less precise than using a valve and a meter to measure discharge. Additionally, the discharge rate was measured only once during the pump test, and although the pump was operating at a constant speed, variations in discharge rate could have occurred. When analyzing the pumping test data, it is assumed that the aquifer is completely homogeneous, but this conceptualization is far from reality. Assumptions such as uniformity of aquifer properties and steady-state flow conditions may not be completely accurate, leading to inaccurate estimations of hydraulic properties. However, the results obtained are reasonable considering the geology of the area, type of the aquifer and the lithology at the well location.

One interesting point to discuss is the screen placement in the well. As the lithology indicates, the ground consists of sand, gravel, pebbles and cobbles after 20 m, which suggests potential for groundwater extraction. One argument for drilling deeper could be that shallow groundwater may contain contaminants, and ideally, shallow and deep groundwater should not be mixed. However, in this case, there are no confining layers separating the shallow and deep groundwater, and from a hydrologic point of view, it is possible that water could be extracted at a depth of 20 m already.

As discussed earlier, steady state was reached quickly after the pump test began, and the same applies to the recovery test. The aquifer responds rapidly to water withdrawal and recovers quickly as well. It could be assumed that one week of pump test and recovery would have been sufficient. The longer the pumping test continues, the higher the cost, as discharged water has an economic value, and the pump consumes electricity. The economic value of groundwater in this case is discussed in the next section. While it's essential to optimize the duration of the pump test, the cost of pumping for a few extra days is not significant compared to the overall cost of the test. Besides, extending the pumping duration increases the reliability of determining boundary conditions since the cone of depression expands further into the aquifer.

6.3 Economic analysis

The new water supply system in Madi distinguishes itself from previous projects by using modern technology and high quality components and aims to build a sustainable system. As mentioned in chapter 3, one important aspect in sustainability is financial viability. The fact that this project is fully funded by donations, raises the question, if similar water supply projects can be built in other rural areas or is this a one-time project.

As presented in table 13 in section 5.4, to cover the cost of operating and maintaining the water supply system in Madi, the water tariff for each household should be set to 214

NPR/month. This water tariff is affordable for most households in the area. However, the income of most people in a rural area like Madi is variable and depends on factors such as weather conditions, health conditions of the family, and the local economy. In some cases, especially in rural areas, people can afford to pay for clean water but they view water as a free and unlimited resource, and therefore, the willingness to pay is not high. One reason for this can be a lack of education about water quality and its importance in the overall health of humans. Through my interviews with local people, I discovered that many are not aware that water can have good aesthetic values but be contaminated, causing serious health problems. Ensuring that people have basic knowledge about water quality and health risks will improve their life-standard, increase the net benefit of water supply projects and reduce the risk for investors.

In case A, where 80 % of the initial investment costs of the project are covered by a loan from a bank (table 14 in section 5.4), the water tariff ranges from 1044-1201 NPR/month, depending on the interest rate of the loan. The ROE for the investment is 3.1-3.7 %, which, according to the *Handbook for the Economic Analysis of Water Supply Projects* (presented in chapter 3), is lower than what a bank would require. The water tariff in this case is high for rural areas and another challenge is financing the remaining 20 % of the project costs. Two options can be, collecting money from the community or finding a donator. Collecting money from the community assumes good economic conditions, which is not realistic in rural areas, and finding an investor who is willing to fund the project can be difficult.

In case B, where the remaining 20 % of the CAPEX is financed by a private loan with 10-12 % interest rate, the NPV for the whole project increases, but so does the water tariff (see table 15 in section 5.4). The water tariff ranges from 1371-1421 NPR/month which is generally considered too high for water services in Nepal. The ROE for the private investment is 5.2-6 %, which is significantly lower than what a private investor would desire (16-20 % is desirable). With a high water tariff and too low ROE, this case is not financially viable at all.

In the first alternative of case C, presented in table 16 in section 5.4, the NPV is increased and the water tariff is decreased to 672 NPR/month when the population is doubled (900 households). The ROE for the private loan and the bank loan is 6.2 % and 3.1 %, respectively, which is still lower than desired values. The fact that the water tariff is low, makes this case worth considering. A low water tariff theoretically implies two things: It is more likely that people are willing to pay and full cost recovery is possible. Therefore, the risk of the investment is lowered, making this alternative not optimal but better in financial terms compared to previous cases.

In the second alternative of case C, where 100 % of the investment costs are covered by a loan from the government with an interest rate of 6 %, the water tariff varies from 639-1438 NPR/month depending on the number of households (see table 17, in section 5.4). A mean value for the ROE in this case is 3.7 %, which is still lower than desired. This alternative is only interesting when the number of households is 900 since it results in the lowest water tariff among all the compared cases.

One way of attempting to make the project more financially viable is to identify cost reduction possibilities. Looking at table 3 in chapter 3, section 3.3.1 one can observe that the overhead water tank, the pipeline, valves, smart meters and solar panels contribute significantly to the total investment costs of this project. There is a possibility that the total investment costs can be reduced by choosing cheaper components, leading to lower water tariffs and making the system more affordable. However, after reducing the costs and analyzing the financial viability, it can be concluded that, although the water tariff is reduced, the ROE on investment is still low which brings back the problem of finding investors. Further, another parameter that can change the cost is the choice of hydraulic test. As mentioned in chapter 2, the hydraulic test carried out in this project is a pump test. Pump tests are usually the most expensive method among hydraulic tests since the test lasts between several days to several weeks. This results in a large amount of water being withdrawn from the aquifer but not utilized. As stated in chapter 3, section 3.1, the groundwater has an economic value and the cost of carrying out a pump test is related to the value of the discharged water. As the value of groundwater is unknown in this case, it has not been included in the project costs. However, an estimated value of groundwater in this case can be calculated by taking the depreciation of the water supply system and the amount of withdrawn water into account. This was not done in this degree project due to lack of time.

One interesting aspect is, whether investing in solar panels for this project is a sound decision. As shown in table 18 in section 5.4, when the degradation of the solar panel system is not taken into account, the cost of produced electricity is lower than the energy fee in Madi. This indicates that the system has reached grid parity, meaning that the cost of producing green electricity is lower than the cost of purchasing electricity from the grid. However, taking into account the degradation of the system, results in a higher cost of producing electricity from the solar system. From an investment perspective, it may not be economically beneficial to invest in solar panels, as it takes 17 years for the investment to become profitable and the expected lifetime of the solar panels is only 20 years (see figure 16 and 17 in section 5.4) This means that after just 3 years of economic viability, a significant amount of money would need to be reinvested to replace the system. While the cost of the reinvestment is likely to be lower than the initial investment cost, given that the infrastructure is already in place and solar system costs are decreasing, it is still a factor that should be considered in this case. One crucial factor that can affect the comparison between solar panels and the grid is the energy fee (NPR/kWh). In this report, a constant value of 7.2 NPR/kWh was used. However, in reality the energy fee fluctuates over time and a comprehensive analysis would require hourly data on the energy fee over at least three years. Additionally, there are other economic values associated with solar systems that are not included in this analysis. For instance, producing green electricity instead of burning fossil fuels has an economic impact that could incentivize the installation of solar panels. There are many uncertainties in this part of the analysis and it is therefore challenging to determine whether investing in solar systems for this water supply project or other projects in rural areas is advisable.

There are numerous other parameters that must be considered when conducting an economic analysis of a water supply project. These may include assessing the economic benefits to the poor to determine the project's poverty impact, conducting a distribution analysis to determine who benefits and who incurs losses from the project, analyzing the consumption pattern and income of the local people and determining the percentage of their income that would be allocated to water services. Nevertheless, it is challenging to determine the impact of the project on all these parameters. This being said, the economic analysis carried out in this project is not complete and needs to incorporate further information to determine whether the project is economically sustainable or not.

To summarize the most important takeaways from the above-discussed points: If we assume that establishing a groundwater supply system in other rural areas will cost as much as the system in Madi, it may be difficult to design an attractive investment portfolio. All the cases (A-C) show that this type of project may not be appealing to investors due to low return on equity and the high investment risk as a result of high water tariffs. It is important to note that the water tariff in this report is calculated based on the full recovery of all investment and operation costs, without considering people's willingness to pay. However, the calculated water tariff is likely too high, which suggests that full cost recovery from project beneficiaries may not be possible without government subsidies. Having said that, it doesn't mean that a water supply project like the one in Madi will be infeasible in other areas. In urban areas where there are more than 1000 households, and the investment cost is covered by two separate loans, the NPV increases and the water tariff decreases significantly, which reduces the risk of not achieving full cost recovery. This is shown in table 16 i chapter 5, section 5.4. However, the ROE is still low and the most important challenge of creating incentives for investors to engage remains unsolved.

To end this discussion, I would like to highlight a crucial part regarding the international perspective of safe drinking water, which was mentioned in chapter 1, section 1.2. In June 2021 the estimated cost for Covid-19 exceeded $80 000 billion (Jonsson, 2022). In contrast, the cost of the water supply system in Madi with the most modern technologies is approximately $594 thousand ($1=132.53 NPR) (converted from table 13 in section 5.4). This raises the question of whether it is challenging to generate sufficient return on equity, or whether it is difficult to garner political interest in funding projects that have potential to positively impact millions of lives. As such, addressing this issue will require not just financial investment, but also political commitment and action.

7 Conclusion & future studies

7.1 Conclusion

The physicochemical and microbiological characteristics of the water samples indicate that the groundwater in Madi exhibits good quality and purity and complies with the established national and international water quality guidelines. Therefore, the water should be safe for drinking and other domestic purposes and there is no need for water treatment. The hydrochemical analysis implies that the groundwater has an alkaline nature. Major processes controlling the groundwater quality seem to be silicate weathering, dissolution of carbonate and cation-exchange. Characteristic of the facies of the water is in region Mg/Ca-HCO_3 and the major process controlling the groundwater chemistry is most likely rock-water interaction. Collecting representative samples of groundwater chemistry can often be challenging, but despite the potential for uncertainties, the results are considered reliable due to the consistency observed across multiple samples collected at different times.

Based on hydraulic tests conducted in 2020 and 2022, the newly constructed water well in Madi appears to have strong potential for groundwater extraction from the unconfined aquifer consisting of sand, gravel, pebbles and cobbles with high permeability and hydraulic conductivity. The pump test revealed high storativity and a very short recovery time, indicating that the aquifer is capable of storing large volumes of water that can be extracted quickly. However, given that the pump test also revealed that surrounding wells are hydraulically connected to the same aquifer, it is crucial to closely monitor groundwater levels to prevent excessive depletion and minimize the risk of overexploitation. The identified characteristics of the aquifer are consistent with the geology and hydrogeology of the project area and the results are reliable as both hydraulic tests yielded almost the same outcomes.

The total cost of building the water supply system in Madi is 7.8 millions of nepali rupees, and each household should pay 214 NPR per month to cover maintenance and operation costs. If the project was not funded by donations and the costs had to be covered by loans, the water tariff would increase to 1044-1438 NPR per month, depending on the interest rate and loan layout. This would be too high for Nepal in general. The water tariff could become affordable if the population increases, but it is challenging to find an investment portfolio design that would offer a desirable return on equity (ROE) for investors. Different loan layouts and the outcome from them are presented in section 5.4. There are several parameters, such as the impact on poverty, changes in consumption patterns, and people's willingness to pay, that have not been considered in this economic analysis. Therefore, it is difficult to conclude whether the water supply project in Madi is financially viable or not.

7.2 Future studies

There are many irrigation wells in the area and they are highly likely all interconnected to the same aquifer. A comprehensive hydrogeological study focusing on groundwater formation and water usage pattern during different seasons would provide a better understanding of whether the aquifer's water supply is sufficient or if alternative sources are needed. In relation to this analysis the risk of depleting the groundwater should be analyzed. In cases where groundwater levels start to decrease, the economic value of the water is increased and to maintain full cost recovery, the water tariff should be increased.

Another interesting area for future studies is assessing the aquifer's susceptibility to contaminants. As access to safe and clean water gets easier, the actual consumption increases, leading to more wastewater production. It is therefore important to examine the groundwater flow and level to pinpoint areas where the potential for contamination is high and to implement additional protective measures. It is important to investigate whether providing access to safe drinking water without considering the wastewater will actually improve people's living standard or make it worse in a longer time perspective (due to the risk of contaminating the groundwater).

One fundamental yet complex aspect in economic analysis of water supply projects that can be highly valuable to analyze is the actual economic value of water, in this case the groundwater. Determining the economic value of the groundwater in Madi can aid in the more efficient allocation of this resource. If the economic value of the groundwater is set below its actual value, there is a risk of over consumption and attracting other industries to rural areas, utilizing a scarce resource at a low cost. This not only jeopardizes the system but imposes extra scarcity on future generations. Hence determining the actual economic value of the water is an important aspect of establishing a sustainable and economically viable water supply system.

An interesting idea for future research is to create a survey to study consumption patterns and determine local populations' willingness to pay for water services before the planning phase of water supply projects, particularly in rural areas. In urban areas, existing users are normally charged for the water supply whereas in the rural areas, there may not be any formal water supply and the rural households often do not have to pay for water use. However, estimating the actual consumption pattern can be challenging in rural areas, as households may lack a clear understanding of their daily water consumption. Directly asking these households may not provide reliable answers. One possible approach is to collect data from an existing water supply system where the consumer's consumption is measured.

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Appendix 1: Geology and hydrogeology of Nepal

Geologically, Nepal occupies the central sector of Himalayan arc. Nearly one third of the 2400 km long Himalayan range lies within Nepal. Nepal is divided into following five major subdivisions from south to north and each zone is characterized by their own lithology, tectonics, and structures:

1. Terai (Indo-Gangetic plain)
2. Sub-Himalaya (Siwaliks)
3. Lesser Himalaya
4. Higher Himalaya
5. Tibetan-Tethys zone

The generall geology of Nepal is shown in figure A1.

Terai zone

The Terai region in Nepal forms the northern boundary of the Indo-Gangetic alluvial basin and is bounded by the Main Frontal Thrust (MFT) which simply is a boundary and can be seen in figure B2. The plain is composed of Pleistocene to recent alluvium, with an average thickness of 1500 meters.

Sub-Himalayan

The Sub-Himalayan Zone, bounded by the Main Frontal Thrust (MFT) to the south and the Main Boundary Thrust (MBT) to the north, primarily consists of Neogene rocks of fluvial origin. The lower Siwaliks contain finely laminated sandstone, siltstones, and mudstones, with a thickness exceeding 2000 meters. The middle Siwaliks comprise medium to coarse-grained sandstone and have a thickness of about 3000 meters, while the upper Siwaliks consist of conglomerate and boulder beds exceeding 1000 meters in thickness. The Dun valleys within the Siwaliks are covered by quaternary fluvial sediments.

Lesser Himalaya

The Lesser Himalayan Zone is bounded by the MBT to the south and the Main Central Thrust (MCT) to the north. It consists of two sequences of rocks, allochthonous and autochthonous to para-autochthonous, and is composed of unfossiliferous sedimentary and metasedimentary rocks such as slate, phyllite, schist, quartzite, limestone, and dolomite. The MBT has brought the older Lesser Himalayan rocks over the much younger Siwaliks.

Higher Himalaya

The Higher Himalayan Zone lies north of the MCT and below the fossiliferous Tibetan-Tethys Zone. It consists of a 10 km thick succession of crystalline rocks called Tibetan Slab, which extend continuously along the entire length of the country. The crystalline units form the basement of the Tibetan-Tethys Zone and include high-grade kyanite-sillimanite bearing gneiss, schist, and marble. Tertiary granites occur at the upper part of the Tibetan Tethys sedimentary rocks.

Tibetan-Tethys Himalaya

The Tibetan-Tethys zone starts at the top of the Higher Himalaya and extends north to Tibet, encompassing Nepal's highest peaks. It is primarily composed of sedimentary rocks like shale, limestone, and sandstone.

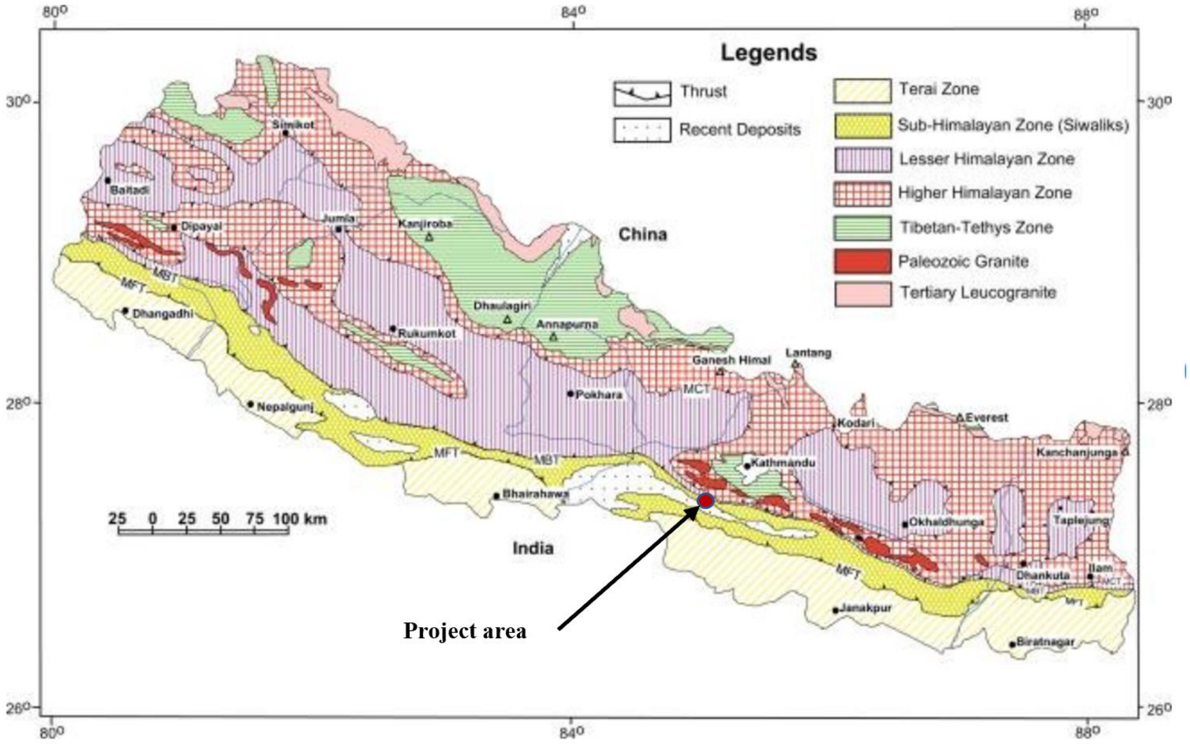
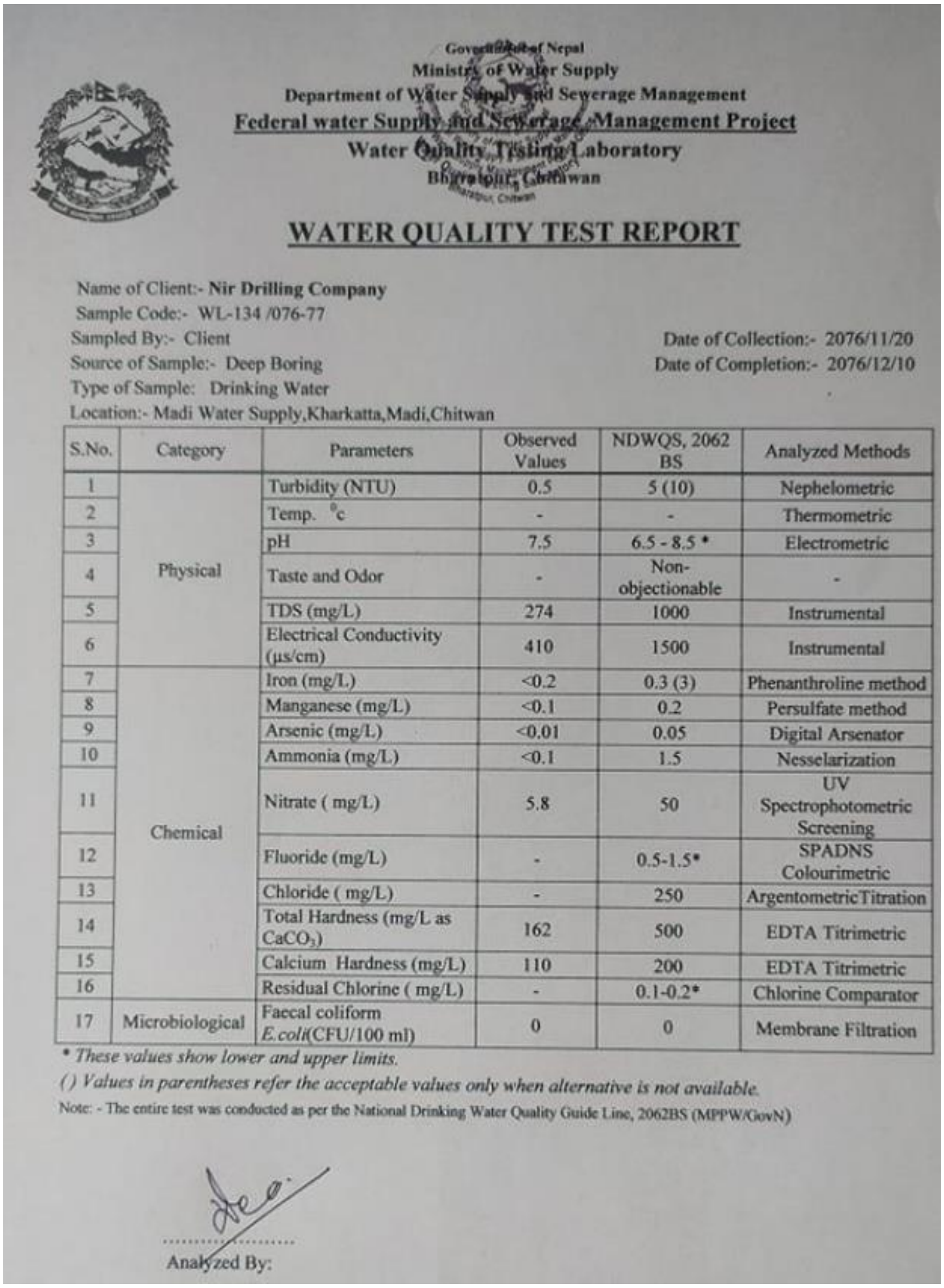


Figure A1: Geology of Nepal (Ranjan, 2012)

Appendix 2: Old groundwater quality results

Tables A1 and A2 below show the results from water quality assessment done in 2020 in Kathmandu and Denmark respectively.

Table A1: Observed values from the water quality evaluation done in 2020 in Kathmandu from samples collection in the WW.



Government of Nepal
Ministry of Water Supply
Department of Water Supply and Sewerage Management
Federal water Supply and Sewerage Management Project
Water Quality Testing Laboratory
Bharatpur, Chitwan

WATER QUALITY TEST REPORT

Name of Client:- **Nir Drilling Company**
Sample Code:- WL-134 /076-77
Sampled By:- Client
Source of Sample:- Deep Boring
Type of Sample: Drinking Water
Location:- Madi Water Supply,Kharkatta,Madi,Chitwan

Date of Collection:- 2076/11/20
Date of Completion:- 2076/12/10

S.No.	Category	Parameters	Observed Values	NDWQS, 2062 BS	Analyzed Methods
1	Physical	Turbidity (NTU)	0.5	5 (10)	Nephelometric
2		Temp. °c	-	-	Thermometric
3		pH	7.5	6.5 - 8.5 *	Electrometric
4		Taste and Odor	-	Non-objectionable	-
5		TDS (mg/L)	274	1000	Instrumental
6		Electrical Conductivity (µs/cm)	410	1500	Instrumental
7	Chemical	Iron (mg/L)	<0.2	0.3 (3)	Phenanthroline method
8		Manganese (mg/L)	<0.1	0.2	Persulfate method
9		Arsenic (mg/L)	<0.01	0.05	Digital Arsenator
10		Ammonia (mg/L)	<0.1	1.5	Nesselarization
11		Nitrate (mg/L)	5.8	50	UV Spectrophotometric Screening
12		Fluoride (mg/L)	-	0.5-1.5*	SPADNS Colourimetric
13		Chloride (mg/L)	-	250	ArgentometricTitration
14		Total Hardness (mg/L as $CaCO_3$)	162	500	EDTA Titrimetric
15		Calcium Hardness (mg/L)	110	200	EDTA Titrimetric
16		Residual Chlorine (mg/L)	-	0.1-0.2*	Chlorine Comparator
17	Microbiological	Faecal coliform *E.coli*(CFU/100 ml)	0	0	Membrane Filtration

** These values show lower and upper limits.*
() Values in parentheses refer the acceptable values only when alternative is not available.
Note: - The entire test was conducted as per the National Drinking Water Quality Guide Line, 2062BS (MPPW/GovN)

Analyzed By:

Table A2: Observed values from the water quality evaluation done in 2020 in Denmark from samples collection in the WW.

eurofins

ilac-MRA DANAK TEST Reg.No. 168

Eurofins Miljø A/S
Ladelundvej 85
6600 Vejen
Danmark
Telefon: 7022 4266
CVR/VAT: DK-2884 8196

Envidan A/S Aarhus
Sommervej 31 4
8210 Aarhus V
Att.: Tina Halkjær Andersen (THA)

Rapportnr.:	AR-20-CA-00932666-01
Batchnr.:	EUDKVE-00932666
Kundenr.:	CA0017432
Modt. dato:	05.03.2020

Analyserapport

Sagsnavn:	Vandprøve fra Nepal
Prøvetype:	Grundvand
Prøveudtagning:	
Analyseperiode:	05.03.2020 - 23.03.2020

Prøvemærke: Vandprøve fra Nepal

Lab prøvenr:	**80802827**	**Enhed**	**DL**	**Metode**	**Urel (%)**
Uorganiske forbindelser					
Ammonium (NH4)	0.062	mg/l	0.005	SM 17. udg. 4500-NH3 (H)	15
Nitrit	0.019	mg/l	0.001	SM 17. udg. 4500-NO2 (B)	15
Nitrat	4.8	mg/l	0.3	SM 17. udg. 4500-NO3 (H)	15
Total Phosphor	< 0.01	mg/l	0.01	DS EN ISO 6878:2004,SM 22. udg. 4500-P (E	15
Chlorid	3.0	mg/l	1	SM 17. udg. 4500-Cl (E)	15
Fluorid	0.28	mg/l	0.05	SM 17. udg. 4500-F- (E)	15
Sulfat (SO4)	6.2	mg/l	0.5	SM 17. udg. 4500-SO4 (E)	15
Aggressiv kuldioxid	< 2	mg/l	2	* DS 236:1977	15
Hydrogencarbonat	304	mg/l	3	DS/EN ISO 9963	15
Organiske samleparametre					
NVOC, ikke-flygtigt org. kulstof	0.54	mg/l	0.1	DS/EN 1484	15
Metaller					
Arsen (As)	0.40	µg/l	0.03	DS/EN ISO 17294m:2016 ICP-MS	20
Barium (Ba)	12	µg/l	1	DS/EN ISO 17294m:2016 ICP-MS	20
Bor (B)	1.7	µg/l	1	DS/EN ISO 17294m:2016 ICP-MS	20
Calcium (Ca)	79	mg/l	0.5	DS/EN ISO 17294m:2016 ICP-MS	15
Kobolt (Co)	0.61	µg/l	0.04	DS/EN ISO 17294m:2016 ICP-MS	20
Jern (Fe)	0.25	mg/l	0.01	DS/EN ISO 17294m:2016 ICP-MS	20
Kalium (K)	1.3	mg/l	0.05	DS/EN ISO 17294m:2016 ICP-MS	15
Magnesium (Mg)	16	mg/l	0.1	DS/EN ISO 17294m:2016 ICP-MS	15
Mangan (Mn)	0.058	mg/l	0.002	DS/EN ISO 17294m:2016 ICP-MS	20
Natrium (Na)	6.2	mg/l	0.1	DS/EN ISO 17294m:2016 ICP-MS	15
Nikkel (Ni)	0.99	µg/l	0.03	DS/EN ISO 17294m:2016 ICP-MS	20

Kopi til:
Envidan A/S Aarhus , Surya Prajapati, Sommervej 31 4, 8210 Aarhus V

23.03.2020

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Tlf: 70224267
G30@eurofins.dk

Kirsten From Jensen
Senior Kunderådgiver

Appendix 3: Results from step-drawdown test conducted in 2020

Figure A2 below shows the data collected from the step-drawdown test carried out in 2020 when the WW was constructed and table A3 shows the recovery data. Obtained aquifer characteristics from this test is presented in table 10 in chapter 5.

Table A2: Step-drawdown data conducted on the WW.

Pump Type : Submersible Pump
Static Water Level : 15.1 m below ground level

Date	Elapsed Time Minutes	Discharge lit/sec	Water Level meter	Draw Down in m	Remarks
2/3/2020	0.00	10 lit/sec	15.10	0.0	I Step
	20.00		16.50	1.4	
	40.00		17.00	1.9	
	60.00		18.00	2.9	
	80.00		19.00	3.9	
	100.00		20.00	4.9	
	120.00		20.00	4.9	
	140.00		20.00	4.9	
	160.00		20.00	4.9	
	180.00		20.00	4.9	
	200.00		20.00	4.9	
	220.00		20.00	4.9	
	240.00		20.00	4.9	
	260.00	20 lit/sec	21.00	5.9	II Step
	280.00		22.00	6.9	
	300.00		22.50	7.4	
	320.00		23.00	7.9	
	340.00		23.50	8.4	
	360.00		23.50	8.4	
	380.00		23.50	8.4	
	400.00		23.50	8.4	
	420.00		23.50	8.4	
	440.00		23.50	8.4	
	460.00		23.50	8.4	
	480.00		23.50	8.4	
	500.00	30 lit/sec	24.00	8.9	III Step
	520.00		24.25	9.1	
	540.00		25.00	9.9	
	560.00		25.20	10.1	
	580.00		25.31	10.2	
	600.00		25.31	10.2	
	620.00		25.31	10.2	
	640.00		25.31	10.2	
	660.00		25.31	10.2	
	680.00		25.31	10.2	
	700.00		25.31	10.2	
	720.00		25.31	10.2	

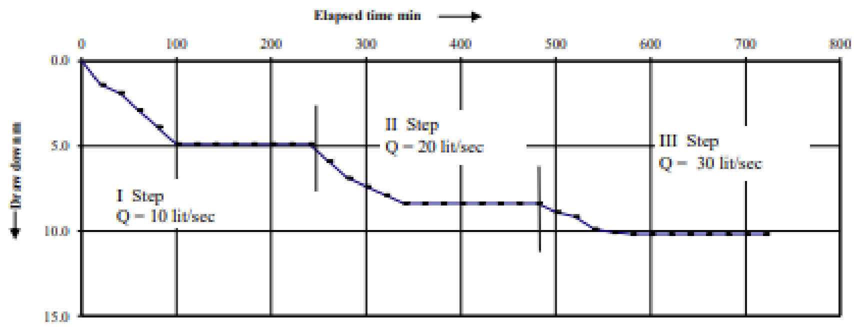

Figure A2: Data collected from the step-drawdown test carried out in 2020.

Table A3: Recovery data of the step-drawdown test.

Date/ Time	Time minute	Water level (m)	Drawdown (m)	Discharge Rate
2/3/2020	0	25.31	0.00	30.0 lit/sec
	1	25.00	-0.31	
	3	21.20	-4.11	
	5	19.00	-6.31	
	7	17.20	-8.11	
	10	16.55	-8.76	
	15	16.52	-8.79	
	30	16.40	-8.91	
	45	16.35	-8.96	
	60	16.25	-9.06	
	90	16.00	-9.31	
	120	15.15	-10.16	
	180	15.10	-10.21	
	240	15.10	-10.21	
	300	15.10	-10.21	
	360	15.10	-10.21	
	420	15.10	-10.21	
	480	15.10	-10.21	
	540	15.10	-10.21	
	600	15.10	-10.21	
	720	15.10	-10.21	
	720	15.10	-10.21	
	840	15.10	-10.21	
	960	15.10	-10.21	
	1080	15.10	-10.21	
	1200	15.10	-10.21	
	1320	15.10	-10.21	
	1440	15.10	-10.21	

Appendix 4: Groundwater quality results from samples collected in 2022

Table A4 below shows the observed values from the water quality analysis. Dates when the samples were collected in the WW and whether they were filtered or not are shown in the table. It can be observed that the values are rather similar.

Table A4: Presenting values from water quality analysis where both filtered and non-filtered samples were analyzed.

Parameter/sample	21/10, filtered	21/10, not filtered	22/10, filtered	22/10, not filtered
Turbidity (NTU)	0,2	0,2	0,2	0,2
Total alkalinity	-	-	-	-
pH	7,66	7,60	7,57	7,44
Tate and Odor	-	-	-	-
TDS (mg/L)	323	334	336	340
Electrical conductivity (µS/cm)	485	502	505	510
Iron (mg/L)	<0,2	<0,2	<0,2	<0,2
Manganese (mg/L)	<0,1	<0,1	<0,1	<0,1
Arsenic (mg/L)	<0,01	<0,01	<0,01	<0,01
Ammonia (mg/L)	<0,1	<0,1	<0,1	<0,1
Nitrate (mg/L)	3,2	3	3	3

Total Hardness (mg/L as $CaCO_3$)	185	195	198	200
Calcium (mg/L)	38	40	41,6	42,4
Magnesium (mg/L)	22	23,2	22,9	22,9
Residual Chlorine (mg/L)	-	-	-	-
Fecal coliform E.coli	0	0	0	0

Appendix 5: Type-curve matching in AquiferTest

Figure A3 shows the Neuman type-curve matching for the WW and figure A4 shows type-curve matching for OW01 which was closest to the WW and used to determine the storativity of the aquifer.

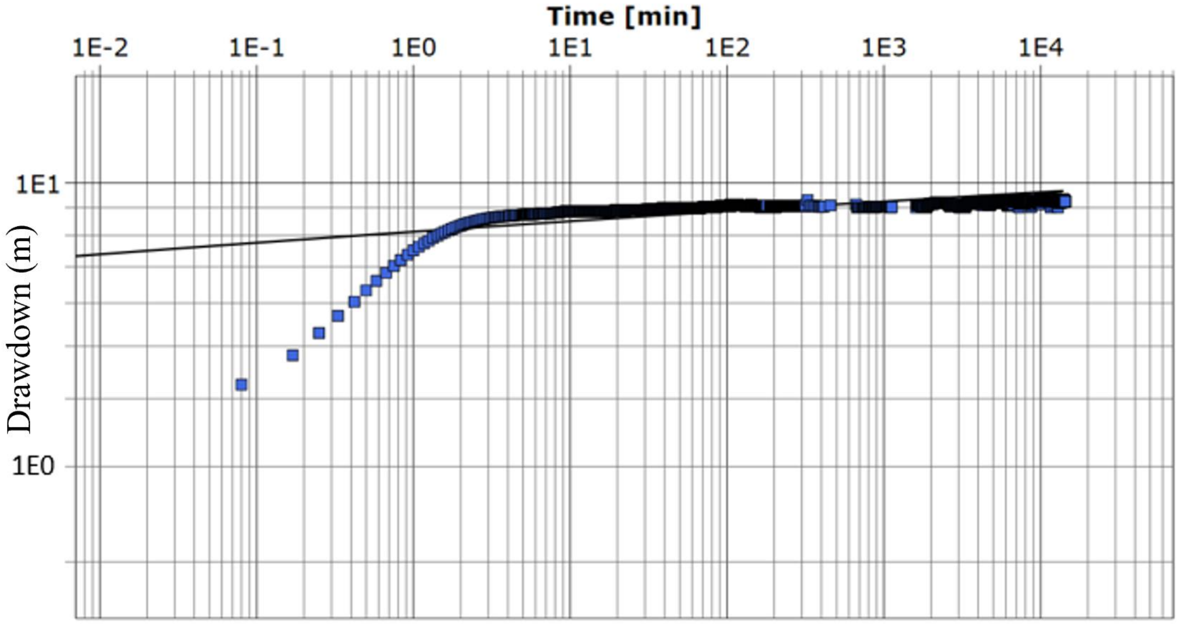

Figure A3: Neuman type-curve matching for WW.

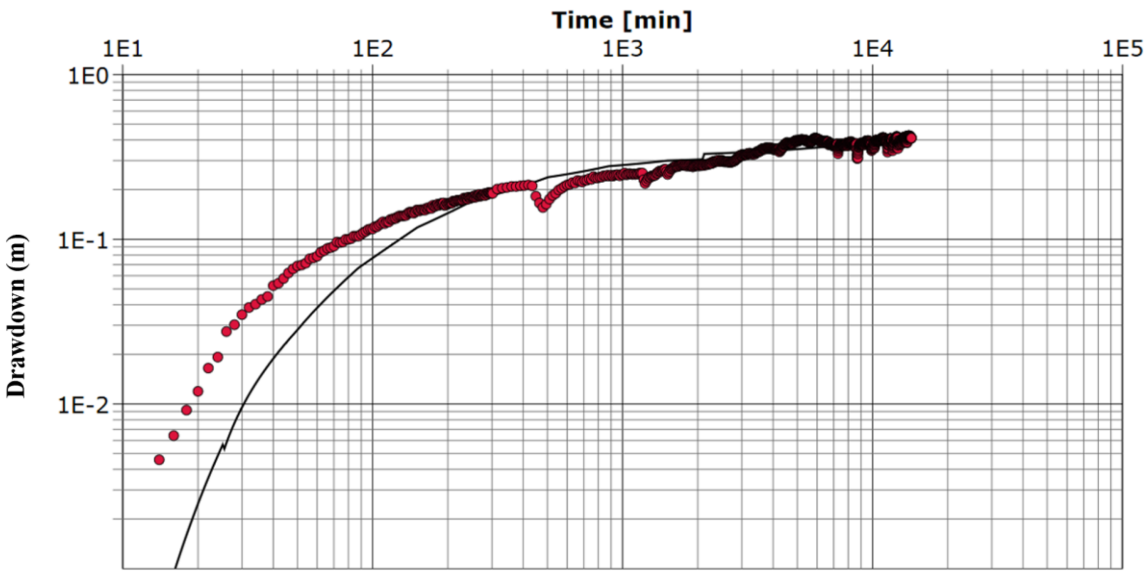

Figure A4: Neuman type-curve matching for OW01.