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Assessing the Feasibility of Hydropower Generation from Water and Wastewater Transboundary Streams in the West Bank, Palestine
(Wadi Al-Samen as a Case Study)

تقييم جدوى إنتاج الطاقة الكهرومائية من جداول المياه والمياه العادمة المشتركة في الضفة الغربية ، فلسطين
(وادي السمن كحالة دراسة)

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Assessing the Feasibility of Hydropower Generation from Water and Wastewater Transboundary Streams in the West Bank, Palestine
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DEDICATION

To my parents,

To my love "Ahmad",

To my heart "Majd",

To my family,

To my friends,

Love you all

Bayan Al-Heeh

June, 2018

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ABSTRACT

Energy is the main engine of life on earth and it is the basis of the progress or backwardness of the nations. The world is facing an energy crisis as a result of the large and growing dependence on conventional energy sources that can be depleted, such as oil, gas and coal. Many countries have tried to overcome energy crisis and achieve energy security by accessing modern and clean energy sources such as renewable energy sources. The Palestine environment has high potential for the application of renewable energy, such as solar energy, wind energy, biomass energy and geothermal energy. In the West Bank, there are 6 major transboundary streams that carry huge amounts of rainwater and wastewater from Palestinian areas to Israeli wastewater treatment plants (WWTPs) inside the Green Line. The main aim of this research was to study the possibility of hydroelectric power generation from water flowing through the West Bank main transboundary streams in dry and wet seasons; Wadi Al-Samen was taken as a case study.

Two methods have been followed to generate hydropower from Wadi Al-Samen. The first method was to exploit the water flowing into the stream to produce electricity as it is. The second method was to store the water by a reservoir for a certain period of time and then release it to produce electricity. For the first method, four sites were proposed to generate hydropower during the dry and wet seasons. For the second method, three alternatives were proposed to generate hydropower during wet season: storage of 5%, 15% and 25% of the total quantity of water flowing into the stream. While during dry season, it was proposed to generate hydropower based on the natural flow of the stream as it is.

The results showed that: for the first method, the amount of hydropower produced from each location during dry and rainy seasons was (19.2, 13.6, 18.6 and 9.2), (1198, 1208, 2069 and 998) KW per day, respectively. The great increase in hydropower generated in rainy season was due to the additional flow of rain water to the hydropower sites. For the second method, the results showed that the amount of hydropower produced by each alternative during wet season was (1021.2, 2248 and 3065.1) KW per day, respectively, while during dry season, the generated hydropower was (20.75) KW per day.

الخلاصة

الطاقة هي المحرك الرئيسي للحياة على الأرض وهي أساس تقدم الأمم أو تخلفها. يواجه العالم أزمة طاقة نتيجة الاعتماد الكبير والمتزايد على مصادر الطاقة التقليدية القابلة للاستنزاف ، مثل النفط والغاز والفحم. حاولت العديد من الدول التغلب على أزمة الطاقة وتحقيق أمن الطاقة من خلال الوصول إلى مصادر الطاقة الحديثة والنظيفة مثل مصادر الطاقة المتجددة.تتمتع بيئة فلسطين بإمكانية عالية لتطبيق الطاقة المتجددة ، مثل الطاقة الشمسية وطاقة الرياح وطاقة الكتلة الحيوية والطاقة الحرارية الأرضية. في الضفة الغربية ، يوجد ستة أودية رئيسية عابرة للحدود تنقل كميات كبيرة من مياه الأمطاروالمياه العادمة من المناطق الفلسطينية إلى محطات معالجة مياه الصرف الصحي الإسرائيلية داخل الخط الأخضر.الهدف الرئيسي من هذا البحث هو دراسة إمكانية توليد الطاقة الكهرومائية من المياه المتدفقة عبر الأودية الرئيسية العابرة للحدود في الضفة الغربية في المواسم الجافة والرطبة ، وقد تم أخذ وادي السمن كحالة دراسة.

تم إتباع طريقتين لتوليد الطاقة الكهرومائية من وادي السمن.الطريقة الأولى هي استغلال المياه المتدفقة الى وادي السمن لإنتاج الكهرباء كما هي . الطريقة الثانية هي تخزين المياه بواسطة خزان لفترة زمنية معينة ومن ثم إطلاقها لإنتاج الكهرباء . بالنسبة للطريقة الأولى ، تم اقتراح أربعة مواقع لتوليد الطاقة الكهرومائية خلال المواسم الجافة والرطبة. بالنسبة للطريقة الثانية ، تم اقتراح ثلاثة بدائل لتوليد الطاقة الكهرومائية خلال موسم الأمطار: تخزين 5 ٪ ، 15 ٪ و25 ٪ من إجمالي كمية المياه المتدفقة الى الوادي . بينما خلال موسم الجفاف ، تم اقتراح توليد الطاقة الكهرومائية على أساس التدفق الطبيعي للوادي كما هو.

بينت النتائج أنه: بالنسبة للطريقة الأولى ، كانت كمية الطاقة الكهرومائية الناتجة عن كل موقع خلال المواسم الجافة والماطرة (19.2, 13.6, 18.6 and 9.2) ، (1198, 1208, 2069 and 998) كيلوواط في اليوم ، على التوالي. إن الزيادة الكبيرة في الطاقة الكهرومائية المتولدة في موسم الأمطار تعود الى التدفق الإضافي لمياه الأمطار إلى المواقع المقترحة. بالنسبة للطريقة الثانية ، أظهرت النتائج أن كمية الطاقة الكهرومائية الناتجة عن كل بديل خلال موسم الرطوبة (1021.2, 2248 and 3065.1) كيلوواط في اليوم ، على التوالي . بينما خلال موسم الجفاف ، كانت كمية الطاقة المتولدة (20.75) كيلوواط في اليوم .

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LIST OF ABBREVIATIONS

CFC	Chlorofluorocarbon
CO2	Carbon dioxide
EDCs	Electricity Distribution Companies
GeoMOLG	The Integrated Spatial Information System of the Ministry of Local Government
GHG	Greenhouse Gases
IEC	Israeli Electric Corporation
MDGs	Millennium Development Goals
MENA	Middle East and North Africa region
PEC	Palestine Electric Company
PETL	Palestinian Electricity Transmission Company
PV	Photovoltaics
PWA	Palestinian Water Authority
UN	United Nations
USA	United States of America
WWTPs	Wastewater Treatment Plants

Chapter One

INTRODUCTION

1.1 Introduction

Energy is an essential component for sustaining life. It is the main fuel for economic and social development and one of the determinants of poverty and development. Lack of access to energy can contribute to poverty, deprivation and economic deterioration. (Reddy, 2000).In the world, the current energy systems are insufficient to meet the needs of the poor, where about 1.5 billion people have no access to electricity, hinder the achievement of the Millennium Development Goals(MDGs) (AGECC, 2010).

Energy is defined as the ability to do work. It is a physical quantity measured by the unit of joule. There are two types of energy sources which are renewable sources and non-renewable sources. Renewable sources are characterized as natural, clean and non-exhaustible sources, while non-renewable sources are characterized as exhaustible and environment polluting sources.

The world is facing an energy crisis due to the increasing in global energy demand, great dependence on fossil fuels, such as coal, oil, and gas and an increase in world population exceeding seven billion people and rising steadily (Coyle and Simmons, 2014). Due to the increasing consumption of fossil fuels, the coal is expected to continue for 200 years, the oil is expected to continue for 100 years and the gas is expected to continue for 150 years (Fakhri et al., 2015). The future potential shortages in fossil fuels lead to concerns about the energy supply security needed to achieve economic growth sustainability (Chinnammai, 2014). Increased uses of fossil fuels have also caused environmental problems; CO_2, CFC and other greenhouse gases are being produced through the utilization of fossil fuel sources (Abdul Wadud et al., 2013). The global emissions of CO_2, is upward to thirty billion tons per year, twenty percent of these emissions are from the United State (Coyle and Simmons, 2014).

The ultimate solution for the energy crisis will be the discovery of harnessing non-conventional energy sources, such as wind power, hydropower, tidal power and solar power. Since these sources are available locally and provides environment friendly (Chinnammai, 2014).

Developing countries can escape poverty and achieve economic development by accessing modern sources of energy (AGECC, 2010). India has tried to achieve energy security after energy crisis of 1970. India has developed the renewable energy sector and has become a leader in renewable energy, especially wind energy and solar energy (OSMANI, 2014). Bangladesh has been suffering from insufficient energy for many years. To meet their energy crisis, Bangladesh trying to utilize renewable energy sources like, solar energy, tidal energy, wind energy, geothermal power, and hydropower (Abdul Wadud et al., 2013).

The environment of Palestine is highly potential for the renewable energy application. For solar energy, the daily average solar radiation is 5.4 KWh /m^2, which encourages the utilization of solar energy for various applications. The mountainous areas in the West Bank, which are more than 1,000 meters above sea level and have a wind speed of more than 5 m/s, are a good source of wind energy (Abu Hamed et al., 2012). Palestine has a strong potential for biomass energy; agriculture waste and animal waste as well as organic solid waste can be exploited for the generation of biogas. Geothermal energy can be utilized in Palestine; the difference in temperature under the ground surface in summer and winter can be exploited to feed the heating and cooling systems in buildings (Yamin, 2015).

Hydropower is the dominate source for generating energy because hydropower is fueled by water, so it’s a clean and cheap fuel source, its relies on the water cycle which is driven by the sun, thus it's a renewable power source compared with fossil fuels that are rapidly being depleted.

"Hydroelectric power captured the energy released from falling water"(Castaldi et al., 2003). When water falls due to gravity, the potential energy of water is converted into kinetic energy. The kinetic energy of water is converted into mechanical energy which in turn can be converted into usable electricity (IRENA, 2015).

In the West Bank, there are 6 major transboundary streams that carry huge amounts of water and wastewater from the Palestinian Authority areas to the Israeli wastewater treatment plants inside the Green Line. These streams are Wadi Al-Samen, Wadi Beit Jala, Wadi Al-Zomar, Wadi Al-Zuhur, Wadi Al-Moqatta, and Wadi Suriq (Table 1.1). However, none of these streams has practiced the hydropower for the sake of contributing to the prevailing energy deficit in Palestine.

Wadi Al-Samen receives a large quantity of water from Hebron regions, and from Israeli settlements, the water flows by gravity until it reaches the Green Line and it is treated inside the Shoket waste water treatment plant inside Israel. The Israeli side is treating the wastewater at the expense of the Palestinian side while at the same time exploiting treated water for agricultural purposes (HWE, 2012). The aim of this study is to assess the probability of generating hydropower from the rainwater and wastewater flowing into Wadi Al-Samen during the dry and wet seasons.

Table 1.1: Major transboundary streams in West Bank, with the source and quantity of wastewater (PWA, 2011).

Stream	Wastewater Source	Wastewater Quantity (m^3/d)
Wadi Al-Samen	Hebron city and Kiryat Arbaa Colony	10500
Wadi Beit Jala	Beit Jala and parts of Bethlehem City	3200
Wadi Al-Zomar	West Nablus, Ein Beit Alma Camp and some communities	4000
Wadi Al-Zuhur	Qalqilia City	6000
Wadi Al-Moqatta	Jenin City and Jenin Camp	3000
Wadi Suriq	Ramallah City	3300

1.2 Research questions

The main research question this study aims to answer is:

Is there a potential for hydroelectric power generation from transboundary streams in the West Bank?

1.3 Aim and objectives

This research aims to study the possibility of utilizing the hydroelectric power from Wadi Al-Samen transboundary stream. The specific objectives are:

- To propose appropriate hydropower methods and techniques that can be applied for producing electricity.
- To identify the potential sites for hydropower utilization.
- To assess the potential amounts of power that can be produced from Wadi Al-Samen transboundary stream.

1.4 Methodology

Research methodology was based on two methods of producing hydropower from Wadi Al-Samen. Scientific papers on hydropower and renewable energy were reviewed. A questionnaire was distributed to understand the status of renewable energy and hydropower in Palestine. The topographic and hydrological data collected was used to calculate the amount of hydropower produced by each hydropower potential site.

Work steps will be as follows:

- Reviewing scientific papers on hydropower and renewable energy.
- Distributing questionnaire about renewable energy and hydropower in Palestine.
- Collecting topographic and hydrological data for each hydropower potential site.

- Analyzing collected data using the Integrated Spatial Information System of the Ministry of Local Government (GeoMOLG).
- Calculating power produced by each hydropower potential site using Microsoft Excel program.
- Making results and discussions.
- Writing conclusions and recommendations.

1.5 Thesis outline

This thesis consists of six chapters: Chapter one presents an introduction to the research, its questions and objectives, chapter two describes the study area, chapter three reviews available literature on hydropower and renewable energy, chapter four shows the methods of generating hydropower from Wadi Al-Samen, chapter five presents the results and discussions, and chapter six summarizes the conclusions and gives recommendations.

Chapter Two

STUDY AREA: WADI AL-SAMEN

2.1 Location

Hebron city is located about 35 km from Jerusalem city, in the southern part of the West Bank. It is bordered by Bani Na'im town to the east, Taffuh town to the west, Halhul city to the north, and Yatta city to the south (ARIJ, 2009).

Hebron basin is part of the Hebron governorate. It is the largest drain basin in Hebron Governorate. The levels of this basin begin from 1020 m north of the basin and go down to 400 m south of the basin (Al-Adra, 2007). Wadi Al-Samen begins from Al-Hilla area and continuous to flow through Wadi Al-Sada and Wadi Abu-Alfaul until it reaches Al-Dhahiriya and then the Negev in the south (ARIJ, 2007). The length of Wadi Al-Samen is about 43.5 km.

There are several Palestinian communities surrounding Wadi Al-Samen, Hebron, Al-Fawwar Camp, Dura, Al-Samu', Yatta, Al-Dhahiriya and Al-Rihiya. Also, there are three Israeli settlements surrounding Wadi Al-Samen, Qriat Arb', A'tnae'l, and Bet Hajay (Zaarir, 2017).

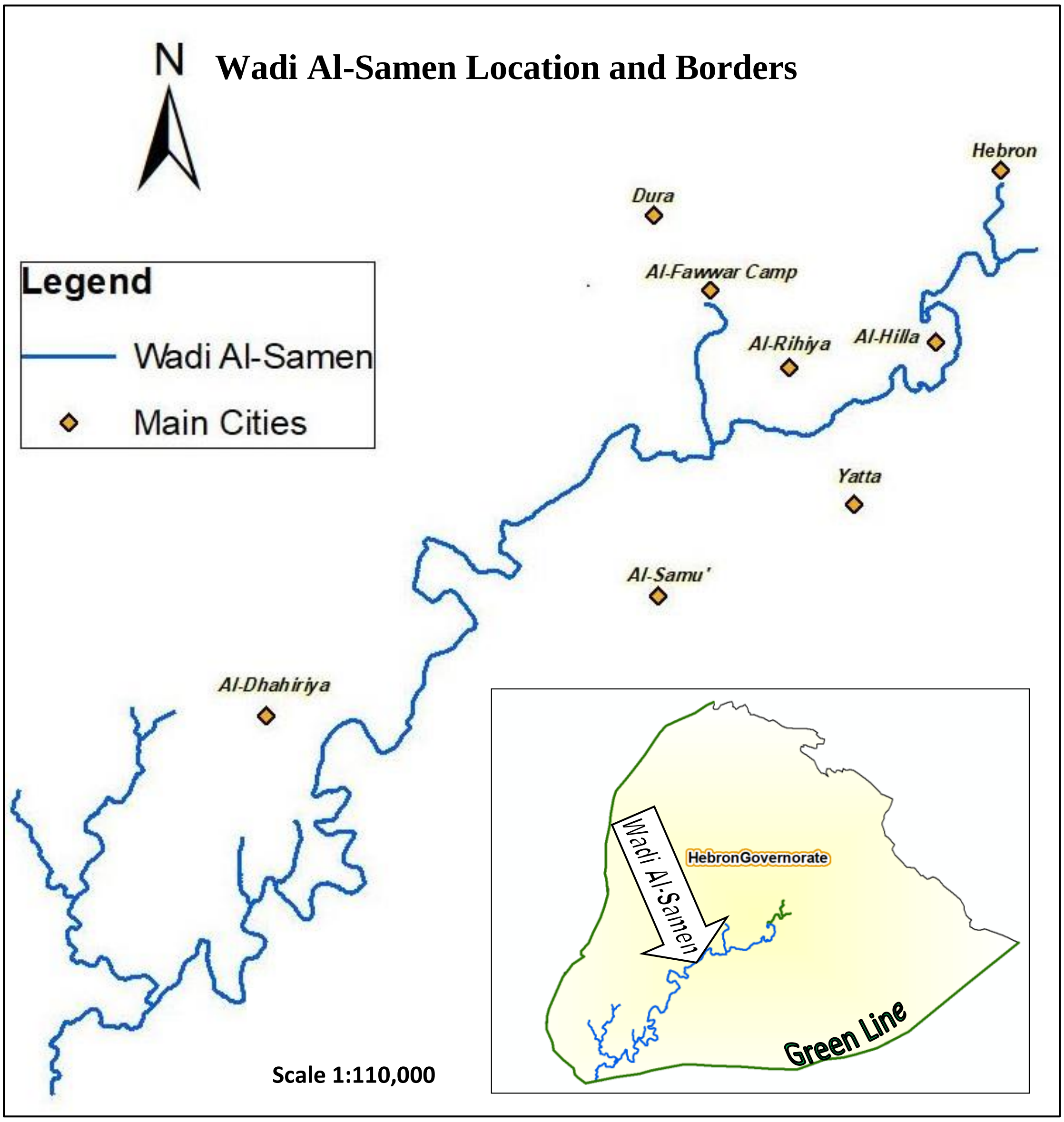

Figure2.1: Location and borders of Wadi Al-Samen.

2.2 Topography

Hebron basin is characterized by a big difference in its topographical features, where the levels range between 1020 m north of Hebron City and drop to 400 m south of Al-Dhahiriya City (Al-Adra, 2007). In Hebron governorate, the highest point is Halhul and the lowest point at Al Rawin area (Zaarir, 2017). Wadi Al-Samen begins from a height of 759 m above sea level and extends until it reaches a height of 400 m above sea level.

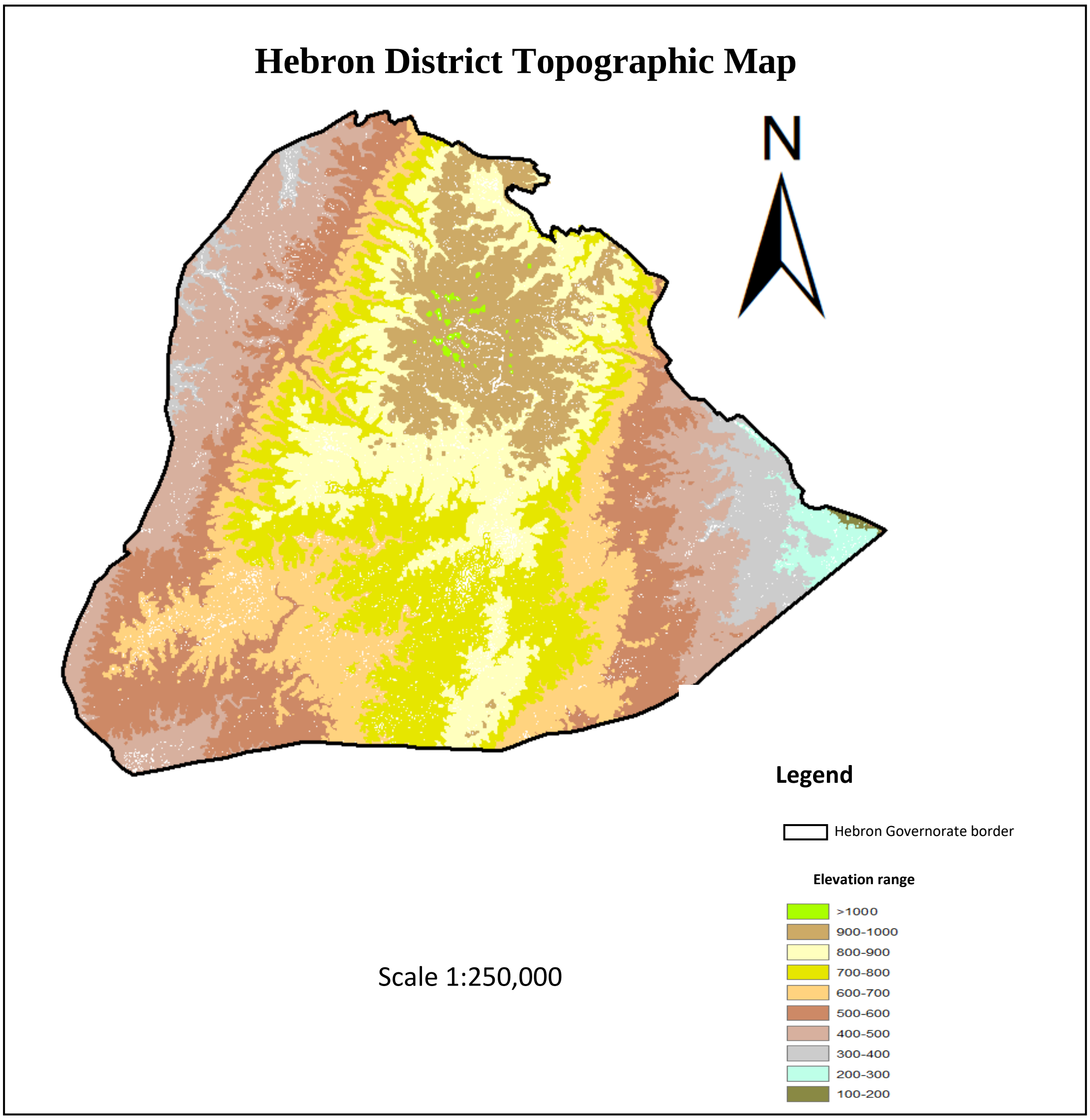

Figure 2.2: Hebron district topographic map.

2.3 Soil

There is a variety of soil in the study area due to climatic, geological and rocky differences (Al-Adra, 2007):

1. Terra Rossa: This soil spreads in the northern regions dominated by the Mediterranean climate. It is characterized by red color, high clay content and low permeability.

2. Rendzians: This soil spreads in the central regions. It is characterized by brown or gray color, high lime content, and high permeability.

3. Brown Lithosols and Loessial Arid Brown Soils: These soils are spread in the southern regions, with desert and semi-desert climate. These soils are characterized by their light brown color and high salt content.

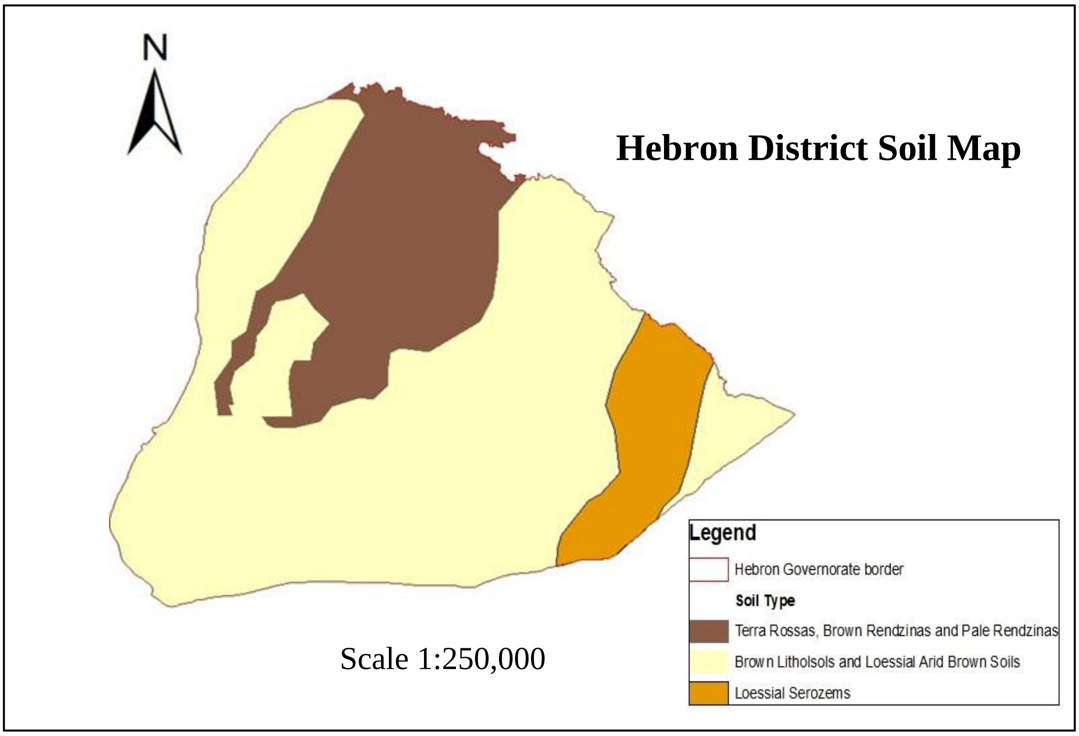

Figure 2.3: Hebron district soil map.

2.4 land use

There is diversity in land use in the study area. Land use was determined using the GeoMOLG program as shown in Figure 2.4.

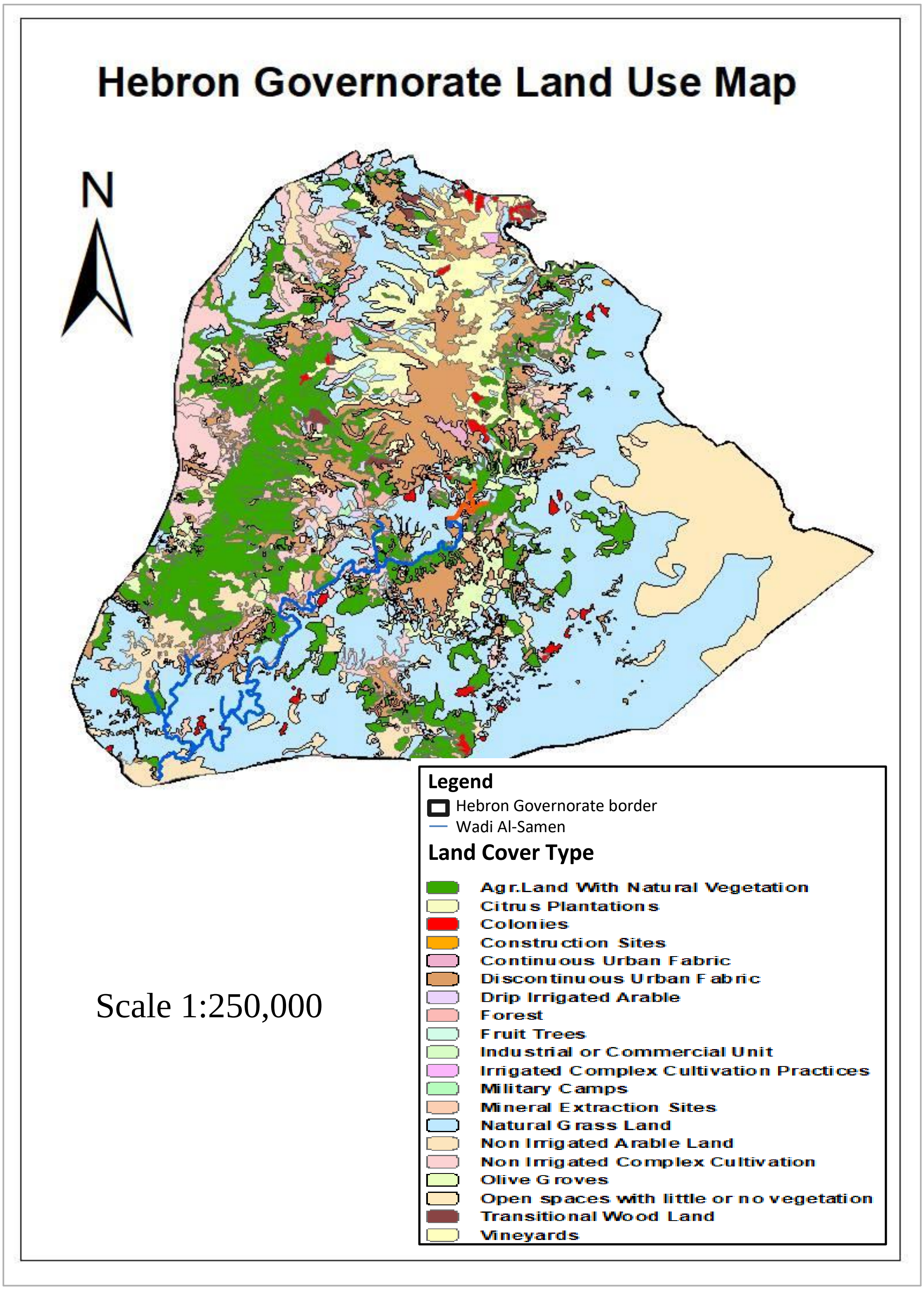

Figure 2.4: Hebron governorate land use map.

2.5 Metrology

2.5.1 Climate

The climate of the study area is classified as dry and semi-dry. This climate is influenced by the marine influences coming from the Mediterranean Sea and the desert influences coming from the Negev desert. The northern regions are dominated by the Mediterranean climate, while the southern regions are dominated by the desert climate, thus the drought is increasing towards the south (PAL; Al-Adra, 2007).

2.5.2 Rainfall

There is a difference in the quantity of rainfall falling on the northern and southern regions of the study area, where the annual rainfall rate on Hebron City, north of the study area 595.9 mm, while the annual rainfall quantity decreases to 336.5 mm in Al-Dhahiriya City, south of the study area (WAFA, 2017). Most of the annual rainfall in November, December, January, February, & March, while the precipitation are decrease in April (PCBS, 2012).

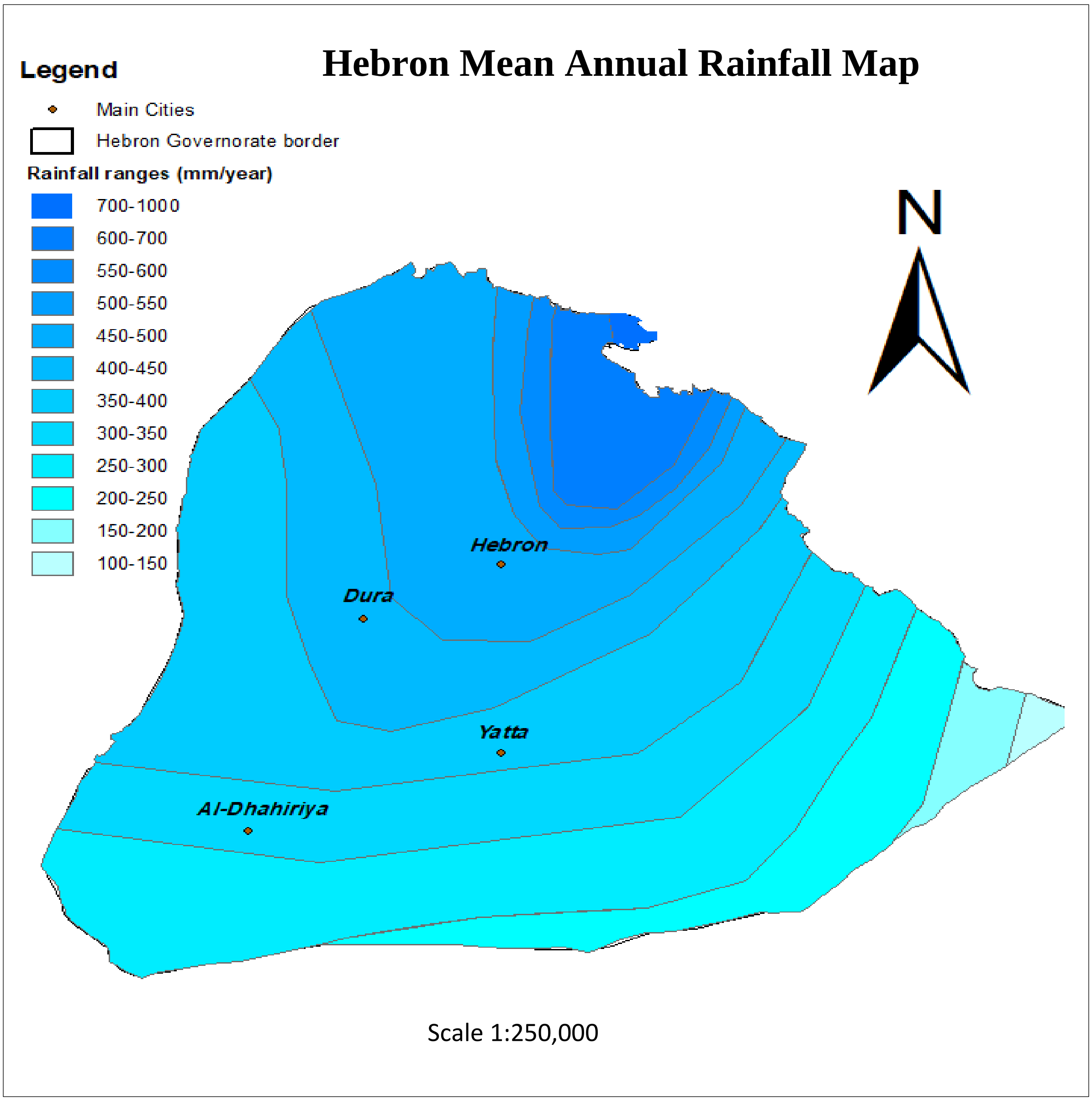

Figure 2.5: Hebron mean annual rainfall map.

2.5.3 Temperature

The average annual temperature in Hebron city is about 16º C (ARIJ, 2009). The study area is characterized by thermal variation due to the effect of both marine influences and desert influences, as well as the effect of the difference in levels (Al-Adra, 2007).

2.5.4 Wind

In summer, the study area is affected by dry northern winds, northeastern and northwestern winds, while in winter It is affected by the airdrops affect Palestine, as well as by the Asian cold wind and by the polar air masses that cause rain (Al-Adra, 2007).

2.6 Geological features

There is a diversity of rocks in the northern and southern regions of the basin, where limestone and dolomite rocks are widely present in the northern parts of the basin, while in the southern parts the cretaceous rocks are predominant (Al-Adra, 2007). The limestone rocks cover 40% of the total area of the basin (Al-Adra, 2007), these rocks are characterized by high permeability, and therefore Wadi Al-Samen is considered as recharge source to the eastern ground water aquifer (Zaarir, 2017). The geological formations of rocks in the basin are: (Al-Adra, 2007)

- Albian: It consists of limestone, marley, dolomite, and marl. This formation covers about 0.7 % of the total area of the basin. The thickness of the limestone at the top of the composition may reach 20 m.

- Upper Cenomanian: It consists of dolomite, limestone and chalk. This formation covers about 41% of the total area of the basin. The thickness of the upper part of this formation is 80-270 m while the thickness of the lower part is 160 m.

- Lower Cenomanian: It consists of dolomite and calcite rocks. This formation covers about 4.7 % of the total area of the basin. The thickness of this formation is 50-130 m.

- Turonian: It composed of limestone and dolomite. This formation takes the second place in terms of spread in the study basin with an area of 36.4%. The thickness of this formation is 90-130 m.

- Senonian: It consists of chalks, flint and marls. This formation is spread in the southern part of the basin and covers about 0.7% of the total area of the basin.
- Modern sediment: It is the sediment that occur due to the running water and are composed of gravel, clay soil and boulder rocks that resulted from the erosion of the wadis.

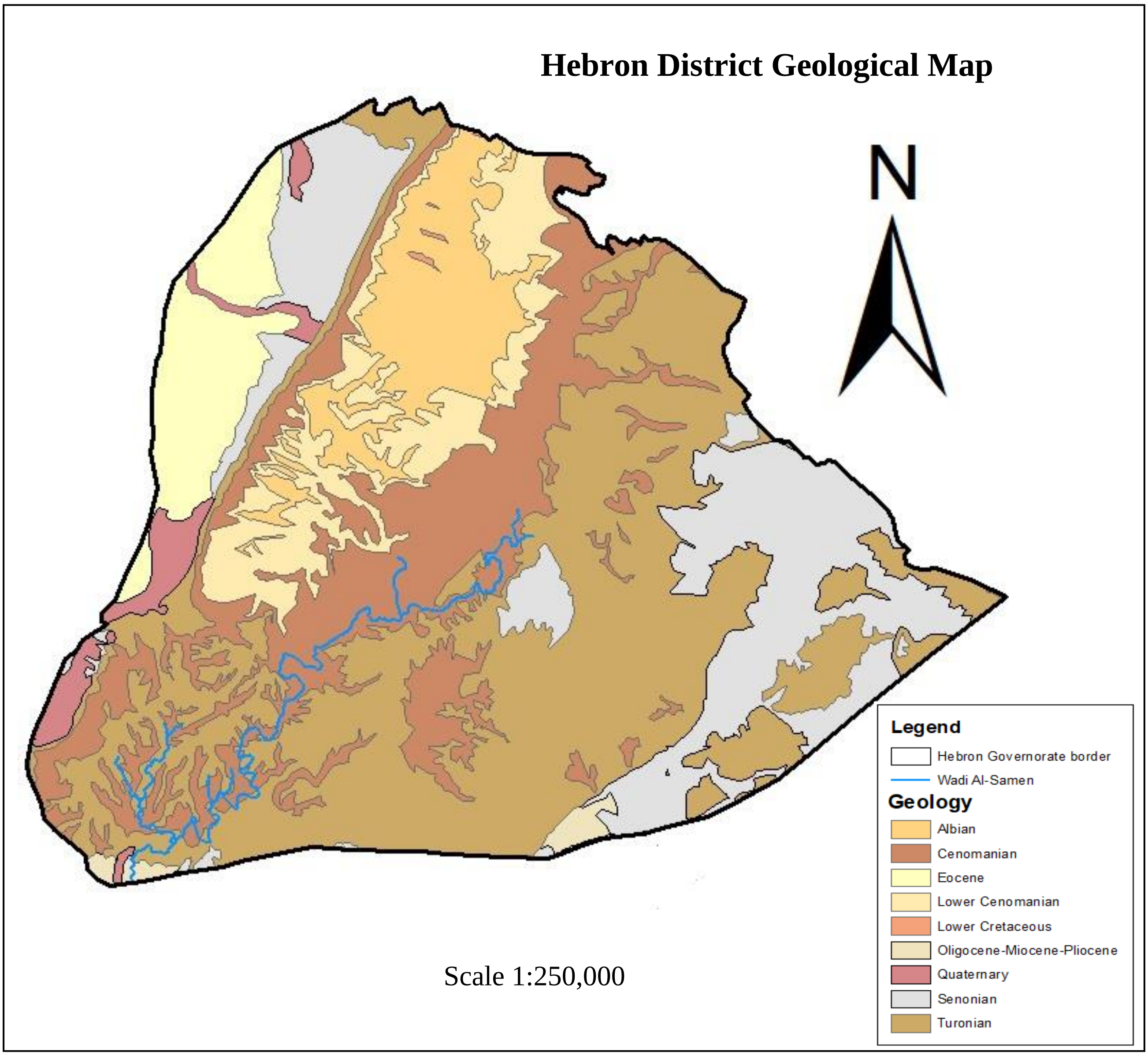

Figure 2.6: Hebron district geological map.

Chapter Three

LITERATURE REVIEW

3.1 Hydropower

3.1.1 Brief history of hydropower

The water power has been exploited for irrigation, grinding grain, and manufacturing textiles since ancient times (IFC, 2015). Greeks used the kinetic energy of falling water to turn water wheels to grind the wheat into flour, more than 2000 years ago (IRENA, 2015; IPCC, 2010). In 1882 the first hydropower plant began operation on the Fox River in Appleton, Wisconsin (Castaldi et al., 2003). Over time, humans began building dams and stored water behind them to generate energy. The three Gorges Dam that spans the Yangtze River, located in China, is the world's largest power station in terms of installed capacity (22,500 MW) (Gleick, 2009).

3.1.2 Principle of hydropower

The principle of hydropower is based on the conversion of the water potential energy into kinetic energy, which in turn converts into mechanical energy. In the presence of a magnetic field, mechanical energy is transformed into electrical energy. Water turbines converts' water pressure into mechanical shaft power. The mechanical shaft power drives the generator which produces electrical power. The power generated is directly proportional to the head and flow rate (Okot, 2013). Water head represent the net head, which equals the difference in height available for power generation (gross head) minus the energy losses.

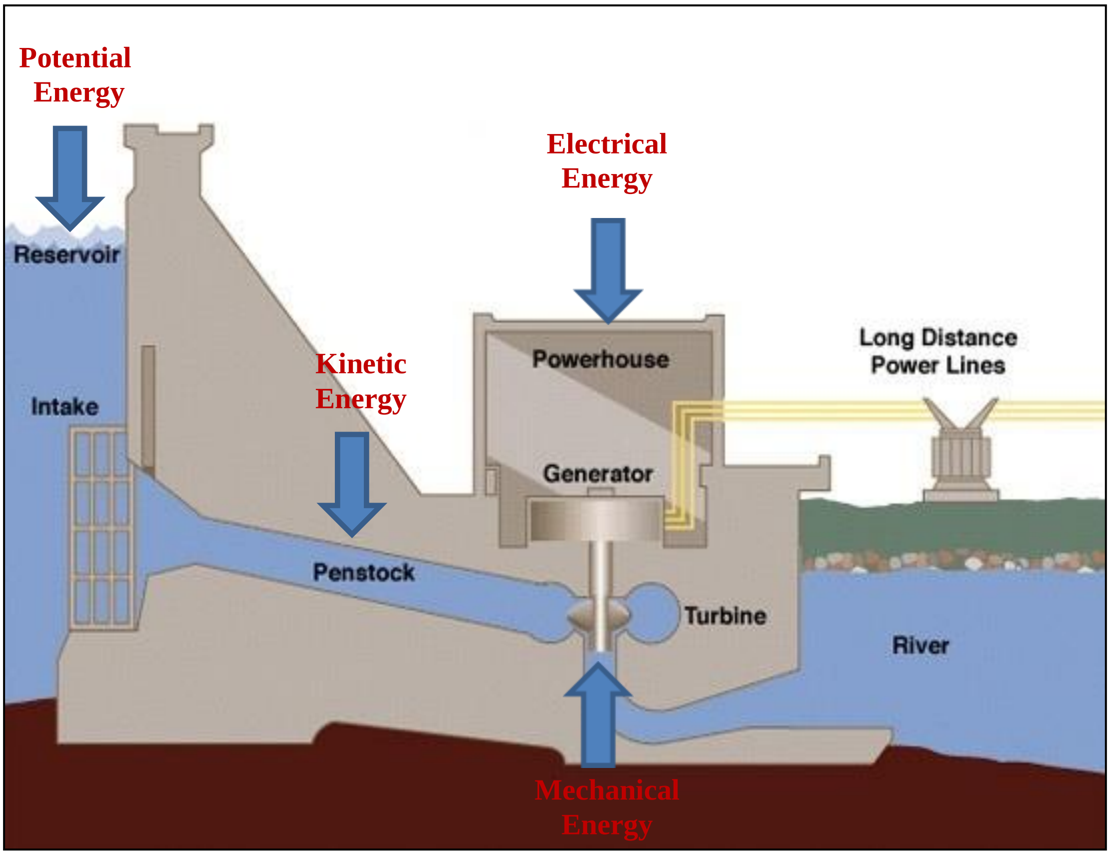

Figure 3.1: Reservoir hydropower plant (AE News, 2018).

3.1.3 Types of hydropower

Hydropower stations are classified based on their function, size and water head. Based on the function, hydropower stations are classified as runoff river scheme, storage scheme, and pumped-storage scheme. Based on the size, hydropower stations are classified as large, medium, small, mini, micro, and pico (Table 3.1). According to water head, hydropower stations are classified as high, medium, low, and ultra-low head (Table 3.2) (Bilgili et al., 2018; IPCC, 2009).

Table 3.1: Classification of hydropower based on size (IPCC, 2009).

Type	Size (MW)
large	> 500
Medium	> 100
Small	> 1-100
Mini	< 1
Micro	< 0,1
Pico	< 0,005

Table 3.2: Classification of hydropower based on water head (IPCC, 2009)

Type	Head
High head	75 m above
Medium head	40-75 m
Low head	3-40 m
Ultra-low head	<3 m

- **Runoff river scheme**

In runoff river projects, the rivers or streams are exploited for the purposes of electricity generation by placing the turbines directly on the river or stream and taking advantage of the natural flow of the river or stream to produce electricity (HARET, 2018). There is a variation in the power generated from these projects because of the variation in the water flow within the river either daily, monthly or seasonally (Kaunda et al., 2012).

- **Water diversion scheme**

In water diversion projects, a channel is used to divert part of the water from the river to penstock, which in turn transfers water to the turbine below to generate electricity (HARET, 2018).

Water diversion projects may include a reservoir that stores water for a certain period of time for the purpose of increasing the capacity of the river and then releasing water to generate electricity. These projects are also implemented without storage where the natural flow of the river is utilized as it is (Sharma and Singh, 2013).

- **Storage scheme**

In hydropower storage projects, water is stored behind a dam by a reservoir for a certain period and then allowed to release for generating electricity. Hydropower storage projects are characterized by: the ability of regulating the flow and thus control the power generated, supplying of electricity in the case of normal demand and the peak demand, and the ability of operating turbines at best efficiency and with a high degree of reliability. Hydropower storage projects are superior to runoff river projects in terms of reliability of power produced (Kaunda et al., 2012).

- **Pumped-storage scheme**

The principle of pumped-storage projects is to pump water from a lower reservoir to an upper reservoir when demand for electricity is low and then to release water to generate electricity when the demand is high. When the demand is low, water is pumped from the lower reservoir, which may be a river, a lake or an existing reservoir, using a reversible turbine by exploiting the excess electricity generated by the hydroelectric power station. The best sites to implement pumped-storage projects are the mountainous areas to take advantage of high topography for potential energy storage (Kaunda et al., 2012).

3.1.4 Hydro turbines

There are two types of turbines used in hydropower stations: reaction turbines and impulse turbines. Reaction turbines, like Kaplan and Francis turbines, are suitable for the locations with low head and high flow rate. While impulse turbines, like Pelton, Turgo, and Cross flow turbines, are suitable for the locations with medium or high head and low flow rate (Židonis et al., 2015).

- **Kaplan turbine**

Kaplan turbines are a type of axial-flow reaction turbines. They are highly suitable for low heads, between 2 to 40 m (Nasir, 2014). Kaplan turbines consist of 3 to 8 blades installed in a vertical axis. Kaplan turbines resemble Francis turbines in the working method.

Figure 3.2: Kaplan Turbine (OEERE, 2018).

- **Francis turbine**

Francis Turbines are a type of radial-flow reaction turbines, as the water enters the runner radically and exits axially. Francis turbines are suitable for a wide range of head between 10 to 350 m. They are consisting of runner blades and vanes (Nasir, 2014).

Figure 3.3: Francis Turbine (OEERE, 2018).

- **Pelton turbine**

Pelton turbines are a type of impulse turbines. They are highly suitable for high heads, between 50 to 1300 m. In Pelton turbine, there is one or more jets that hit with the turbine wheel. Each jet releases water through a nozzle and there is a valve to control the flow of water (Nasir, 2014).

Figure 3.4: Pelton Turbine (OEERE, 2018).

- **Turgo turbine**

Turgo Turbines are a type of impulse turbines. They are highly suitable for medium heads and works efficiently at different ranges of flow. In Turgo turbines, the runner is small and has a high speed and the water flows from the opposite direction of the runner (Benzon et al., 2016).

Figure 3.5: Turgo Turbine (HARET, 2018).

- **Cross flow turbine**

Cross flow turbines are a type of impulse turbines. They are suitable for heads ranging from 3 to 200 m. Cross flow turbines consist of runner and nozzle. The nozzle directs the water to runner at a specific angle and water enters the turbine wheel at an angle of 16° to the tangent of the wheel circumference (Chattha et al., 2010; Nasir, 2014).

Figure 3.6: Cross-flow Turbine (HARET, 2018).

3.1.5 Hydropower in the world

A Study by (Nautiyal et al., 2011) illustrated the reasons why small hydroelectric power projects are a key element for achieving sustainable energy development in India. First, the possibility of using water streams to provide energy safely and with little environmental and social impacts. Second, Small hydropower projects are classified as renewable sources of energy because they exploit the energy of falling water (water is a non-exhaustible source). Third, small hydropower projects are polluting free source, inexpensive, and do not need fossil fuels. Finally, small hydropower plants help develop remote areas by providing electricity, transportation and communication lines. The study also showed that India's small hydro power projects have a total potential of 15,000 MW, and only 16% of this potential are exploited for electricity generation.

A study by (Jaber, 2012) studied the obstacles facing the development of small hydropower projects in Jordan, as well as drawing attention to some small rivers and streams that can be exploited in the future as a good source of hydropower generation. In Jordan, the limited surface water resources, the high investment cost of hydropower projects, and the link between the profits of hydropower projects and the local market conditions are the obstacles facing the development of hydropower projects in Jordan. The main sources for hydropower generation in Jordan are: The King Talal dam on the Zarqa River with a rated capacity of 5 MW and a scheme at Aqaba thermal power station which utilizes the available head of returning cooling seawater, also with a capacity of 5 MW.

A study by (Alam et al., 2017) showed current hydropower sources in Nepal. This study pointed to three major river systems in Nepal that can produce 50,000 MW power, which are: Koshi River system, Gandaki River system, and Karnali River system. This study also showed that Nepal can become a major exporter of green power as it is rich in hydropower and can generate more than 90,000 MW power from its water resources. Currently, Nepal produces only 847 MW power from its water resources.

A study by (Kong et al., 2015) focused on the status of small hydropower station in China. This study showed China's interest in the development of small hydropower projects, where China has developed 44815 small hydropower stations with the installed capacity of 59.24 GW by the end of 2010. The study also showed that China has achieved a great achievement in rural electrification based on small hydropower. Small hydropower also contributed to rural economic development and improvement of peasant life style.

A study by (IRENA, 2017) showed the capital, operation and maintenance costs of small hydropower projects. The capital cost includes civil works cost and electro-mechanical equipment cost (the equipment cost is about 50% of the total cost). According to IEA, the operation and maintenance costs of small hydro power projects are about 2.2% - 3% of the total project cost. The average cost of hydropower project about USD 0.05/KWh.

Table 3.3: Comparison between different types of renewable energy in terms of global power capacity and levelized cost of electricity (Kabir et al., 2018; IRENA, 2017).

Renewable technology	**Global power capacity (GW, 2015)**	**Levelized cost of electricity(USD/KWh)**
Hydropower	1064	0.047
Bio-power	106	0.05(India) - 0.06(China)
Geothermal power	13.2	0.04-0.14
Solar PV	227	0.08-0.12
Wind power	433	0.06

A study by (Bilgili et al., 2018) showed the developments of hydropower in the world and also in Turkey. This study reviewed 6 countries which have the highest hydropower capacity in the world: China, Brazil, USA, Canada, Russia, and India, respectively. This study showed that hydropower serves more than 160 countries worldwide and provides more than 16.6% of the global electricity. The study also showed that hydropower is the most cost-effective and reliable source for Turkey and that Turkey is the top country in terms of hydropower potential in Europe with a generating capacity of 216TWh/year.

A study by (Willner, 2014) focused on three aspects: the role of hydropower in achieving energy security, the possibility of producing electricity from pumped-storage projects in Israel, proposed projects to exploit the difference in sea level between seas to produce electricity. The study showed that: Hydropower is a reliable source of electricity generation and a sustainable source in terms of environmental and social, the adoption of storage technology to produce electricity achieves high reliability and flexibility, and hydropower supplies 85% of the world's renewable electricity. The study highlighted some of the hydropower pumped-storage projects in Israel, including: Ma'ale Gilboa and Kochav ha-Yarden projects. The first project is located east of Haifa city, about 50 km away, the production capacity of this project will reach 300 MW and it is expected to provide Israel with 2.5 % of the electricity. The study also showed that Israel plans to increase its reliance on pumped-storage projects to achieve 800 megawatts by 2020. The study reviewed several projects that were planned to exploit hydropower technology for the generation of electricity: the Mediterranean Sea - Dead Sea project, the Red Sea - Dead Sea project, and the Jordan Valley hydropower pumped-storage project.

A study by (U.S.DOE, 2016) highlighted the role of hydropower technology in the development of the power sector in the U.S. First, hydropower promotes social development and creates new jobs; hydropower provided about 143,000 jobs by the beginning of 2014. Second, hydropower contributes to economic development and reduces costs; hydropower supplied the US with 10% of electricity between 1950 and 2015.The U.S. can develop hydropower capacity to reach 150 GW by 2050. Finally, hydropower reduces carbon emissions and contributes to environmental sustainability; the study showed that existing hydropower and new development contribute to the reduction of GHG emissions equivalent to $5.6*10^8$ metric tons CO_2.

3.2Renewable energy in Palestine

3.2.1 Current energy situation in Palestine

The primary energy sources in Palestine are fossil fuels (78%) and renewable energy (22%). The renewable energy sources exploited in Palestine are solar energy from water heaters and biomass energy from wood, olives and charcoal (Figure 3.7) (Abu Hamed et al., 2012).

The energy sector in Palestine faces several challenges. First, the scarcity of conventional energy resources, the high population growth, and increasing energy demand have created energy shortage and future energy crisis. The average consumption of electricity per capita is about 830 KW / hour per year and the annual consumption is expected to reach 8.4 GW/h in 2020 (PEPRI, 2012). Second, the energy market in Palestine is strongly affected by the political stability; Palestine has to import all its need (100%) of petroleum products from Israeli market, about 86% of electricity from the Israeli, about 4% of electricity from Egypt and Jordan, and about 10% of electricity from Palestine Electric Company (PEC) - Gaza. In Palestine, the cost of electricity is about 0.13 €/kWh**,** this cost is highest when compared to the neighboring countries since Palestinian energy is imported and it is subjected to taxes **(**Yaseen, 2005). Finally, the use of conventional energy sources has significant impacts on the environment (PEPRI, 2012). Palestine needs to reduce dependence on imported energy and exploit cheap and sustainable sources of energy to ensure the security of the power supply at an acceptable cost.

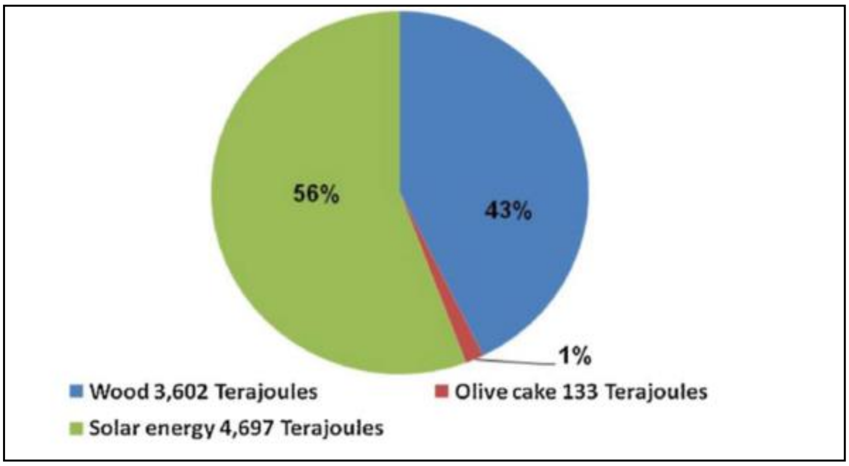

Figure 3.7: Renewable energy sources in Palestine (Abu Hamed et al., 2012).

A study by (Yaseen, 2005) highlighted the political, technical, marketing and social barriers that hinder the development of the renewable energy sector in Palestine. Political barriers include the lack of governmental interest in the development of renewable energy sources, the obstacles imposed by the occupation on the import and export movement and the absence of regulations and provisions governing the renewable energy sector. Technical barriers include lack of human capacity, vocational training and pilot projects in the field of renewable energy. Marketing barriers include the high investment cost in renewable energy and the absence of private sector participation in the development of the renewable energy market. Social barriers include lack of awareness about the importance of renewable energy sources and low family income impedes investment in renewable energy.

3.2.2 Types of renewable energy in Palestine

- **Solar energy**

A study by (Juaidi et al., 2016) showed the facts that made the exploitation of solar energy for electricity generation available in Palestine: the high sunshine hours (3000 hours/year), the presence of a large number of rural villages not connected to the electricity network and the high cost of fossil fuels in Palestine.

There are several political, technical and financial restrictions that hinder the exploitation of solar energy to generate electricity in Palestine. First, political restrictions include the prevention of the occupation of any Palestinian attempts to generate electricity using solar energy in the area C, which forms about 60% of the Palestinian areas. Second, technical constraints include the lack of technical and human capacity in solar energy in the local market. Finally, financial constraints include the inability of Palestinians to invest in solar energy due to the high cost of investment in this field (PEPRI, 2012).

- **Wind energy**

A study by (Ismail et al., 2013) highlighted a huge project launched in Palestine with the aim of exploiting wind energy to produce electricity. This project was implemented at Alahli Hospital in Hebron city with the aim of providing the hospital with more than 40% of its energy needs at a cost of 1.63 million dollars.

- **Biomass energy**

A study by (Ismail et al., 2013) confirmed that bio energy is a reliable source for Palestinians. Palestinians in rural areas rely heavily on agriculture and livestock, which are considered an important source of biogas production.

- **Geothermal energy**

A geothermal energy project was implemented in Palestine by MENA geothermal company. This project was implemented in a residential complex in Ramallah city in order to preserve a comfortable temperature for the room all the time. This project has shown a decrease in costs paid for heating and cooling by more than 70% (Ismail et al., 2013; Juaidi et al., 2016).

3.2.3 Laws, polices, and strategies of renewable energy in Palestine

A study by (Marei, 2016) highlighted the regulatory framework for renewable energy in Palestine. This study showed that electricity in Palestine is fully controlled by the Israeli Electric Cooperation (IEC), and that the UN has confirmed Israel's violation of the Palestinian electricity network. The study stressed that any future agreements between Palestine and Israel on electricity should ensure easy access of the Palestinians to the electricity system, as well as the removal of the electricity charges imposed on imported electricity by Palestinians. The study highlighted the renewable energy strategy in Palestine and explained that its goal is to utilize renewable energy sources to get 10% of electricity by 2020. The study also showed that the approval of regulations and legislation related to renewable energy technology, and the existence of sufficient financial resources and capabilities in the field of renewable energy are basic stipulations for achieving the objective of the strategy. The study reviewed the law prepared by the Palestinian government regarding renewable energy in Palestine, which defines the responsibility of the Palestinian Electricity Transmission Company (PETL), Palestinian Energy And Natural Resources Authority *(*PENRA), Palestine Electric Company (PEC), and electricity distribution companies (EDCs) for improving the renewable energy sector in Palestine.

3.3The Integrated Spatial Information System of the Ministry of Local Government (GeoMOLG):

GeoMOLG is the first integrated spatial information system in Palestine, developed and operated by the Ministry of Local Government (MOLG) and in cooperation with the German Society for International Cooperation (GIZ).The utility of GeoMOLG system is to provide a large amount of spatial information such as streams, agricultural land classification, classification of the West Bank into areas A, B and C, contour, biodiversity areas, aerial photos, and approved urban master plan.

GeoMOLG system has easy access to spatial information and provides information with high accuracy (MOLG, 2014).

In this research, GeoMOLG application was used to determine the potential sites for hydropower generation, determining the catchment area for each hydropower potential site, determining the head available for hydropower generation based on the topographic map, and determining the length and slope of the stream.

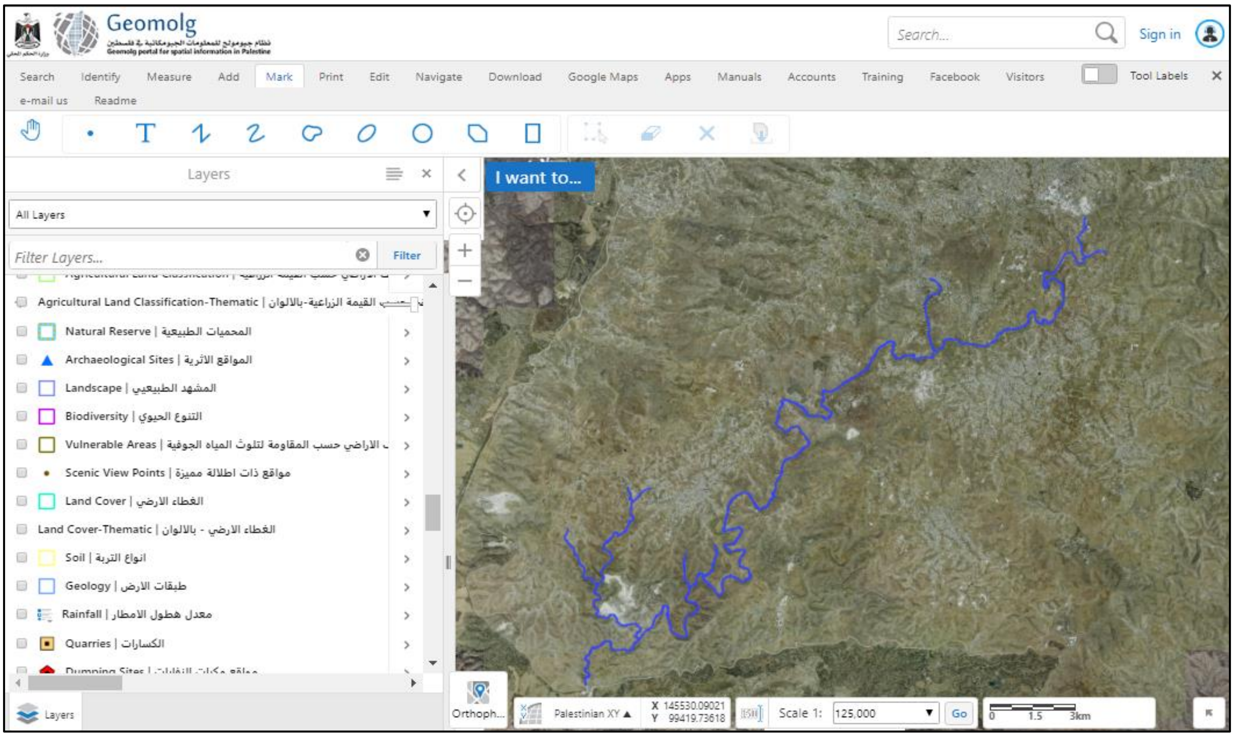

Figure 3.8: The Integrated Spatial Information System of the Ministry of Local Government (GeoMOLG).

Chapter Four

METHODOLOGY

4.1 Background

For the estimation of hydropower amount that can be generated from Wadi Al-Samen, two methods were adopted. The first method was Runoff river and relied on exploiting the natural flow of the stream to generate electricity as it is. Four sites were adopted to generate hydropower using runoff river method. The second method was to store water by a reservoir for a certain period and then release it to generate electricity. Three alternatives were adopted to store water flowing into Wadi Al-Samen.

4.2 Hydropower generation methods

4.2.1 Runoff river scheme

4.2.1.1 Sites selection

The potential Hydropower generation sites were selected depending on the head and water discharge. The sites were selected within the first 28 km of the stream. The remaining part of the stream is the southern part located in area C which is under the control of the Israeli occupation, which may hinder the exploitation of this part. The stream was divided into segments and the potential energy was calculated for each segment. Four locations were proposed for hydropower generation.

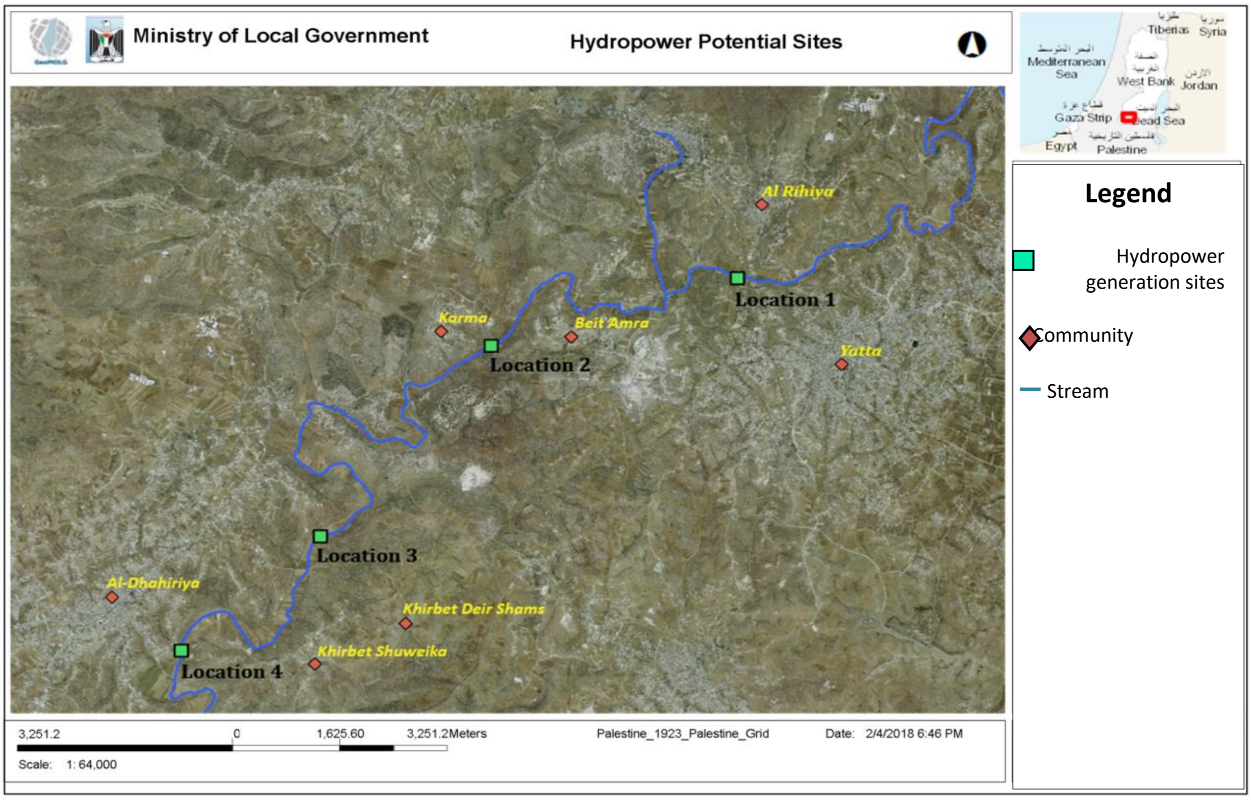

Figure4.1: Hydropower generation sites.

Location1: This location was selected considering head and water discharge. It is characterized by high head and low water discharge compared to other sites. The reason for selecting this site is its nearness to some of the communities such as Yatta and Al Rihiya, therefore this location can provide electricity for some parts of these communities with an acceptable cost. It is located in area A, which is under the control of Palestinian Authority.

Location 2: This location is characterized by high water discharge coming from a large drainage area. It is located near Karma village and can be exploited to provide electricity for some of the village houses. It is located in area C, which is under Israel control, which may hinder the exploitation of this site.

Location 3: This location is characterized by high head and high water discharge and thus the possibility of generating a high power compared to other sites. It is located near some communities such as Al-Dhahiriya City, Khirbet Deir Shams, and Khirbet Shuweika, therefore it can be used to supply parts of these communities with electricity. It is located in area A, which is under the control of the Palestinian Authority.

Location 4: This location is characterized by low head and high water discharge compared to other sites. The reason for selecting this site is its nearness to Al-Dhahiriya City and thus it can provide parts of the city with electricity with an acceptable cost. It is located in area A, which is under the control of Palestinian Authority.

Table 4.1: Hydropower generation sites, with distance, elevation and coordinates along Wadi Al - Samen.

Location No.	Distance from the beginning of Wadi Al - Samen (Km)	Elevation (m)	Coordinate	
			X	Y
1	7.5	686	157023	96252
2	13.2	635	153303	95148
3	21.6	565	150721	92034
4	25.7	530	148620	90167

4.2. 1.2 Hydrology

- **Catchment Area**

The catchment area of Wadi Al-Samen was determined by identifying the area from which water flows into the stream, based on the topographic map using the GeoMOLG software.

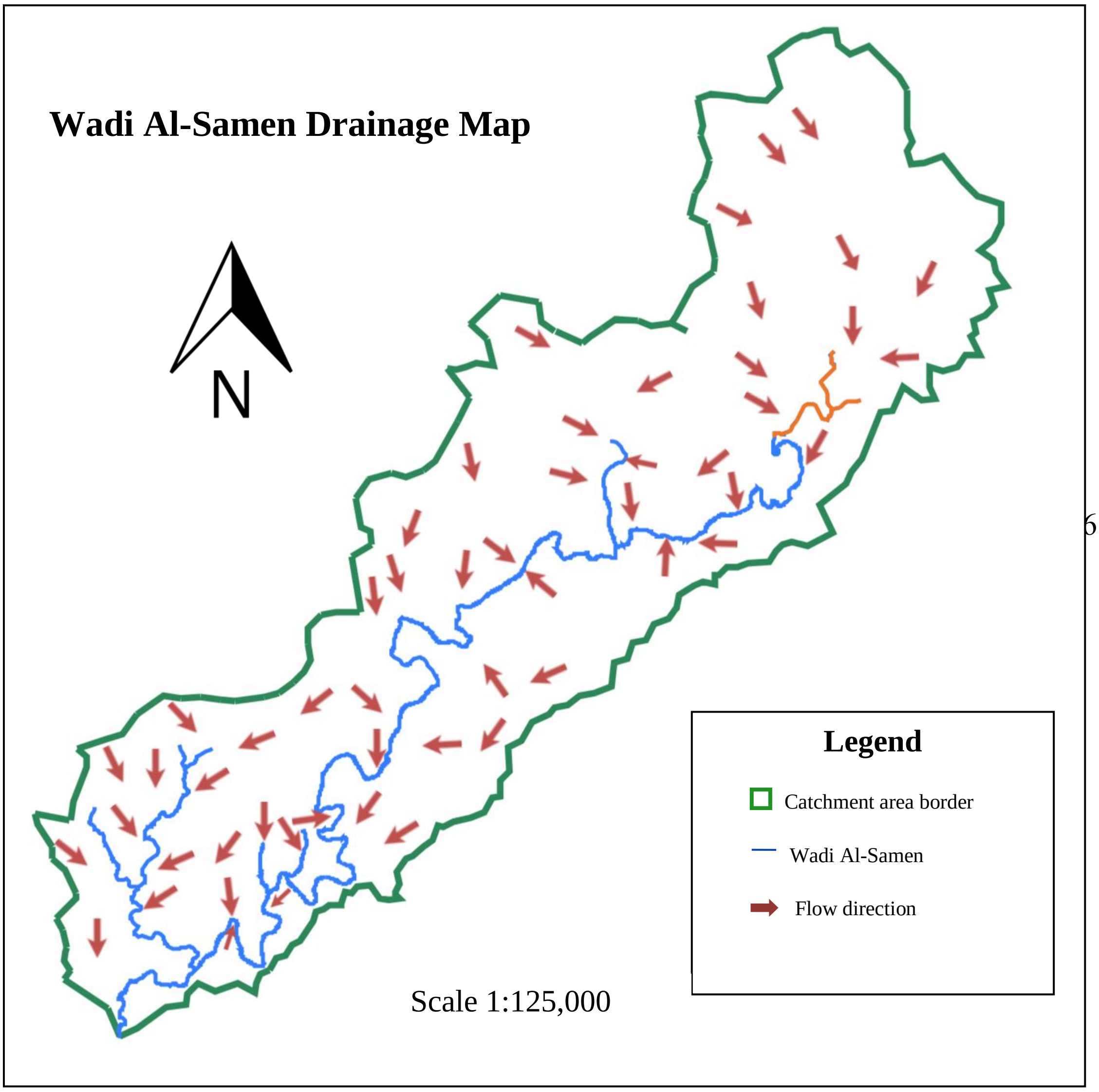

Figure 4.2: Wadi-Al-Samen drainage map.

- **Rainwater and wastewater quantity**

The quantity of wastewater flowing into each hydropower generation site during dry and wet seasons was calculated, considering the quantity of water lost by evaporation and infiltration, using the following equation:

Net wastewater quantity (m^3/d) = wastewater quantity (m^3/d) - infiltration quantity (m^3/d) - evaporation quantity (m^3/d).

Table 4.2: Water losses from Wadi Al-Samen during dry and wet seasons (Tal et al., 2014).

Season	Evaporation (%)	Infiltration (%)	Total loss (%)
Dry	6.5	64.5	71
Wet	4	72	76

The quantity of rainwater flowing into each hydropower generation site was calculated based on the catchment area and mean daily rainfall rate considering evaporation, infiltration and number of rainy days, as shown in the following equations: Mean daily rainfall (mm) = mean annual rainfall (mm) / number of rainy days.

Net daily rainfall (mm) = mean daily rainfall (mm) - infiltration (mm) - evaporation (mm).

Quantity of rainwater (m^3/d) = {catchment area (km^2) * net daily rainfall (mm)}*1000

Table 4.3: The main Rainwater discharge regions in Wadi Al-Samen, with the mean annual rainfall rate, 2012-2017 (WAFA, 2017).

Regions	Mean annual rainfall (mm)
Hebron	595.9
Yatta	389.3
Dura	507.2
Al-Dhahiriya	336.5

4.2.1.3 Water head

The head of water was calculated by taking the difference in height between the upstream intake point and the downstream discharge point, using the topographic map as shown in Figure 4.3.

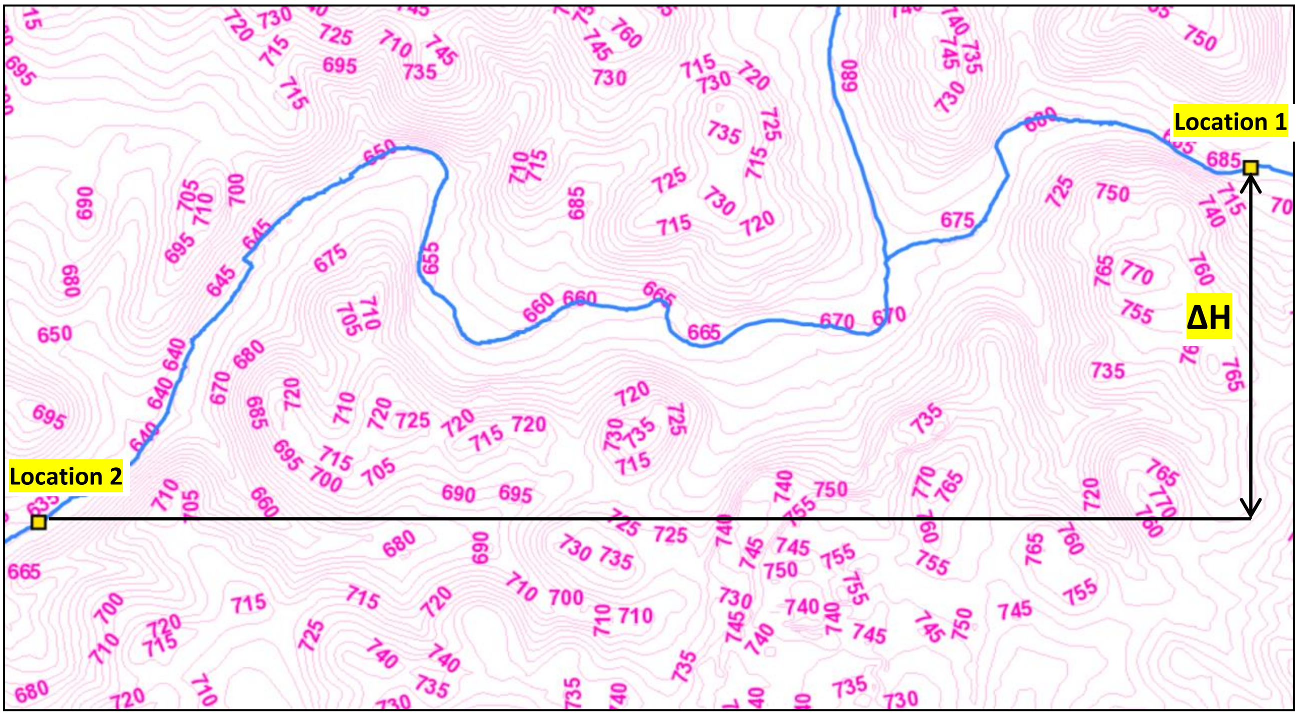

Figure 4.3: Head difference between the first and second hydropower generation site.

4.2.2 Storage scheme

The aim of storage is to adjust the flow patterns in Wadi Al-Samen because water flow rate through the stream varies throughout the year. This flow is low in summer and high in winter. By using reservoir, water can be stored in dry and wet seasons and then utilized during the peak demand period to produce electricity.

4.2.2.1 Criteria for reservoir site selection

The potential site of the reservoir was selected at a height of 560 m, considering the following factors:

1. The location of the reservoir was selected within area A and B, which are under the control of the Palestinian Authority.

2. Land availability and price: The location of the reservoir was selected so that the land areas on which the reservoir will be located, as well as the area adjacent to the reservoir, are classified within land with low and medium agricultural value.

3. Distance from the residential areas: The reservoir site was selected to be far enough from residential areas. There are 6 residential communities around the reservoir area, which are: Al-Dhahiriya, Khirbet Deir Shams, Khirbet Shuweika, Khirbet Al-Simia, Abu Al-Ꞌ Urqan, and Abu Al-Ghuzlan. The distance between the reservoir point and the nearest houses pool in each community was measured based on the aerial photo, as shown in Table 4.4.

Table 4.4: Communities surrounding the reservoir area, with the distance between the reservoir point and the nearest pool of houses in each community.

Community	**Distance between the reservoir point and the nearest houses pool (m)**
Khirbet Deir Shams	1380
Al-Dhahiriya	800
Khirbet Shuweika	960
Khirbet Al-Simia	2760
Abu Al-ꞌUrqan	2300
Abu Al-Ghuzlan	2000

4. Hydrological study: The potential site of the reservoir was selected to collect a large amount of water from different locations. The catchment area of the reservoir was calculated using GeoMOLG software. The quantity of rainwater and wastewater discharged into the reservoir area was calculated considering water loss based on Table 4.2.

5. Topographic study: The topographic study of the reservoir area helped determine the proposed dam shape. The site is considered as a wide valley. The embankment dam is a good choice in this case (USACE, 2004).

6. Geological study: The reservoir area consists of Cenomanian rocks, mainly composed of dolomite and lime. The soil that spreads in the reservoir area is

the Rendzians soil, characterized by low strength, high lime ratio, and high water permeability. The geological study of the reservoir area helped to propose the embankment dam as a suitable dam type (USACE, 2004).

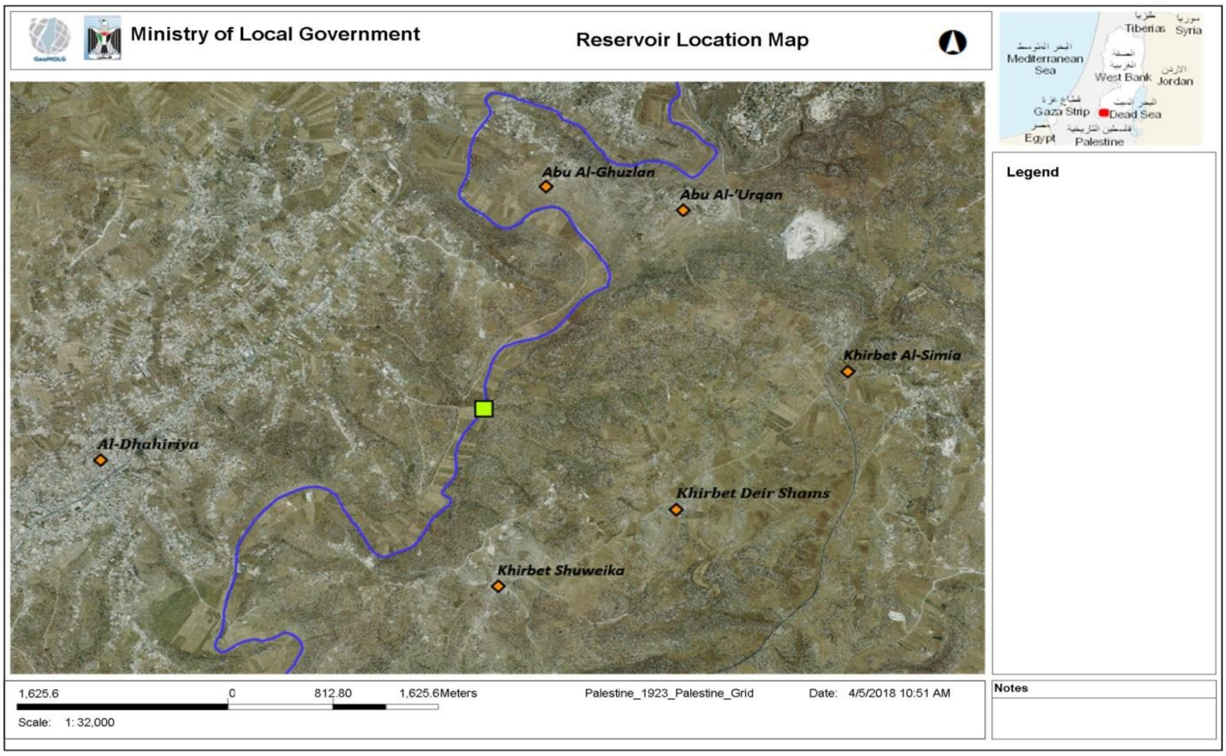

Figure 4.4: Location of the reservoir

4.2.2.2 Wet season storage scheme

- **Flow rate**

There are two sources of water accumulated in the reservoir area during the wet season, rainwater and wastewater. The total volume of water that can be collected in the reservoir in wet season was calculated.

Total volume of water (m^3) = wastewater volume (m^3) + rainwater volume (m^3).

- **Water Head**

The height of water level in the reservoir was taken as the only water head, due to the low slope in the downstream reservoir area.

- **Reservoir storage capacity and dimension**

Three alternatives were proposed for the better exploitation of part of the total volume of water for generating hydropower while at the same time preserving areas under the reservoir from drought. The dimensions of the reservoir were selected depending on the volume of water.

4.2.2.3 Dry season storage scheme

- **Flow rate**

The only source of water in the reservoir in dry season is wastewater. The quantity of wastewater flowing daily to the reservoir area was calculated considering the evaporated and infiltrated quantity.

It was proposed to utilize wastewater for hydropower generation without storage; because storage of wastewater in the reservoir is insufficient to create high water levels and the result is low water pressure and low power output.

- **Water head**

The head of the water was measured based on the topographic map, which is the difference in elevation between the stream beginning point and the reservoir bottom point.

4.3 Power Calculations

The output power of hydroelectric turbine was calculated using the following equation:

$$P = \eta \rho Q g H \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where:

P = available power (W).

η = overall efficiency ($\eta_{turbine} * \eta_{generator} * \eta_{trans}$).

ρ = density of water (1000 kg/m^3).

Q = flow rate passing through the turbine (m^3/s).

g = acceleration of gravity (9.81m/s^2).

H= Water fall height (m).

4.4 Turbine description

The most commonly used types of turbine are Kaplan, Francis, Pelton, Turgo, and cross -flow. The suitable types of turbines were selected depending on the water head and the flow rate using the next figure.

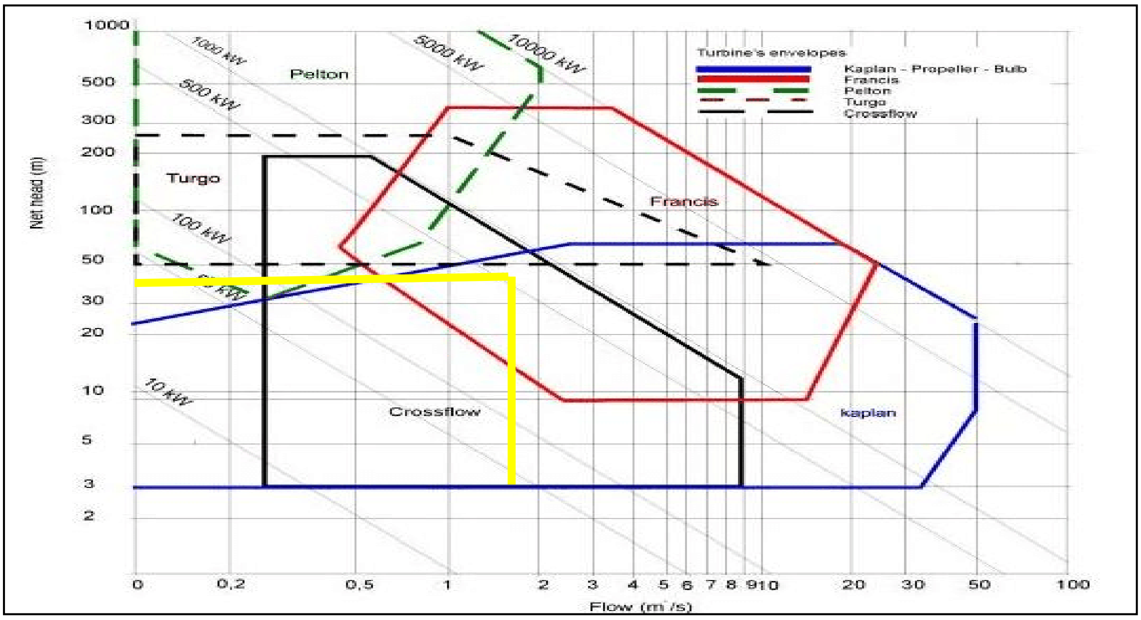

Figure 4.5: Turbine selection chart based on head and flow rate (Adejumobi and Shobayo, 2015).

4.5 Turbines efficiency

The efficiency of the proposed turbines was determined using the following table.

Table 4.5: Typical best efficiencies of small turbines (TEMİZ, 2013).

Turbine Type	Best Efficiency
Kaplan single regulated	0.91
Kaplan double regulated	0.93

Francis	0.94
Pelton n nozzle	0.90
Pelton 1 nozzle	0.89
Turgo	0.85

4.6 Generator description

There are two main types of generators used in hydroelectric power generation, which are: induction generators and synchronous generators. The appropriate types of generators were suggested depending on the power output levels.

Chapter Five

RESULTS AND DISCUSSIONS

5.1 Runoff river scheme

5.1.1 Quantity of wastewater

The main sources of wastewater in Wadi Al-Samen are Hebron City, Kiryat Arbaa Colony and Al-Fawwar camp. These communities are connected to sewage networks and discharge wastewater daily into the stream. The quantity of wastewater flowing from Hebron City and Kiryat Arbaa Colony is about 10500 m^3/d (PWA, 2012 as cited in ARIJ, 2015). Al-Fawwar Camp generates about 0.0796 Mm^3 of wastewater per year (ARIJ, 2009). The daily quantity of wastewater produced from Al-Fawwar camp and discharged to Wadi Al-Samen is 154.8 m^3/d, as shown in Table 5.1.

Table 5.1: Calculations of the quantity of wastewater produced from Al-Fawwar camp and discharged to Wadi Al-Samen (PCBS; ARIJ, 2009).

Community	Population number (2016)	Average household size	No. of housing units	% of housing units connected to the sewage network	Average wastewater production L/cap. day)(	The quantity of wastewater entering the sewage network and discharged to Wadi Al-Samen (m^3/d)
Al-Fawwar Camp	8642	5	1728	70%	25.6	**154.8**

The total quantity of wastewater flowing into Wadi Al-Samen = 10500 + 154.8 = 10655 m^3/d.

The first proposed location receives wastewater from Hebron City and Kiryat Arbaa Colony. The other locations receive wastewater from the previous sites and from Al-Fawwar Camp. Table 5.2 shows the net quantity of wastewater reaching each hydropower generation site during dry and wet seasons.

Table 5.2: The quantity of wastewater with infiltration, evaporation and net wastewater quantity reaching each hydropower generation site during dry and wet seasons.

Location No.	Wastewater Quantity (m³/d)	Dry Season			Wet Season		
		Infiltration (m³/d)	Evaporation (m³/d)	Net Quantity (m³/d)	Infiltration (m³/d)	Evaporation (m³/d)	Net Quantity (m³/d)
1	10500	6772.5	682.5	3045	7560	420	2520
2	10655	6872.475	692.575	3089.95	7671.6	426.2	2557.2
3	10655	6872.475	692.575	3089.95	7671.6	426.2	2557.2
4	10655	6872.475	692.575	3089.95	7671.6	426.2	2557.2

➡ In the wet season, the net quantity of wastewater reaching the hydropower generation sites is low compared to the dry season, due to the increase in total water losses in wet season (76%) compared to the dry season (71%).

5.1.2 Quantity of rainwater

The catchment area of Wadi Al-Samen is about 200 km² with an average annual rainfall of 595.9 mm in the northern parts and decreases to 336.5 mm in the southern parts.

Each generation site receives rainwater from different drainage regions. The first site receives rainwater from Hebron and Yatta regions, the second and the third sites receive rain water from Hebron, Yatta and Dora regions, and the last site receives rainwater from the previous regions and from Al-Dhahiriya region. The average annual rainfall rate of the generation sites catchment area is 492.6, 497.5, 497.5, and 457.2, respectively.

The number of rainy days was taken from Hebron station for the years 2014, 2015, and 2016, which was 36, 56, and 50, respectively (PCBS). The average number of rainy days in Wadi Al-Samen catchment area was estimated to be **47 days**. The mean daily rainfall of the generation sites catchment area (mm) = 10.48, 10.59, 10.59 & 9.73, respectively.

Table 5.3: Hydropower generation sites with average annual rainfall, daily rainfall, evaporation, infiltration, net flow, the catchment area and rainwater runoff volume.

Location No.	Average Rainfall (mm/y)	Rainfall (mm/d)	Evaporation (mm/d)	Infiltration (mm/d)	Net Flow (mm/d)	Catchment Area (km²)	Rainwater runoff Volume (m³/d)
1	492.6	10.48	0.419	7.546	2.515	74.6	187649
2	497.5	10.59	0.423	7.621	2.540	107	271826
3	497.5	10.59	0.423	7.621	2.540	133.8	339909
4	457.2	9.73	0.389	7.004	2.335	142.3	332219

➡ Rainwater runoff volume is increasing when going downward in the stream, due to the increase drainage area when going downwards, but runoff volume begins to decrease as it approaches the southern regions because of the low rainfall rate in the southern regions of the stream.

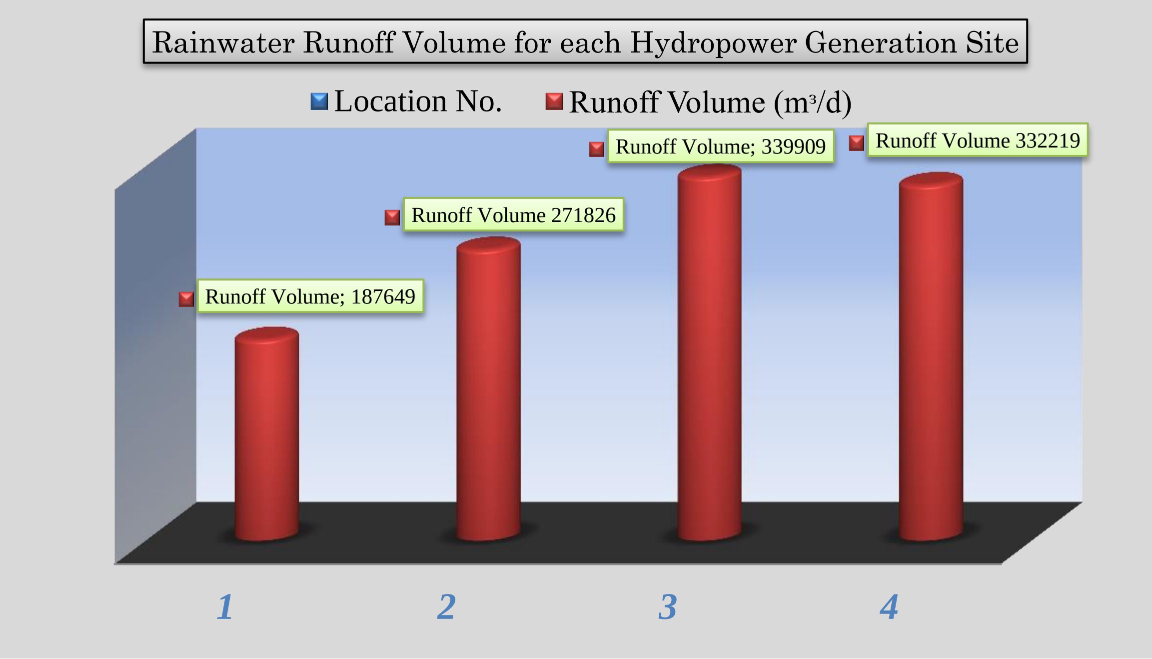

Figure 5.1: Rainwater runoff volume for each hydroelectric power generation site.

Table 5.4: Total quantity of water flowing to the hydropower generation sites during wet season (rainy days **=47 day**).

Point No.	Q wastewater (m^3/d)	Q rainwater (m^3/d)	Q Total (m^3/d)
1	2520	187649	190169
2	2557	271826	274383
3	2557	339909	342466
4	2557	332219	334776

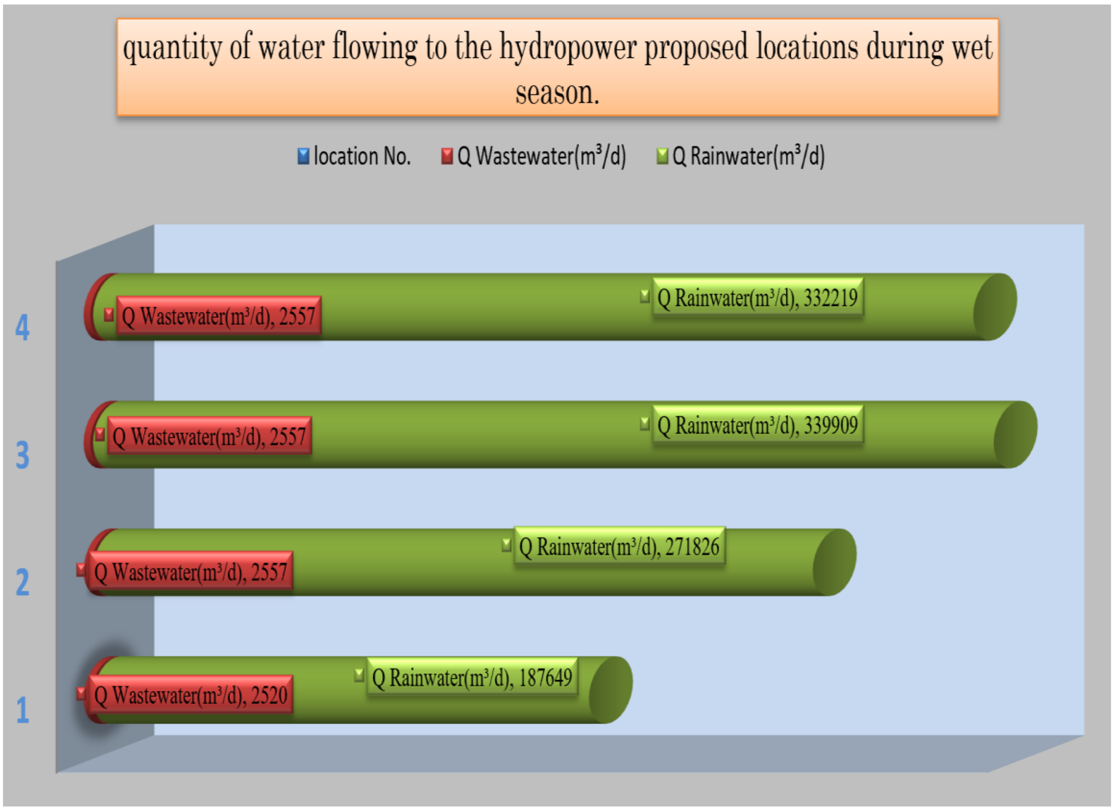

Figure 5.2: Total quantity of water flowing to the hydropower generation sites during wet season (47 days).

5.1.3 Head of water

The heights of the hydropower generation sites are (686, 635, 565 & 530) m, respectively. The head of water for the generation sites are (73, 51, 70 & 35) m, respectively.

➡ According to (IPCC, 2009), Location 1, 2 &3 are classified as medium head locations, while location 4 is classified as low head location.

5.1.4 Turbine description

The type of turbine for each generation site was selected depending on Figure 4.5. The results show that: the suitable turbine for the three first locations, which are classified as locations with medium head, is Francis turbine with efficiency up to 94%. The suitable turbine for the last location, which is a location with low head, is Kaplan turbine with efficiency up to 93%, as shown in Table 4.5.

5.1.5 Generator description

The Induction generators are proposed to be used for several reasons: they are cheap and need less maintenance compared to Synchronous generators, can work at different speeds with constant frequency and suitable for low power output level (less than 10 MW) (Kunwor, 2012). The efficiency of induction generator is 85 % (Srpcic, 2012). The efficiency of transmission (ηtran) is assumed to be 95%.

5.1.6 Power output

The hydroelectric power generated from each location during dry and wet seasons was calculated using Equation 4.1, as shown in Table 5.5.

Table 5.5: The daily quantity of hydropower generated by each hydropower generation site during dry and wet season.

Location No.	ΔH (m)	η_{total}	Dry Season **(245 days)**		Wet Season **(120 days)**			
					With Rain **(47 day)**		Without Rain **(73 day)**	
			Q (m^3/s)	Power (KW)	Q (m^3/s)	Power (KW)	Q (m^3/s)	Power (KW)
1	73	0.76	0.035	19.2	2.2	1198	0.0292	16
2	51	0.76	0.036	13.6	3.17	1208	0.0296	11.2
3	70	0.76	0.036	18.6	3.96	2069	0.0296	15.4
4	35	0.75	0.036	9.2	3.87	998	0.0296	7.6

➡ In dry season, the impact of the head was significant on the amount of power produced from each location; the first location with the highest head (73 m) produced the largest amount of power, while the last location with the lowest head (35 m) produced the least amount of power.

➡ In wet season (47 days), the impact of flow was significant on the amount of power produced from each location; the third location with the highest amount of flow (3.96 m^3/s) produced the highest amount of power compared to other sites.

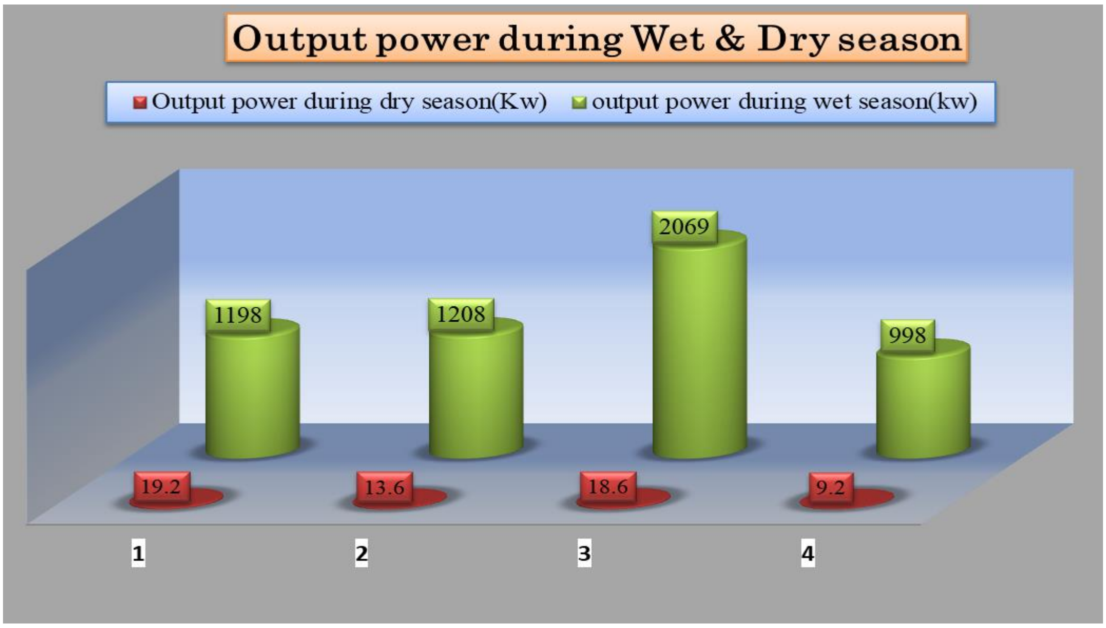

Figure 5.3: The output power generated by each hydropower generation site during dry season and wet season (wet season = 47 days).

5.2Storage scheme

5.2.1 Wet season storage scheme

- **Wastewater flow rate**

During wet season, wastewater flows daily to the reservoir area. The total quantity of wastewater flowing towards the reservoir area is 10655 m^3/d, coming mainly from Hebron City, Kiryat Arbaa Colony, and from Al-Fawar Camp. Using Table 4.2, the evaporation rate = 0.04* 10655= 426.2 m^3/d and the infiltration rate = 10655*0.72 = 7672m^3/d.

The total quantity of wastewater that reaches the reservoir area (net quantity) = 10655 - 426.2 - 7672 = 2557 m^3/d. Assume the wet season is 4 months. The cumulative quantity of wastewater in reservoir after 4 months = 2557 *4 *30 =**306840 m^3**.

• Rainwater flow rate

The catchment area of the reservoir is about 137.7 km². The main rainwater discharge regions are Hebron, Yatta, Dura, and Al-Dhahiriya. The annual rainfall rate for the discharge regions is shown in Table 4.3. The average rainfall rate for the reservoir catchment area = ∑annual rainfall rate for the discharge regions /4 = 497.5 mm /y.

Taking the number of rainy days = 47 day, the daily rainfall rate in the reservoir catchment area = 497.5/47 = 10.58 mm.

By using Table 4.2: The evaporation rate = 10.58 * 0.04 = 0.42 mm/d and the infiltration rate = 10.58 * 0.72 = 7.62 mm/d. Surface runoff = 10.58 - 0.42 – 7.62 = 2.54 mm.

The daily volume of runoff water of the reservoir catchment area = 2.54 * 137.7 *1000 = 349758 m^3/d. After 47 day, the runoff volume = 349758*47 = **16.4 Mm^3**.

The total quantity of wastewater and rain water that can be collected from the reservoir catchment area during wet season = Q_{total} = (16.4 *10^6 + 306840 **=16.74 Mm^3**.

• Reservoir storage capacity and dimension

Three alternatives were proposed for the better utilization of part of the total water quantity:

Alternative 1: The storage of 5% of the total water quantity. The storage quantity = Q1 = 16.74 * 10^6 * 0.05 = **837000 m^3**.

Alternative 2: The storage of 15% of the total water quantity. The storage quantity = Q2 = 16.74 * 10^6 * 0.15 = **2,511,000 m^3**.

Alternative 3: The storage of 25% of the total water quantity. The storage quantity = Q3 = 16.74 * 10^6 * 0.25 = **4,185,000 m^3**.

The reservoir surface area for each alternative was determined depending on the storage quantity and the water head as shown in Table 5.6.

Table 5.6: Storage alternatives with, storage quantity, water head, and reservoir surface area.

Alternative	**Storage quantity (m^3)**	**Water head (m)**	**Reservoir surface area (L*W) (m^2)**
1	837000	10	450 * 200
2	2,511,000	10	650 * 300
3	4,185,000	10	1200 * 350

- **Electro - mechanical equipment's**

The water head of the reservoir is 10 m. It was proposed to use **Kaplan** turbine, with efficiency up to 93 %, because it is more suitable for low head and is able of working with all ranges of flow rate (Ferreres and Font, 2010).

The Induction generator was suggested to be used, with an efficiency of 85 % (Gregor, 2012). The efficiency of the transmission is assumed to be 95%. The overall efficiency = 0.93 * 0.85 * 0.95 = **0.75**

- **Output power**

Assuming the turbine operates **1 hour** a day:

The first alternative:

➡ The storage quantity = 837000 m^3. Assume the utilization of 50000 m^3 per day. The flow rate (m^3/s) = 50000 / (60*60) =13.88 m^3/s.

➡ The output power = 0.75 * 1000 * 13.88 * 9.81 * 10 = 1021.2 KW.

➡ The storage quantity will suffice for 16.7 days. The amount of power produced after 16.7 days = 17095 KW.

➡ No. of Storage times = (16.74 * 10^6) / 837000 = 20 times.

➡ Total amount of power = 20 * 17095 = 341,900 KW.

The second alternative:

➡ The storage quantity = 2,511,000 m^3. Assume the utilization of 110000 m^3 per day. The flow rate (m^3/s) = 110000 / (60*60) = 30.55 m^3/s.

➡ The output power = 0.75 * 1000 * 30.55* 9.81 * 10 = 2248 KW.

➡ The storage quantity will suffice for 22.8 days. The amount of power produced after 22.8 days = 51254.4 KW.

➡ No. of Storage times = (16.74 * 10^6) / 2,511,000 = 6.6 times.

➡ Total amount of power = 6.6 * 51254.4 = 338279 KW.

The third alternative:

➡ The storage quantity = 4,185,000 m^3. Assume the utilization of 150000 m^3 per day. The flow rate = 150000/ (60*60) = 41.66 m^3/s.

➡ The output power = 0.75 * 1000 * 41.66 * 9.81 * 10 = 3065.1 KW.

➡ The storage quantity will suffice for 27.9 days. The amount of power produced after 27.9 days = 85516.3 KW.

➡ No. of Storage times = (16.74 * 10^6) / 4,185,000 = 4 times.

➡ Total amount of power = 4* 85516.3 = 342065 KW.

5.2.2 Dry season storage scheme

During dry season, the quantity of wastewater flowing daily towards the reservoir = 10655 m^3. Using Table 4.2, the evaporation rate = 10655* 0.065 = 692.6 m^3 /d and the infiltration rate = 10655 * 0.645 = 6872.5 m^3/d. The net wastewater quantity = 10655 - 692.6 – 6872.5 = **3090 m^3/d**.

The daily flow rate = 3090/(24*3600) = 0.0357 m^3/s.

The head of water = 759 – 680 = **79m**.

➡The output power = 0.75 * 1000 * 0.0357 * 9.81 * 79 = **20.75** KW.

Assume dry season = **245 days.** The total power after 245days = 20.75 *245= 5083.75 KW.

5.3 Runoff river scheme or Storage scheme

There is a difference in the total power produced from runoff river and reservoir schemes. The results show that: In dry season, runoff river is more feasible for hydropower generation compared with the reservoir. While in wet season, the reservoir is more feasible for hydropower generation. Table 5.7 shows the major differences between runoff river and reservoir schemes.

5.4 Discussion about how the site affects costs

The sites were chosen so that the cost is minimal for electrical installations and periodic maintenance. For runoff rivers, the four sites were chosen to be close to residential areas and did not require expensive electrical wiring and to get as much energy as possible. The greater the distance between the location of power production and the residential area, the greater the cost. As for dams, they are structurally expensive, but effective in terms of energy production.

When comparing the runoff river and dam in terms of cost we find that:

- The cost of constructing the dam is much higher than the cost of constructing the four sites of the runoff river.

- The power generated from the dam is much higher than the power generated from the four sites of the runoff river.

- For runoff river sites, the cost of energy generation is cheap, and the cost of maintenance is low compared to dams.

Table 5.7: Comparison between runoff river scheme and reservoir scheme

Technology	**Power output**		**Power reliability**	**Environmental impacts**	**The possibility of use for other purposes**
	Dry season	**Wet season**			
Runoff river	Total power generated daily by the four locations = **(60.6 KW).** Total power in dry season = (60.6*245) = **14.85 MW**.	Total power generated by the four locations on a rainy day = **(5473 KW).** Total power generated by the four locations on a day without rain = **(50.2 KW).** Total power in wet season = (5473*47) +(50.2*73) = **261 MW**.	The generating energy is affected by the flow variation in the stream	Few environmental impacts	Not possible
Storage	Total power generated daily = **20.75 KW.** Total power in dry season = (20.75*245) = **5 MW.**	Total power generated from each alternative in wet season = about **(340 MW**).	Flow regulation and thus control of generated power	- Spread of mosquitoes and odors - Pose a danger to humans - Loss of number of agricultural land	The possibility of exploiting water for agricultural purposes, if it treated

➡ The runoff river is more feasible for hydropower generation in dry season, due to the production of power from four locations compared to their production from one location below the reservoir.

➡ The reservoir is more feasible for hydropower generation in wet season, due to the storage of large amounts of water from large discharge area (about 137.7 Km^2) and the ability to control flow and thus control the produced power.

5.4 Questionnaire Analysis

This part of the chapter analyzes and discusses the results of the questionnaire. The questionnaire was distributed to: different age categories, different levels of education like BSc, MSc, and PhD, and different work categories like Government, Municipality, NGO, Universities, Donor, and Private sector. The items of the questionnaire were divided into three main items:

- **Renewable energy development plans, private sector investment in renewable energy, and awareness of the importance of using renewable energy sources.**

There is not enough awareness of the importance of using renewable energy sources, as the response ratio for awareness did not exceed 50%, and therefore there is a need to raise awareness of the importance of reliance on renewable energy. There are future plans to develop the renewable energy sector in Palestine (response ratio = 73.9%) and stimulate the private sector to invest in renewable energy (response ratio = 47.8%).

- **The laws regulating renewable energy and stimulating the use of hydropower technology, and the interest of government institutions to support and develop renewable energy projects.**

There are some laws regulating the renewable energy sector in Palestine, but there is not enough knowledge of these laws, since the response rate for the existence of laws did not exceed 30.5% Therefore, these laws need to be developed and published through the municipalities and various governmental institutions. Ithas been shown that municipalities support the development of renewable energy projects (response ratio = 52.1%). As for hydropower, it has also been shown that there is little interest in the development of hydropowertechnology, since the response rate for the existence of laws that promote the use of hydropower did not exceed 26.1%. The Israeli occupation is one of the obstacles that prevent the exploitation of hydroelectric power because of its control over most of the surface water sources in Palestine.

- **Experiences and knowledges in the field of renewable energy and in the implementation of renewable energy projects, and the existence of researches, studies and equipment's related to renewable energy.**

Palestine has experiences and knowledges in the field of renewable energy (response rate = 43.5%), but their area lack of scientific experiences capable of managing and implementing hydropower projects (response rate = 54.5%), this lake is due to the absence of a scientific specialization in renewable energy and hydropower.

The responses showed that: There are some researches and studies on the production of electricity from water in Palestine (response rate = 43.5%) and there are some equipment that can be used to produce energy (response rate = 34.8%).The Israeli occupation is hindering the import of equipment related to renewable energy by reserving and imposing taxes on imported equipment.

Chapter Six

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The energy sector in Palestine faces several challenges. The Israeli occupation completely controls the electricity in Palestine and the Palestinian consumption of electricity is the lowest and the highest cost compared to the neighboring countries.

The research showed that there is no interest by the Palestinian government in the development of renewable energy sources and there is an absence of regulations and provisions governing this sector.

It was found that the levelized cost of hydropower is equal 0.047USD/KWh (IRENA, 2017) and it is the cheapest among other renewable sources such as solar, wind, biomass, and geothermal.

The research showed that Wadi Al-Samen receives a large amount of rain water and wastewater, but more than 70% of this water is lost by evaporation and filtration.

The results showed that runoff river was more feasible for hydropower generation in dry season, with total capacity reached to 14.5 MW. While in wet season, the storage was more feasible for hydropower generation with a capacity reached to about 340 MW.

The study showed that the Israeli occupation is one of the obstacles that hinder the implementation of hydro technology, where the occupation prevents the application of hydro technology in parts of Wadi Al-Samen located within area C, under the control of the occupation.

6.2 Recommendations

- Preparing awareness programs on the importance of renewable energy and the need to reduce dependence on traditional energy sources.

- Establishment of research and experimental stations to develop renewable energy sources in Palestine.

- Introducing renewable energy as a scientific course taught in Palestinian universities.
- For the reservoir project, it is recommended to place WWTP before the reservoir in order to reduce the environmental impact of wastewater and benefit from treated water for agriculture purposes.

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APPENDIX A: Hydropower Calculations

Table A.1: Runoff river-Calculations of the quantity of rain water and wastewater flowing into the hydropower generation sites during rainy season.

point	Rainfall (mm/y)	Rainfall (mm/d)	Evaporation (mm/d)	Infiltration (mm/d)	Net flow (mm/d)	Catchment area (km^2)	Catchment area (m^2)	Q Rain (m^3/d)	Q Wastewater (m^3/d)	Infiltration (m^3/d)	Evaporation (m^3/d)	Net wastewater flow(m^3/d)	Total flow (m^3/d)
1	492.6	10.48	0.419	7.546	2.515	74.6	74600000	**187649.2**	10500	7560	420	2520	**190169.2**
2	497.5	10.59	0.423	7.621	2.540	107	107000000	**271825.5**	10655	7671.6	426.2	2557.2	**274382.7**
3	497.5	10.59	0.423	7.621	2.540	133.8	133800000	**339908.9**	10655	7671.6	426.2	2557.2	**342466.1**
4	457.2	9.73	0.389	7.004	2.335	142.3	142300000	**332219.0**	10655	7671.6	426.2	2557.2	**334776.2**

Table A.2: Runoff river-Calculations of the hydropower generated by each site during rainy season

Power (KW)	Point	Distance (km)	Elevation (m)	ΔH (m)	Total Flow(m^3/d)	*n* total	Power(W)	Power(KW)
1	7.5	686	73	190169.2	2.2	0.76	1197931.0	1197.9
2	13.2	635	51	274382.7	3.17	0.76	1207524.1	1207.5
3	21.6	565	70	342466.1	3.96	0.76	2068638.2	2068.6
4	25.7	530	35	334776.2	3.87	0.75	997790.1	997.8

Table A.3: Runoff river - Calculations of the hydropower generated by each site during dry season

Point	**Q Wastewater(m^3/d)**	**Infiltration (m^3/d)**	**Evaporation (m^3/d)**	**Net flow (m^3/d)**	**Distance (km)**	**Elevation (m)**	**ΔH (m)**	***n* total**	**Power (W)**	**Power (KW)**
1	10500	6772.5	682.5	3045	7.5	686	73	0.76	19181.3	19.2
2	10655	6872.475	692.575	3089.95	13.2	635	51	0.76	13598.5	13.6
3	10655	6872.475	692.575	3089.95	21.6	565	70	0,76	18664.6	18.6
4	10655	6872.475	692.575	3089.95	25.7	530	35	0.75	9209.5	9.2

Table A.4: Storage – Calculations of hydropower generated by each alternative during wet season

Alternative	Q storage (m³)	Utilization quantity per day (m³) (turbine operates 1 hour)	Q (m³/s)	ΔH (m)	*n* total	Power (W)	Power (KW)
Alternative 1 (storage of **5%**)	837000	50,000	13.88	10	0.75	1021221	1021.22
Alternative 2 (storage of **15%**)	2,511,000	110,000	30.55	10	0.75	2247716.25	2247.72
Alternative 3 (storage of **25%**)	4,185,000	150,000	41.66	10	0.75	3065134.5	3065.13

Table A.5: Storage -Calculations of hydropower generated during dry season

Location	Q (m³/d)	Infiltration (m³/d)	Evaporation (m³/d)	Net quantity (m³/d)	Q (m³/s)	ΔH (m)	*n* total	Power (W)	Power (KW)
1	10655	6872.475	692.575	3089.95	0.0357	79	0.75	20787.1	20.8

APPENDIX B: Questioner Form

Research questionnaire about renewable energy and hydropower in Palestine

This is a brief questionnaire survey as a partial requirement of the MSc research of Eng. Bayan Heeh at Birzeit University.

Thank you for your kind cooperation

1	Age	
2	Gender	1- Male 2- Female
3	Education level	1- BSc 2- MSc 3- PhD
4	Employer category	1- Government 2- Municipality 3- NGO 4- Universities 5- Donor 6- Private
#	**Question**	**Give 1-5 score** **(1 = strongly disagree, 5 = strongly agree)**
5	There strong legislations and laws regulating the renewable energy sector in Palestine.	1, 2, 3, 4, 5
6	There are long-term national plans that aim to develop the renewable energy sector.	1, 2, 3, 4, 5
7	There are incentives to encourage the private sector to invest in renewable energy.	1, 2, 3, 4, 5
8	There is interest by the Palestinian National Authority and Municipalities to develop a feasible	1, 2, 3, 4, 5

	strategy aiming at supporting renewable energy projects.	
9	There are sufficient experiences and knowledge in the field of renewable energy among the national and institutions.	1, 2, 3, 4, 5
10	There are legislations and laws that promote the use of hydroelectric power technology.	1, 2, 3, 4, 5
11	There are researches and studies on the production of electricity from water in Palestine.	1, 2, 3, 4, 5
12	There is enough awareness about the importance of using renewable energy sources.	1, 2, 3, 4, 5
13	There is local and scientific expertise's capable of managing and implementing hydropower projects.	1, 2, 3, 4, 5
14	There are systems and equipment that can be used to exploit renewable energy sources.	1, 2, 3, 4, 5