An-Najah National University
Faculty of Graduate Studies

DETERMINING SUITABLE SITES FOR RAINWATER HARVESTING PONDS USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN TULKARM GOVERNORATE

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Dedication

To Palestine, my homeland and my refuge... to its steadfast prisoners... to its martyrs... to the steadfast free people wherever they are in the homeland and in the diaspora... to beloved Jerusalem... to the cradle of Christ...

To the captain of my ship who suffered the bitterness of life for my sake, and whom my eyes have never seen a man like, to the man in whom the qualities of goodness, righteousness and kindness were combined, to my dear father, thanks for his great blessings, and for fulfilling some of his rights.

To the tender voice, to the candle that burned to light me, to the first flower in my life, to the rain cloud that rained down the sky of my life, to my dear mother, may God prolong her life...

To my dear brothers and sisters, my source of strength and inspiration…

To my comrades and friends...

To those who paved the path of knowledge for us...An-Najah National University.

To everyone who taught me a letter, instilled good morals in me, and was the reason for my success.

I dedicate this humble effort to you all out of appreciation and gratitude from me to all of you, and I ask God Almighty to benefit those who follow the path of knowledge, and to place it in the balance of my good deeds on the Day of Resurrection.

Acknowledgment

First of all, I thank God Almighty at all times, and I thank Him for fulfilling my dream of completing my studies and obtaining a master's degree in engineering and surveying, and thanks go to His Prophet Muhammad, may God bless him and grant him peace.

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I also thank the members of the discussion committee for the valuable comments and advice they provided.

I would like to thank everyone who contributed to the success of this thesis.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

DETERMINING SUITABLE SITES FOR RAINWATER HARVESTING PONDS USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN TULKARM GOVERNORATE

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

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Signature: Adham Dibas

Date:19/12/2023

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DETERMINING SUITABLE RAINWATER HARVESTING SITES USING GEOGRAPHIC INFORMATION SYSTEMS (GIS) IN TULKARM GOVERNORATE WATERSHEDS

By

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Abstract

This study uses geographic information systems to study rainwater harvesting and methods to exploit it in the Tulkarm Governorate. It aims to calculate the amount of surface runoff to analyze the water budget in the study area and determine periods of water surplus and deficit, which will benefit the agricultural sector in exploiting periods of a water surplus when the soil is saturated and does not suffer from a lack of moisture. It also identifies water deficit periods when a lack of soil moisture may affect crops.

The modified Thornthwaite (1955) method was applied to calculate the water balance, monthly and annual rainfall averages, and temperatures between 2011 and 2020.

The results show that the average amounts of surface rainwater runoff in the governorate reach 186 mm annually. There are two periods of spatial distribution of soil moisture: a period of water surplus extending from December to March and a period of water deficit from May to October. January has the highest water surplus, reaching 129 mm; July and August have the highest water deficit, reaching 170 mm. These are consistent with the climate features that this region experienced during that period.

The results also show that the locations closest to the outlets of the main water streams are the most suitable locations for establishing a water collection pond. Therefore, the main effort in this research focused on collecting rainwater in specific locations during the period of water surplus by creating harvest ponds, especially during the first precipitation periods.

Keywords: Rainwater harvesting, Water budget, Tulkarm Governorate, Palestine, GIS.

Chapter One

The General Framework of the Study

1.1 Introduction

Lack of water resources in Palestine is a severe problem that hinders the implementation of development programs and plans since rainfall is one of the most essential natural resources in arid and semi-arid areas. This affects the welfare, productivity, health, and environment of Palestinian citizens (Al-Batsh, et al., 2019). Because Palestine has fewer permanent rivers (Isaac, 2000), precipitation is the only source of surface water flow feeding the subterranean aquifer (Shadeed et al., 2022). In arid and semi-arid regions where it commonly rains during a few months of the year, rainwater collection is essential more than in wet areas (Judeh & Shahrour, 2021). It is the most practical strategy to protect human, animal, and plant life.

In most areas of the Mediterranean basin between latitudes (40 to 45) north, atmospheric general circulation models indicated a drop in winter precipitation and increased drought severity (Karas, 2001). It is anticipated that by the year 2100, the precipitation rate will fall in sizable portions of the basin by 10% to 40% because the Mediterranean basin is predicted to have a warmer climate with less precipitation (Shehadeh, 2012; Karas, 2001)

The main expected consequence of climate change in the Middle East region is decreased precipitation in Jordan, Palestine, Iraq, and Syria (Onol & Semazzi, 2009; Isaac, 2000) The Mediterranean basin also expects a decrease in rainy days (Christensen, et al., 2007). Climate fluctuations will increase, resulting in heavy rains that may lead to floods and cause high rates of soil erosion, in addition to many other cases where drought prevails (Shehadeh, 2012). Drought leads to the degradation of agricultural lands, pastures, and forests and a lack of irrigation and drinking water. Climate change has effects that will go beyond agricultural production and is expected to have repercussions on all systems that produce biological elements, leading to an imbalance between the need for water and its availability. Climate change may exacerbate drought, desertification, and soil erosion (United Nations Environment Program (UNEP, 1991).

Estimating the soil water balance, based on monthly averages of rainfall and temperature, is the best way to determine the soil moisture potential in the region it represents due to its role in determining agricultural patterns and the characteristics of the region, whether it is characterized by a water surplus or suffering from a water deficit.

Estimating the amount of rainwater lost due to evaporation and transpiration is one of the basic issues in water studies because it is directly related to the soil moisture content (Alananzeh, 1996). It is also important in drought studies, which results from the equation between precipitations on the one hand and evaporation from the soil and transpiration from plants on the other hand (Shehadeh, 1981).

Any changes in the water budget will affect agriculture, dams, and irrigation projects. Therefore, it is imperative to determine periods of water deficit or surplus in the soil to estimate the extent of environmental stress to which plant and biological life are exposed, especially in arid and semi-arid environments (Mather & Yoshioka, 1968). It is also important to determine the potential evapotranspiration in arid environments with a shortage of the necessary water World Meteorological Organization (WMO, 1961). Consequently, it is necessary to calculate the water balance using empirical equations to determine the available soil moisture and periods of water deficit and surplus in the study area.

Water Harvesting refers to gathering water during a specific period in the hydrological cycle (Al-Dhoeb, 2012). This process begins with the arrival of rain on roofs of buildings or land and continues through the stage of water flow in the form of torrents, wadis, and streams, or impounding water of a river or valley by constructing a dam in its course. The dam is used to store and utilize water in times of lack of rain or drought when draining is reduced or stopped (Awawdeh et al., 2010). The secret to greater rainfall utilization for agriculture is water collection, which increases the amount of water available per unit of cropping land and reduces the impact of drought (Libiszewski, 1995).

Palestinian farmers have used rain harvesting techniques since ancient times (Shadeed & Alawna et al., 2022), especially in mountainous areas. They dig channels to divert surface runoff rainwater and store it in ponds or tanks for drinking and irrigation after the rainy season ends (Al-Dhoeb, 2012). This region has witnessed many civilizations; each showed the best examples of using the available water resources wisely. The effects of these civilizations remain and are evident in the progress in this field of science (Al-Salaymeh et al., 2010).

One of the main issues facing the 21st century is the lack of water. Like many Middle Eastern countries (Nazer et al., 2009), Palestine is defined by its geographical aridity and semi-aridity (Shadeed et al., 2023). Palestine has experienced drought in recent years, in addition to losing control over most of its water resources due to the occupation (Musallam, 2011; Qannam, 2003).

This study employs the Geographic Information System (GIS) technology to investigate rainwater collection and examine methods to find the best places to build a rainwater collection pool in the Governorate of Tulkarm. Therefore, the main objective of this research is to identify ideal locations for collecting rainwater and runoff for use to irrigate crops while preserving biodiversity and vegetation.

1.2 The Problem

The Tulkarm area, like the rest of the West Bank, suffers from the Israeli occupation authorities' control over water sources. Therefore, rainwater collection is essential to enhance the water resources and support the economic growth and society in the region. Finding the best water harvesting sites is challenging because it consumes time, effort, and resources. However, the technological assistance provided by GIS has made it easier to select ideal sites for constructing water harvesting ponds.

The best rainwater harvesting site depends on its ability to meet the basic technical criteria of a water harvesting system. Any technology chosen must be suitable for agricultural methods and socioeconomic conditions.

The study area was chosen because the agricultural land must optimally exploit the scarcity of rainfall in recent years in a region with high temperatures. A part of this area has been allocated for the production of crops and pastures. Its marginalized population depends on rain for agriculture and livestock. The Israeli occupation controls most of the water in the West Bank, exacerbating the crisis and requiring solutions.

Water harvesting increases the amount of water in the soil, enhances soil formation and fertility, reduces runoff and erosion rates, and improves productivity and land value. This study considers a model that can be used in other regions of Palestine.

1.3 Study Significance

This study is important because it provides a detailed database of water resources in the region for planners and researchers using GIS technology. It also deals with an important issue related to the possibility of exploiting surface water and reducing the severity of insufficient quantities of water for the population due to Israeli's full control over the Palestinian water resources.

The following statements summarize the importance of this study:

- Optimal use of water that falls on the semi-arid study area has not been used before based on the facts presented.

- The study focuses on the issue of rainwater harvesting, which plays an important role in enhancing agricultural production, leading to increased economic returns.

- Rainwater harvesting helps maintain many environmental aspects of the study area, e.g., it improves vegetation cover and reduces soil erosion.

1.4 Study Objectives

The main goal is to recommend ideal locations for establishing rainwater harvesting ponds by analyzing data using GIS, analyzing the water budget in the study area, and determining periods of water surplus and deficit to benefit from periods of surplus for rainwater harvesting.

Secondary Objectives

- Develop a GIS methodology that can be used to identify a potential rainwater harvesting site.

- Create a model that can be applied locally and in similar locations by identifying the required data (biophysical, social, and economic) for water collection and integrating it into the geographic information framework.

1.5 Study questions

- When accurate information is scarce, can GIS be used to identify and improve water collection sites?

- What is the amount of running water that can be collected in the governorate?

- Is the topographical nature of the study area suitable for water harvesting?
- Could water collection ponds be suitable for use in the study area?

1.6 The Study Methodology

Two approaches were used to collect information and data about the study area: 1) References and reports; 2) Collecting geological, soil, land use, and topographical maps that provide information to describe the study area. The analytical descriptive method was used to explain the general rainwater harvesting methods in Palestine and the study area in particular. The GIS technology was used for data processing and analysis to identify the best locations for rain harvesting.

This analytical mathematical model included the amount of rainfall, soil type, land use, slope, stream density, elevation, and geological formation, which influenced the process of extracting the most suitable location for rain collection by estimating the amount of surface runoff.

Two types of data were used in this study: 1) Qualitative data represented by maps of different subjects and information used to classify soil texture types, geological formation, land uses, and its cover; 2) Quantitative data represented by aerial photographs, digital elevation models, and precipitation records.

There are very few hydrological statistics for the West Bank, so data were obtained from a variety of sources and formulas. The following GIS layers were created using the collected data:

- **Maps**: The natural characteristics of the study area were identified in maps obtained from the Palestinian Ministry of Local Government (Geomolg, 2023) namely the land cover, soil texture, and geology of the study area.
- **Statistics**: Many reports and statistics, which are closely related to meteorological data from the (PCBS, 2000) and population statistics issued by the Palestinian Department of General Statistics (PCBS, 2023), were used to support the objectives of the study.

- **Aerial photographs** with a resolution of 15 cm taken by the Department of Geography, An-Najah National University, were used to determine the optimal location for constructing a water collection pond on the results map.

- **Digital Elevation Models (DEM)** with 12.5 m resolution were obtained from the University of Alaska website (ASF, 2023).

1.7 Previous Studies

The following are important related studies:

- Wifag et al. (2007) investigated the feasibility of harvesting seasonal flood waters passing through four valleys in the Seleti region of Sudan, north of the Khartoum State. They calculated the amount of storm runoff and determined the best locations for building dams to protect residents from floods. The water is used for irrigated agriculture to improve pastures, support sustainable community development, and manage water resources. GIS and remote sensing have been used as auxiliary tools to identify water harvesting areas in valleys, select potential sites for water harvesting systems, and evaluate the potential for water harvesting in the area.

- Sinha and Dubey (2000) studied the semi-arid Jaipur region in India. They found a significant increase in water demand for domestic, agricultural, and industrial uses because of rapid population growth in the region. A reliable, accurate, and up-to-date database on land and water resources has been created by combining meteorological and remote sensing data. This database is a requirement for an integrated strategy to calculate surface runoff and recommend ideal locations for rainwater harvesting to increase the opportunity for groundwater recharge.

- Prinz et al. (1998) identified possible methods for water harvesting in an experimental area in central Syria. They proposed a methodology that uses remote sensing data with minimal field work, which helps combat desertification by increasing the efficiency of water use from rain through proper planning for water harvesting.

- Harshi et al. (2010) found that cropland productivity improved after identifying a potential hydrological model for water harvesting and storage by building regional dams and conserving soil moisture. They investigated the geography of potential water management, selecting the criteria used to place the system at appropriate levels and selecting weights of relative importance. They used integrated strategies for efficient and effective water management and the numerical Curve Number (CN) to calculate surface runoff.

- Al-Ghamdi and Abu Ras (1991) compared two methods for calculating surface runoff using the Soil Conservation Service (SCS). The model uses the Land-Sat TM satellite data to choose effective satellite data to determine the numerical CN values. The first method, i.e., the traditional method, relies on automated satellite data processing to classify land cover and its uses, classify the hydrological layers of the soil, and then calculate the CN values. The second method is called the visual map. It does not require soil classifications or information but relies on the direct correlation between the values of the surface runoff equation. The results obtained by the two methods are largely identical. The results were identical when compared with those obtained by an independent working group charged with estimating surface runoff for the same study area.

The water harvesting study in this study area used the traditional method to calculate surface runoff using land cover classification, soil hydrological groups, and the CN method.

- Shammout (2003) applied the CN model to determine the impact of land uses in the Wadi Zarqa Basin in Jordan by classifying land cover using Landsat images and concluded that satellite data was a useful means of classifying land cover in the basin. The study also concluded that soil moisture and land cover change are among the most important factors affecting surface runoff throughout the basin.

  This study is similar to the study of water harvesting in Tulkarm Governorate in terms of applying the numerical CN model and equations for calculating surface runoff. However, it does not use hydrological models and actual soil moisture due to insufficient information about the region.

- Sorman (1993) also addressed the calculation of surface runoff for the Wadi Tabla Basin in the Kingdom of Saudi Arabia based on Technical Release Model 55 (TR-55). It is a technical model that provides a simplified procedure for calculating surface runoff, discharge rate, and required sizes of flood tanks. The US Environmental Conservation Service first published this model. The CN model for runoff has also been used in the study of hydrological discharge. This study recommended applying the CN method to other areas due to the accuracy of its results.

- Fealy et al. (2010) also divided suitability criteria for rainwater harvesting into 9 categories, taking into account only natural factors and ignoring the influence of human aspects in choosing the optimal place for water harvesting.

- Ghodieh and Burgan (2017) used natural and human criteria to suggest the best sites for building dams on the western slope of the Hebron Plateau. Contour lines with a vertical interval of 5 meters were adopted to analyze topographic surfaces based on a set of integrated programs from the GIS program represented in (ArcGIS 10.1) and its extension (Arc Hydro 2.0). The study showed that there are 15 sites for constructing dams with varying storage capacities, and 3 sites were identified as the best storage capacity for building dams because the total amount of actual running water in the basins reached 21,315,000 m^2.

- Asmar et al. (2020) determined the spatial distribution of land cover and land use changes (LULC) and their impact on potential surface runoff at the sub-watershed level of eleven major watersheds in the Nablus Mountains. Remote sensing data (Landsat 5, 7, and 8 images from 1984, 2000, and 2016) were used to detect and measure land use and area changes. The GIS and Soil Conservation Service Curve Number (SCS-CN) methods were used to calculate potential runoff for 487 rainy days (2008-2018). Seven classes of LULC were identified using the supervised classification method in GIS (10.5). The results showed a significant increase of 5.8% in a potential annual runoff between 1984 and 2016 due to land use changes (LULC), amounting to approximately 7.8 million m^3 (MQM). The runoff estimation model indicated that the upstream sub-watersheds of Qana, Deir Ballut, and Zumar are highly suitable sites for rainwater harvesting and flood mitigation projects.

- Shadeed (2011) studied rainwater harvesting using GIS in the West Bank, Palestine. A rainwater harvesting (RWH) suitability map was developed based on a combination of spatially weighted factors of land use, soil texture, topography (slope), and runoff coefficient. The Model Builder of Arc Map 9.3 model, which allows weighted overlay of thematic datasets, was used to create the RWH suitability map for the West Bank.

The results indicated that about 40% and 11% are suitable and highly suitable for RWH, respectively.

- Merwade (2019) aims to determine how to construct a raster dataset of SCS-CN for any watershed using land cover and soil data. The results show that the SCS-CN method is used in many hydrological models to calculate excess precipitation, and the CN grid gives the advantage of extracting the CN for any area in the watershed without performing any calculations.

- Hessane and Jabri (2019) focused on collecting and preparing data necessary for hydrological modeling of the Sebou High Watershed upstream of the Allal El Fassi Dam in Morocco. They describe a methodology for combining remote sensing techniques, including GIS and digital terrain models (DTM), with hydrological models to prepare a spatial hydrological modeling for flood forecasting.

- Salha et al. (2019) extracted the torrential stream network in the Bethlehem Governorate using GIS. They evaluated the risks of torrential rains and the most vulnerable areas in the governorate to predict and reduce their risks. They extracted a network map of the Wadis and identified stream networks using GIS to assess flood risks and produce accurate and illustrative maps pinpointing high-risk areas. They also reviewed the role of GIS in creating opportunities and reducing disaster risks by taking advantage of heavy rains and conducting hydrological analysis to benefit from floodwaters by identifying the optimal areas for flood accumulation.

Chapter Two

Characteristics of the Study Area

2.1 Description of the study area

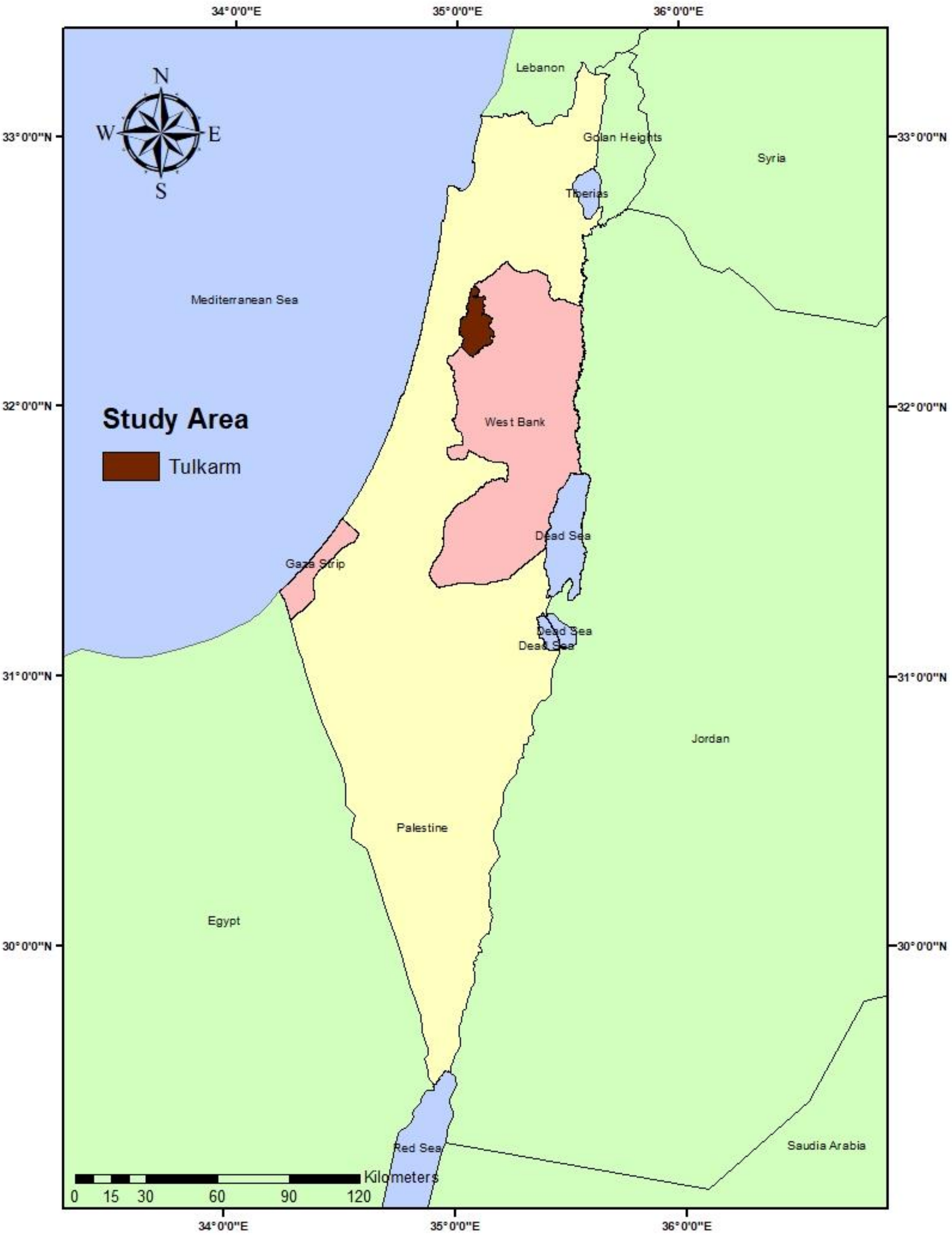
The Tulkarm Governorate is located in the eastern part of the central Palestinian coastal plain, 15 kilometers from the shore of the Mediterranean Sea, where the plain meets the foothills of the Nablus Mountains (The Palestinian Encyclopedia, 1984). It is between latitudes 32° 11′ and 32° 28′ north of the equator and between longitudes 35° 0′ and 35° 11′ east of Greenwich Line (Google Earth, 2023).

It is in the middle, between Jenin to the north, Qalqilya to the south, between the plains to the west and the mountains of Nablus to the east. It is located on a plateau that rises between 65 and 535 meters above the mean sea level (MSL). Its lowest point reaches 65 meters above MSL in the Zeita plains (Figure 5 shows the DEM map). The governorate overlooks two valleys: Wadi al-Zumar to the north and Wadi Ateen to the south; both come from the mountainous heights in the east and flow into the Mediterranean Sea in the west (Asmar et al., 2020; Al-Barqawi, 1994).

In 1945, the Tulkarm Governorate was about 83,5361 km^2, of which 16 km^2 was for roads, valleys and railways. 16.9% of it fell into the hands of the Zionists, and after the Nakba 1949, its area was about 333 km^2. In other words, a third of the governorate's lands were usurped by the Israeli occupation (Al-Dabbagh, 2002). According to 2010 statistics, the governorate area was about 246.12 km^2, equivalent to 4.4% of the West Bank area (Abu-Farah, 2014).

Figure 1

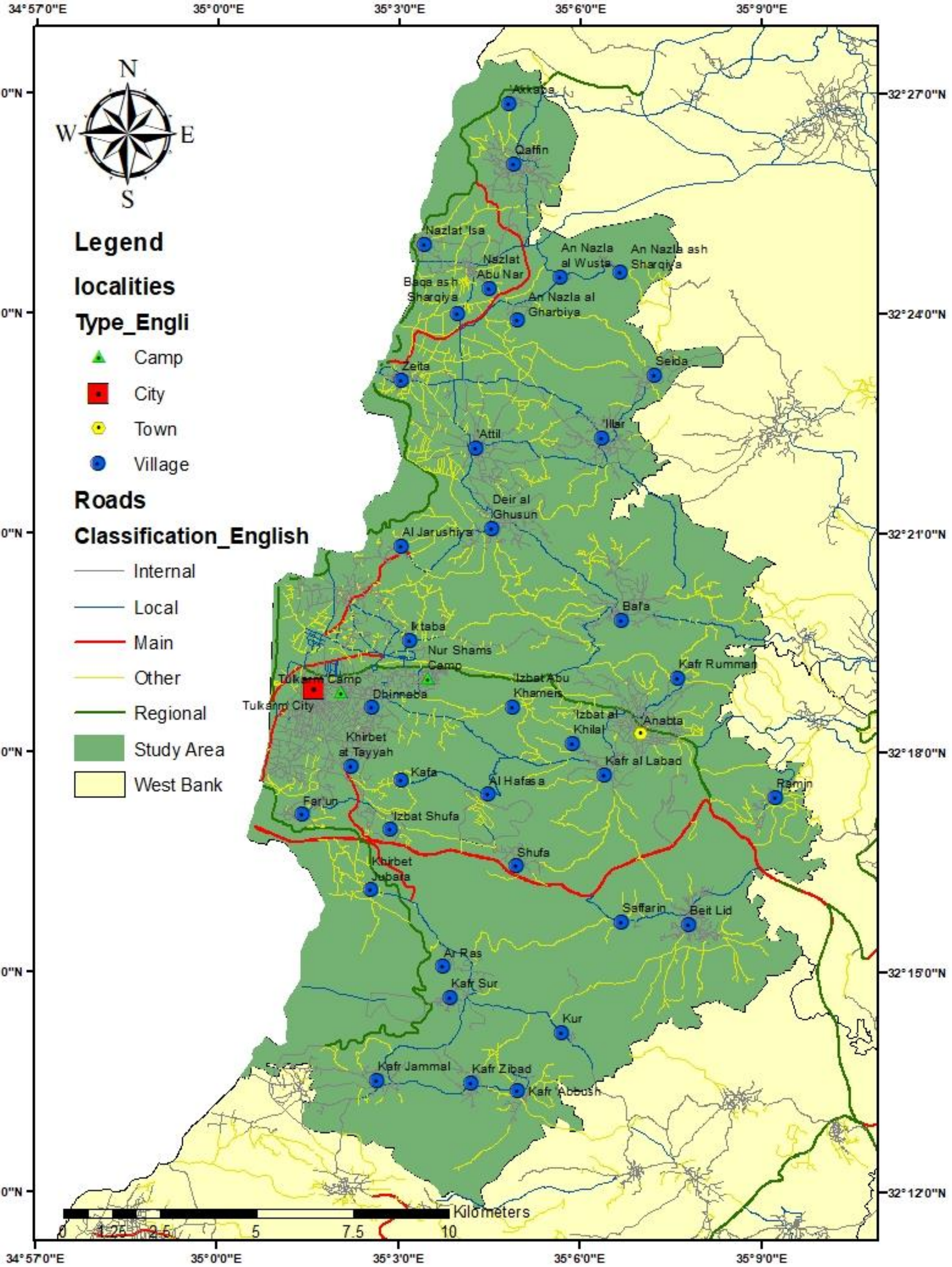
Tulkarm Governorate Location



Source: (Geomolg, 2023)

Figure 2

Tulkarm Governorate



Source: (Geomolg, 2023)

According to the census issued by the Palestinian Central Bureau of Statistics (PCBS, 2023), there are 42 population centers in Tulkarm Governorate: 9 urban communities, 31 rural communities, and two camps.

This area was chosen due to the need to exploit rainwater for agricultural lands due to the rain scarcity in an area where the cost of water is high due to the Israeli occupation's control over it. Note that the research area experiences an average annual rainfall between 450 and 600 mm and can serve as a model for other Palestinian cities.

2.2 Population

Tulkarm governorate includes 42 population centers with its administrative borders. The population was 136,094 and in 2000 and 165,791 in 2010. The general population density in mid-2021 was 807.7 individuals/km^2. The population of the study area was 198,856 individuals (PCBS, 2023). The population is constantly increasing, leading to increased urbanization at the expense of other land covers in the governorate, which must meet future demand for it.

Table 1

Population growth rate in the study area between 2000 -2021

Year	*Population*	*Population Growth*
2000	136,094	-----------
2006	153,363	17,269
2010	165,791	12,428
2015	182,053	16,262
2021	198,856	16,803

Source: (PCBS, 2023).

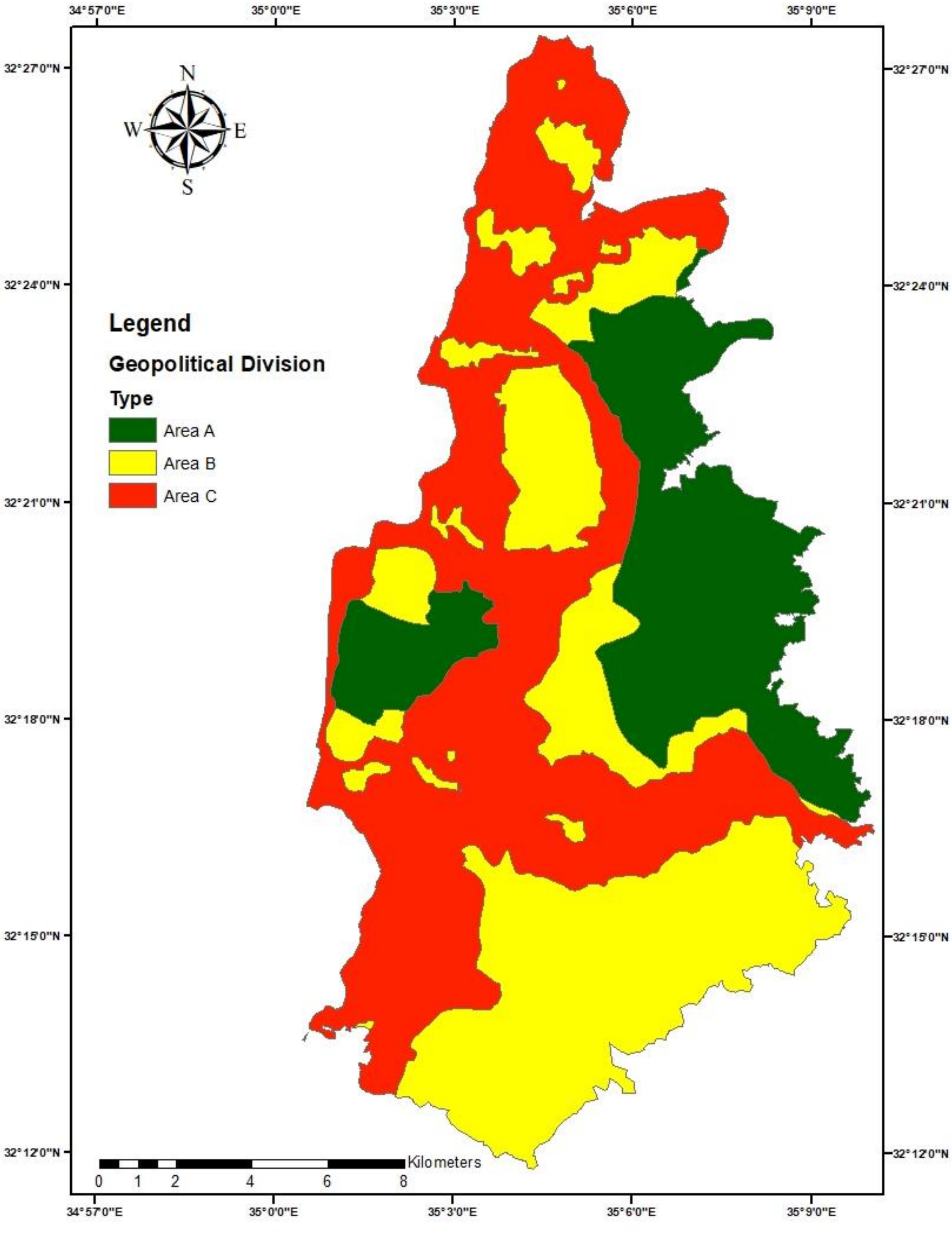
2.3 Geopolitical situation of the Study area according to the Oslo Accords in 1993

The Tulkarm governorate suffered from the geopolitical division stipulated in the Oslo agreement, especially since most of its areas are lands (C), which are under the military and administrative control of the Israeli occupation authorities. Areas (B) are under the administrative control of the Palestinian National Authority and militarily under the control of the Israeli occupation authorities. Areas (A) are under the military and administrative control of the Palestinian National Authority. Zone (C) constitutes 42.21%

of the total study area, while Zones (A) and (B) make up the rest. Table (2), Appendix (C) shows the geopolitical division of the study area, as shown in Figure 3.

Figure 3

Geopolitical division of Tulkarm Governorate



Source: (Geomolg, 2023)

2.3.1 Apartheid Wall

The Israeli occupation authorities erected the apartheid wall in 2002 and seized fertile agricultural lands in the governorate. As a result, the governorate lost large areas of its lands, especially agricultural lands, and olive trees were cut down. An example is what happened to the village of Nazlit Issa, north of the governorate. According to 2007 statistics, about 300 dunums of agricultural land were confiscated, approximately 1990 olive trees were destroyed, 524 dunums were isolated behind the wall, and 90 dunums of citrus trees were destroyed.

In addition, the confiscation of ten water-producing groundwater wells in the governorate limits the ability of its residents to extract water and manage water resources (Malhis, 2003).

2. 3. 2 Israeli Colonies

The Israeli occupation's policies to usurp Palestinian lands include establishing settlements, expelling indigenous people, and exploiting natural resources for their benefit. Figure 4 shows three settlements established in the governorate as follows (Abu-Sa, 2014):

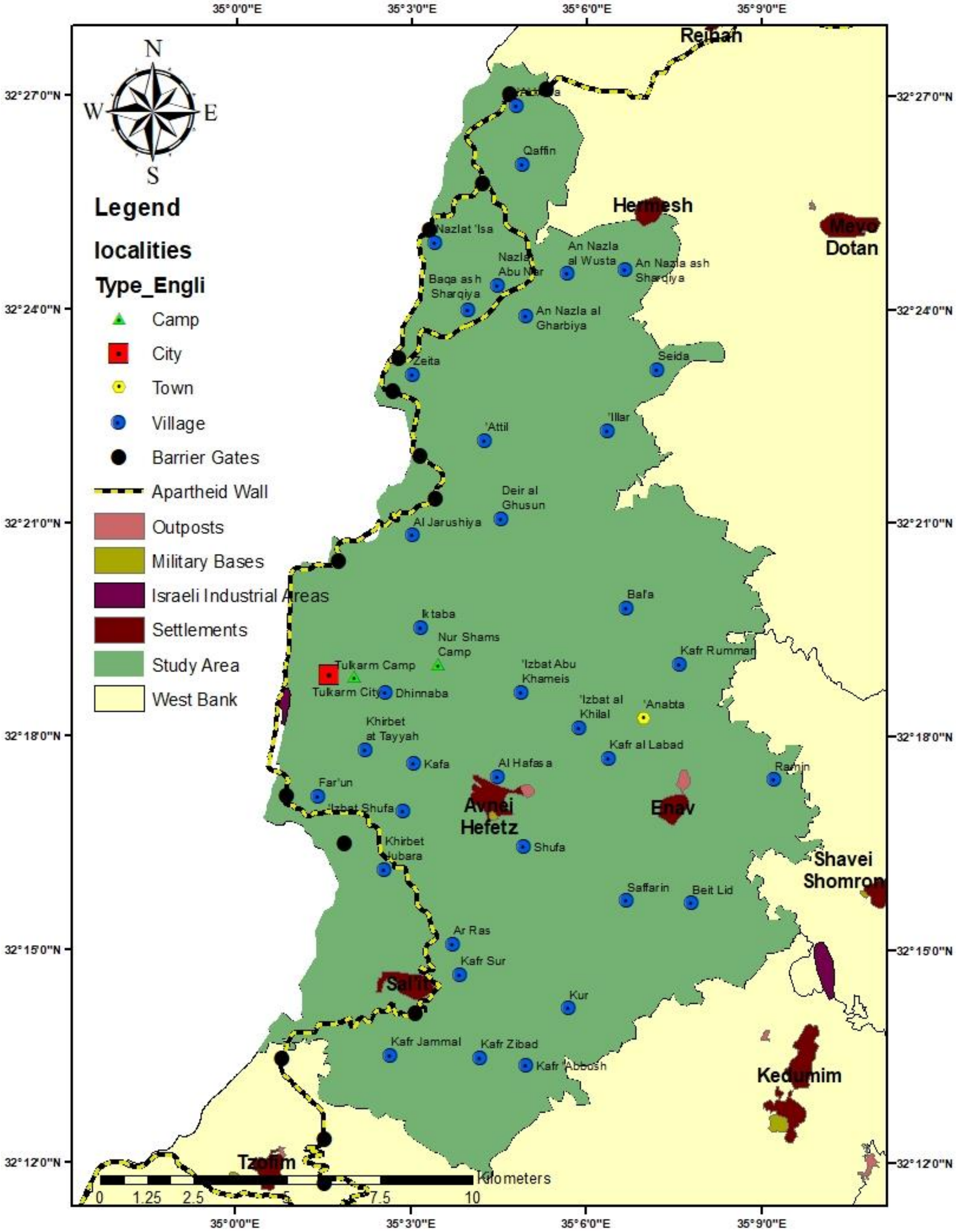
- **Avni Hefetz Colony**: Established in 1987 on the lands of the village of Shufa. In 1990, it was transformed into a permanent settlement with an area of 750 dunums. It expanded at the expense of agricultural land, reaching an area of about 1766.6 dunums in 2005. In 2011, it was expanded to become an area of about 1768.5 dunums.
- **Sal'it Colony**: An agricultural settlement one kilometer from the armistice line. It was built on the lands of Kufr Sur village, south of the governorate. 1,300 dunums were confiscated for its construction, and its area reached about 1075 km^2 in 2011.
- **Enav Colony**: Established in 1981 on land confiscated from Ramin, Kufr El-Libad, and Beit Lid, east of the Tulkarm governorate. It is connected to the armistice line at the entrance to the city of Taybeh, along a 12-kilometer bypass road, built at the expense of the lands of Shufa, Saffarin, Beit Lid, and Ramin villages. The side areas of this street are considered military zones. In 2011, its area amounted to about 775,683 dunums.
- **The industrial settlement area in the Tulkarm Governorate**: It is called Baraem Al-Salam. It began in 1983 with the first factory, the Jeshouri factory. It was expelled

from Israel because of the negative environmental impacts it caused on the population. It is located west of the governorate. This factory produces various chemical fertilizers, and other factories followed until the number of factories reached 12.

Yassin (2013) confirms that Israeli factories, like any industrial area, contain waste, and there are three types of waste: liquid, solid, and gaseous. Liquid waste generated by Israeli factories is not treated properly, negatively affecting the strategic groundwater reserve in the Tulkarm area and the vegetation and wildlife. The most serious problem lies in gaseous pollutants, and the information obtained from Palestinian workers in those factories is that the factories produce paints and pesticides, which are dangerous materials and pollute the environment if not dealt with through the environmental health system. The main problem lies in air pollutants, which are sulfur, nitrogen, and other gases that affect the ozone layer, as well as carbon monoxide and carbon dioxide gases. The effect of these gases is very negative if their presence exceeds the permissible limit. Subsequently, it affects human health, especially diseases of the respiratory system, eyes, and skin, and is considered a major source of cancer. These gases also negatively affect plants and cause shortness of breath for citizens who live near them, especially in the evening when the air is activated.

Figure 4

The apartheid Wall and the Israeli Settlements in Tulkarm Governorate



Source: (Geomolg, 2023)

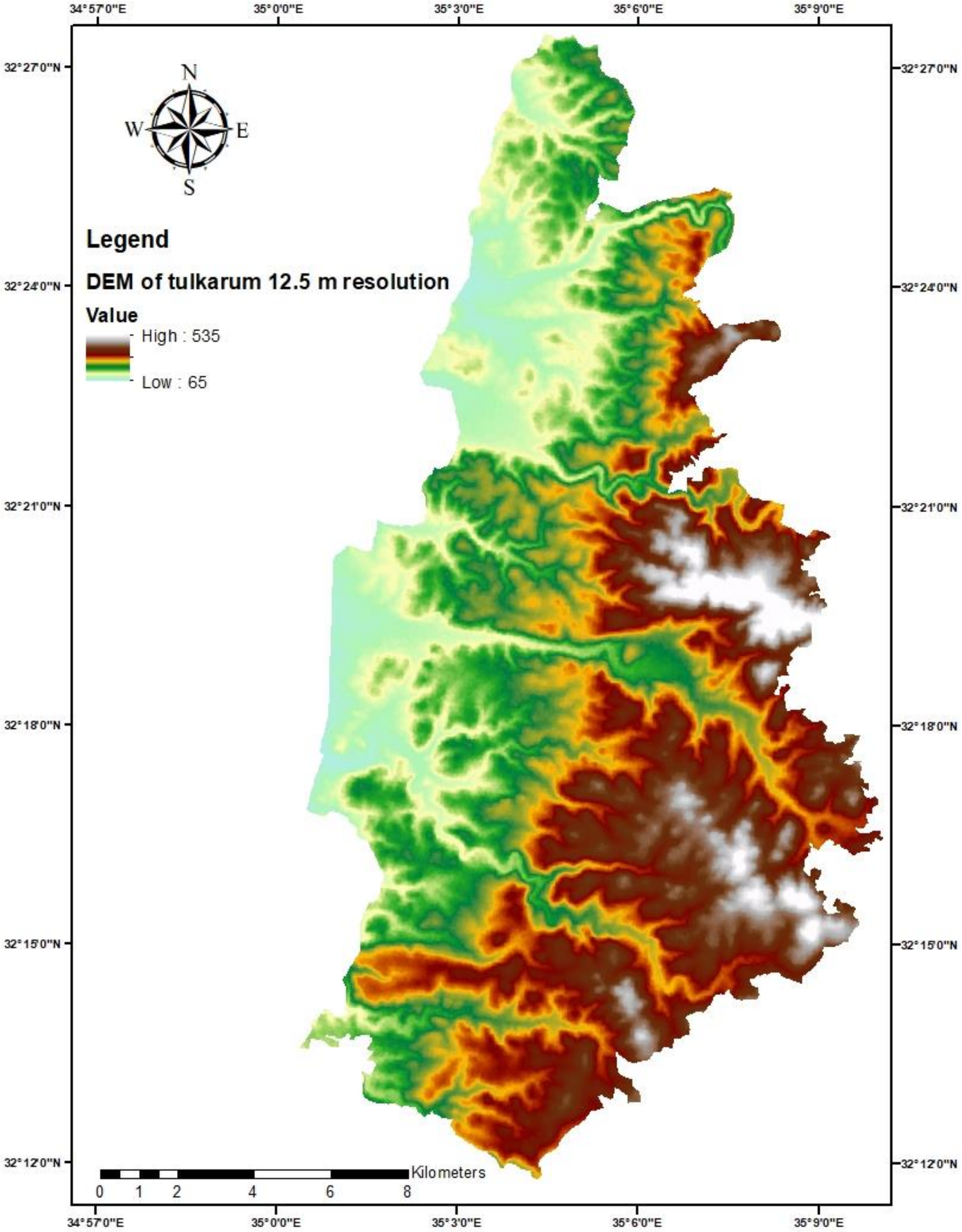
2.4 Topography of the Study Area

Tulkarm Governorate is a hilly region divided by wadis left by the winter torrents that descend from the eastern mountainous highlands towards the west. The height of the plateau is 218 meters on average (Figure 5 shows the DEM map) and decreases on its four sides until it reaches its lowest level at 65 meters above sea level, where the coastal plain meets it. The elevation increases as we head east and northeast of the governorate, and altitudes range between 300-514 meters above sea level (Al-Barqawi, 1994).

The Governorate is characterized by the diversity of its terrain, as shown in Figure 5. This diversity results in climate differences in terms of temperature, humidity, and rain, thus affecting the distribution of vegetation cover. The plain areas are famous for vegetables, field crops, and citrus fruits, whereas almond and olive trees and shrubs are widespread in the mountains.

Figure 5

Topography of the Tulkarm Governorate



Source: (ASF, 2023)

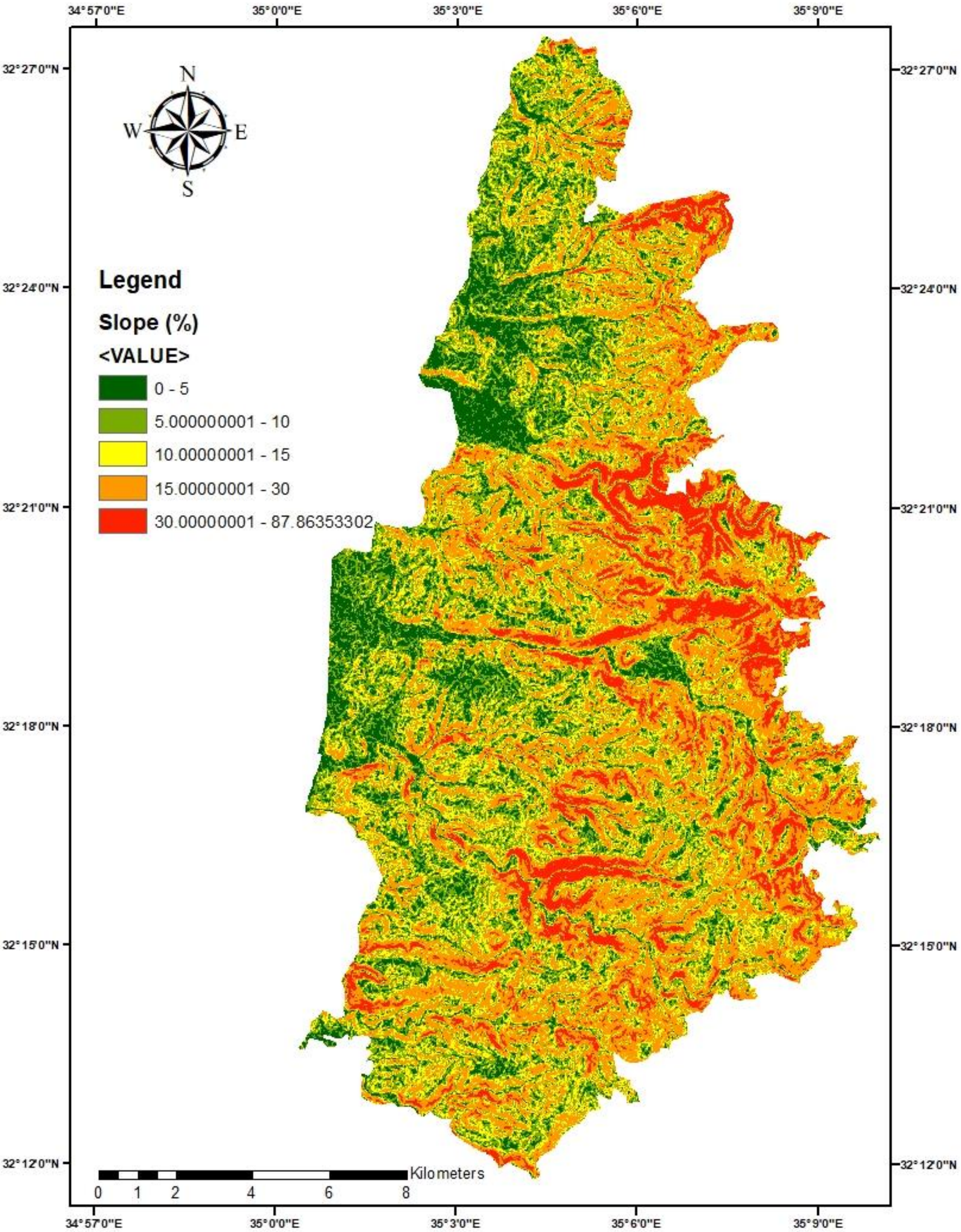
2.4.1 Slope Inclination

The importance of studying the slope inclination lies in knowing the factors affecting the formation of geomorphological forms. Areas with steep slopes lead to the erosion of rocks from the soil above them. Areas with low slopes are covered by a layer of soil that protects the rocks from mechanical weathering factors (Burqan, 2015).

A 12.5 m resolution DEM was used to identify the degrees of slope in the Tulkarm Governorate, which represents the governorate’s topography. Table (3), Appendix (C), shows the slope distribution (%) in the study area, as in Figure 6.

Figure 6

Slope distribution (%) in Tulkarm Governorate



Source: (ASF, 2023)

2.5 Climate

Climate plays a major role in determining the characteristics of environments, relationship between climate characteristics, and description of each element. The Palestinian territories are considered transitional regions in terms of climate because they lie between the Mediterranean and the dry climate. Palestine is characterized by a hot and dry climate in the summer, a cold and wet during the winter, and a short transitional period between the two main seasons. The transitional seasons are usually characterized by the crossing of desert depressions and dry southeasterly or southerly winds (Ayed & Alwishahy, 1999).

The Tulkarm Governorate follows a Mediterranean climate, with local influences due to location and topography. It experiences an intermediate climate between the inland and coastal climates, but it is closer to the coastal one due to its proximity to the Mediterranean Sea and the absence of topographical obstacles and barriers that prevent the arrival of these influences. Therefore, its climate is characterized by adequate rainfall, moderate temperature, and a long dry season. The summer and winter seasons appear in the governorate, while spring and fall seasons are unclear due to their shortness and gradual change (Al-Barqawi, 1994).

- **Temperature**

The average temperature is about 27.50C° in August and 12.84C° in January from 2011 to 2020 (NASA, 2023). Table (4), Appendix (C) shows the average monthly temperatures (C°) in study area for the years 2011-2020.

- **Winds**

The average wind speed in the Tulkarm Governorate for the year 2020 was 7.308 km/h (NASA, 2023). In winter, adverse westerly winds blow, accompanied by the arrival of depressions over the Mediterranean Sea. These winds cause turbulent weather, resulting in rain and thunderstorms with lightning. The wind speed is moderate and increases from December to February.

In summer, the influence of the westerly winds decreases and takes the form of local winds that blow from the sea to the land during the day (sea breeze), decreasing the temperature.

Westerly winds blow during spring, but to a lesser extent, in addition to the Khamasin winds, which are southeasterly winds from the desert. It is a hot and dry wind. The autumn winds are the western winds at the beginning of the season; the southeastern (Khamaseen) winds prevail at the end of the season and are loaded with dust (Hassan, 2008). Table (5), Appendix (C) shows the monthly wind speed and direction in the study area for the year 2020.

Winds are of great importance and strongly impact vegetation through the transfer of pollen from cultivated plants, land desertification, and soil transfer. Winds play a role in the occurrence of rain by transporting rain-laden clouds and affect plants in terms of humidity, which decreases with increasing transpiration and evaporation.

- **Humidity**

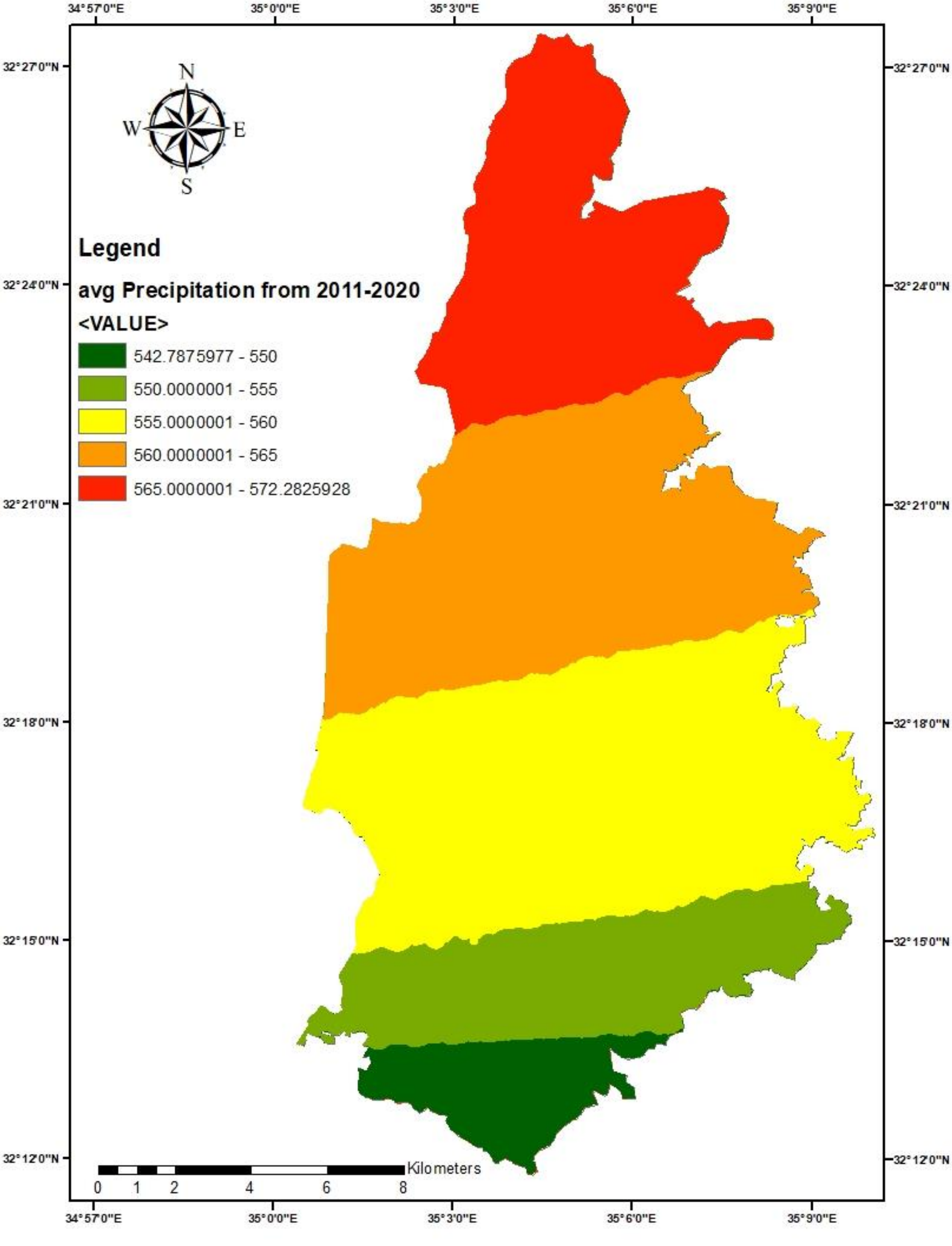
The annual relative humidity from 2011 to 2020 reached 68.95% (NASA, 2023). The governorate is considered a high-humidity area due to the blowing of the westerly winds laden with water vapor. Table (6), Appendix (C) shows the monthly average of relative and specific humidity in the study area for the years 2011-2020.

- **Rainfall**

The annual rainfall rate from 2011 to 2020 is about 558 mm/year (PCBS, 2000), with about 49 rainy days. January is the rainiest month of the year in terms of rainfall and rainy days. Rainfall extends from November to March. The beginning and end of the rainy season vary according to the amount, distribution, and duration of rain from year to year (Hassan, 2008). Table (7), Appendix (C) shows the average monthly rainfall in (mm) in the study area for the years 2011-2020.

Figure 7

Average annual rainfall (mm/year) in Tulkarm Governorate for the years 2011- 2020



Source: (PCBS, 2000)

2. 6 Geology

Palestine is considered a miniature geological model of the Arabian Shield, especially the Asian Shield, because it resembles the study area in its general appearance, especially in the eastern part of it, such as Syria and Lebanon. A granite base has been in the area since ancient times, which has been flooded by sediments of geological phases, especially the second, third and fourth phases.

In the third phase, the study area was exposed to erosion, landslides, and volcanic eruptions, forming the western and eastern slopes separated by the Jordan River.

The western slopes were fragmented by transverse faults extending from east to west, where the study area is located on the Hawaran Plateau, which forms the foothills of the Nablus Mountains and is surrounded by hills from the east. Soft, chalky formations appear on the surface, and due to these formations, valley hollows extend into these hills from the south and east. These formations cover the soil with a few stones (Al-Barqawi, 1994).

In the fourth stage, creeping sand spreads under the plateau due to heavy rains coming from the eastern highlands. It is red and contains silt and gravel deposited on the plateau. This sand mixes with the clay deposits, forming loamy clay soil suitable for agriculture (Al-Dabbagh, 2002).

The following is the order of geological eras from newest to oldest (Khader, 2012), as shown in Figure 8:

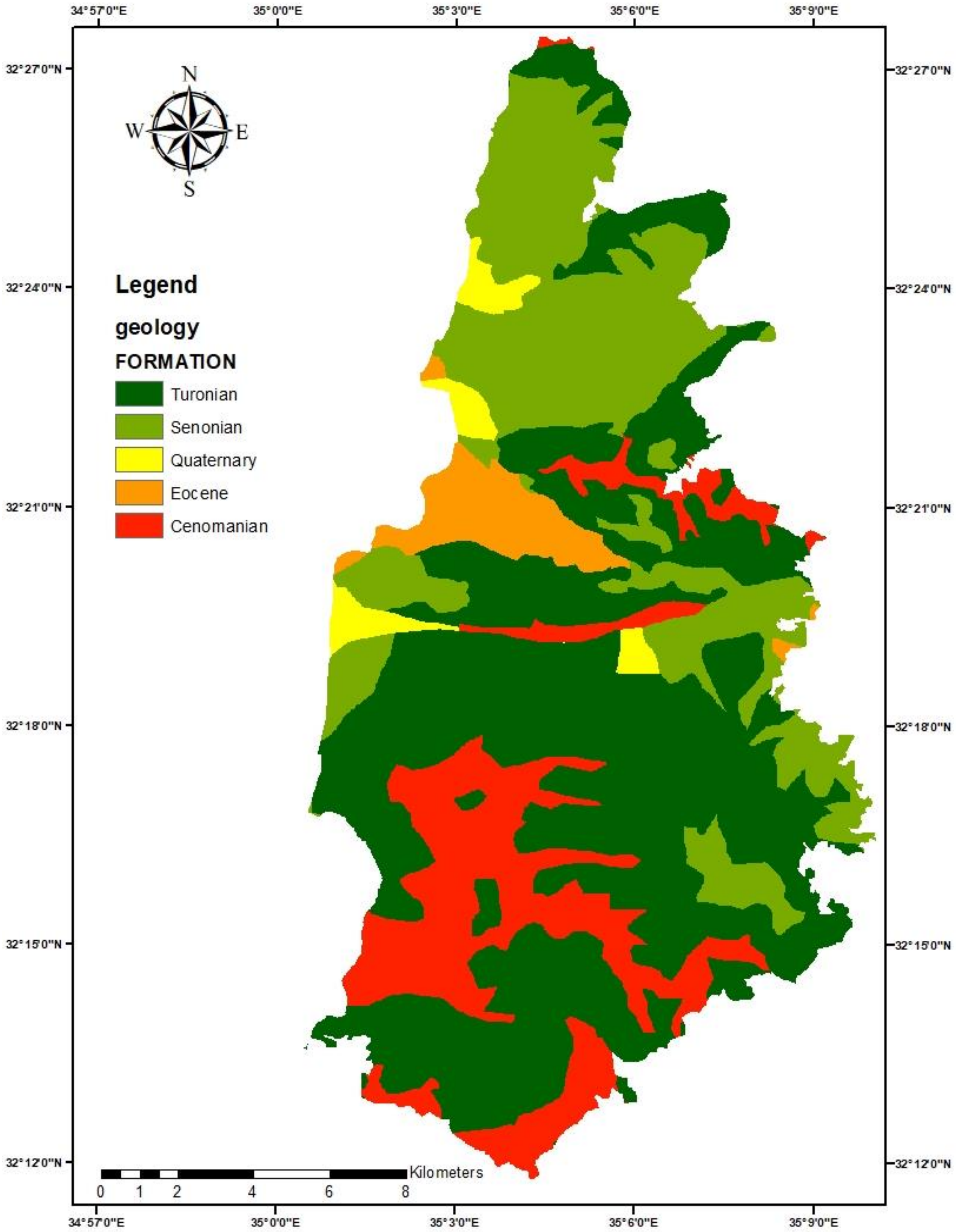
- **Quaternary Period**: The current and recent geological period follows the Neogene Era and extends from 2.58 million years ago to the present. This period consisted of deposits of thin formations that arose on either side of the main valleys and were composed of flint, sand, clay, dolomite, and limestone.
- **Eocene Period**: A geological period that extends from about 56 to 33.9 million years ago, the second epoch of the Paleogene Era. This period consists of fossil rocks of limestone, chalk, and numolite.
- **Senonian Period**: The last part of the Cretaceous Era, which consists of the Coniacian, Santonian, Campanian, and possibly the Maastrichtian era. This period extended from 89.8 to 66 million years ago and consists of layers rich in phosphate and silica.

- **Turonian Period**: The second period in the Late Cretaceous Era, which extends between 93.9 million years and 89.8 million years ago. This period consists of formations of thick and thin layers of limestone and dolomite, which take the form of a cliff and are used as building stones.
- **Cenomanian Period**: The oldest period in the late Cretaceous Era, which extended between 100.5 and 93.9 million years ago. The Cenomanian Rock is an obvious groundwater barrier, mainly because it is composed of marlstone.

Figure 8 shows that most of the study area is Turonian geological formations, with the Senonian geological formation spreading north, the Cenomanian geological formation south, and the Quaternary and Eocene geological formations west, Table (8), Appendix (C) shows the distribution of geological formations in the study area.

Figure 8

Geological formations in Tulkarm Governorate



Source: (Geomolg, 2023)

2. 7 Soil

The mixture of minerals, water, and air forms the living organism known as soil, which is the incoherent upper layer of the Earth’s surface on which plants grow (Abu Samour, 1997). It is the final result of the interaction of several factors such as rocks, climate, vegetation, topography, and time. Soil is the surface layer that arises from the disintegration of rocks due to various factors, and mixes with the remains of plants and animals.

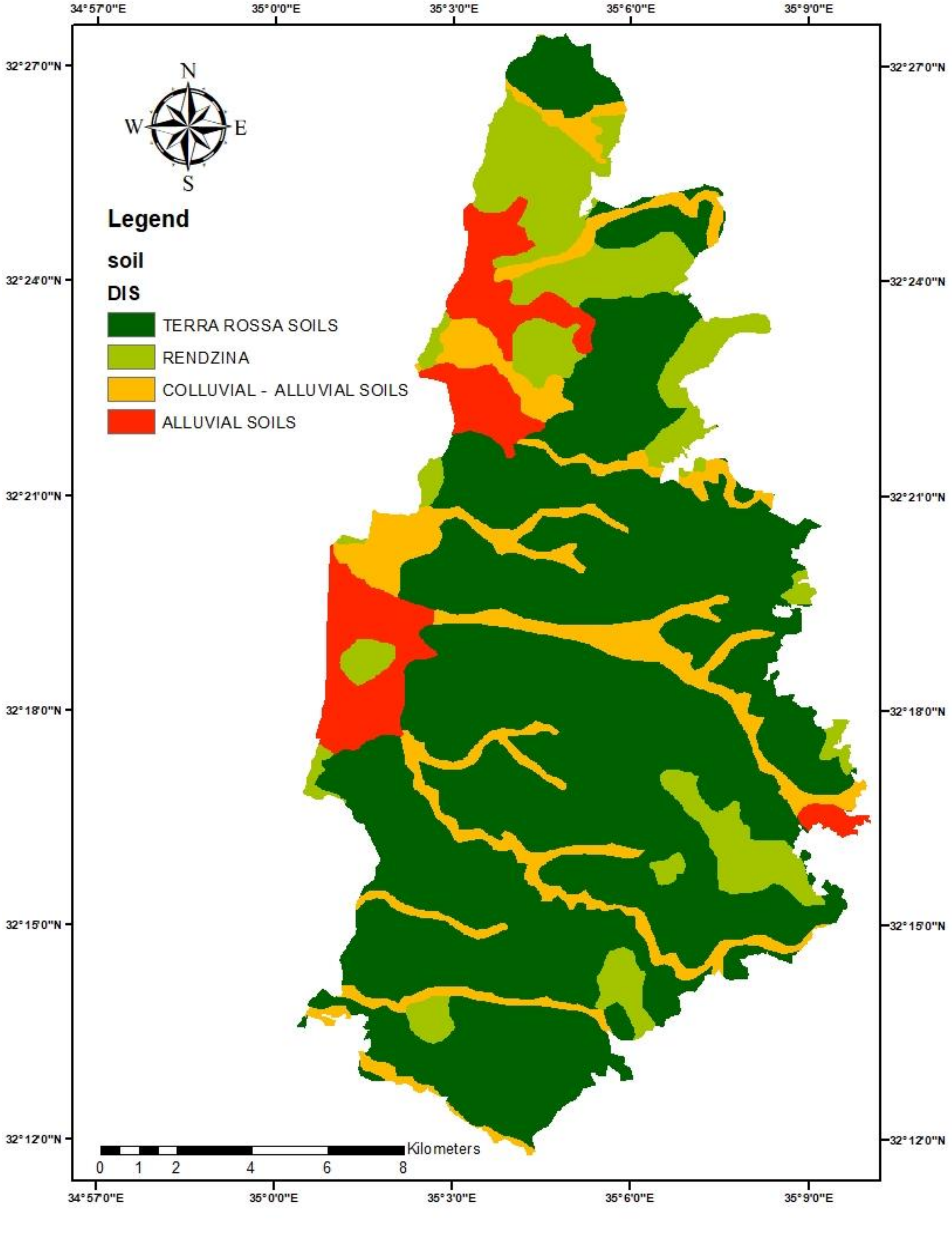
The study area generally covers fertile soil consisting mostly of limestone, and its thickness increases in plain areas and decreases in mountainous highlands. The soil of the study area is one of the most fertile soil types in Palestine because the percentage of organic matter is high, and it is generally suitable for agriculture (Hassan, 2008).

The soil is dense in the plains and thin in the mountain highlands, where it is exposed to erosion in the winter, especially if these areas are devoid of vegetation. Figure 9 shows that the governorate contains four main types of soil: red terra rosa soil, Brown Mediterranean Forest soil (Rendzina), Alluvial soil, and Colluvial-Alluvial soil. Table (9), Appendix (C) shows the distribution of soil texture in the study area.

Figure 9 shows that most of the lands of the study area have a Terra Rosa soil texture, with the Rendzina texture spread in the mountainous highlands, and the Colluvial-Alluvial soil texture is spread on the sides of the main Wadis. In contrast, the Alluvial texture is spread in the western plains.

Figure 9

Soil Texture in Tulkarm Governorate



Source: (Geomolg, 2023)

2. 8 Land Use and Vegetation Cover

Agriculture is one of the most important economic resources for a large segment of the region's population. It is also one of the most important sources on which the population depends. The Israeli policy in the occupied territories places obstacles in front of Palestinians that prevent them from practicing their agricultural activity, one of Palestinian agriculture's most important issues.

In addition to the population increase, farmers lack knowledge of the agricultural cycle and rely on rain-fed agriculture. Consequently, some have turned to non-agricultural jobs to cover their expenses after the recent drought and rainwater scarcity. These are the most important issues in the Palestinian agricultural sector (Wahiba, 1986).

Natural and human controls determine the quality of vegetation cover, growth form, and geographical distribution. For example, the location of the study area in the coastal plain led to moderate temperatures and acceptable amounts of rainwater, which formed suitable environments for the growth of dense vegetation compared to the rest of the areas in the West Bank (Abu-Sa, 2014).

The land area of the Tulkarm Governorate was about 246.12 km^2 in 2010, of which 83.6 km^2 were cultivated areas. It constitutes 34% of the total study area and 9.4% of the agricultural land area in the West Bank, according to the agricultural census 2009-2010 (Palestinian Central Bureau of Statistics, 2011)

The study area is primarily an agricultural area famous for growing fruit trees, especially olive, citrus, and almond. It also includes a large number of greenhouses dedicated to growing irrigated vegetables.

- **Natural vegetation**

It includes forests and natural grasses. Grass spreads throughout most of the governorate’s lands because they do not require large amounts of water. It also spreads independently or alongside trees and forests in the plains and mountainous areas.

Forests spread in the governorate through a group of shrubs represented by Bal’a bushes in the east of the governorate and bushes in the north (Figure 10). It is a group of trees that tolerate the cold of winter and the summer's drought and have dense needle leaves, such as coniferous forests and evergreen oak forests (Abu-Sa, 2014).

▪ Agricultural vegetation cover

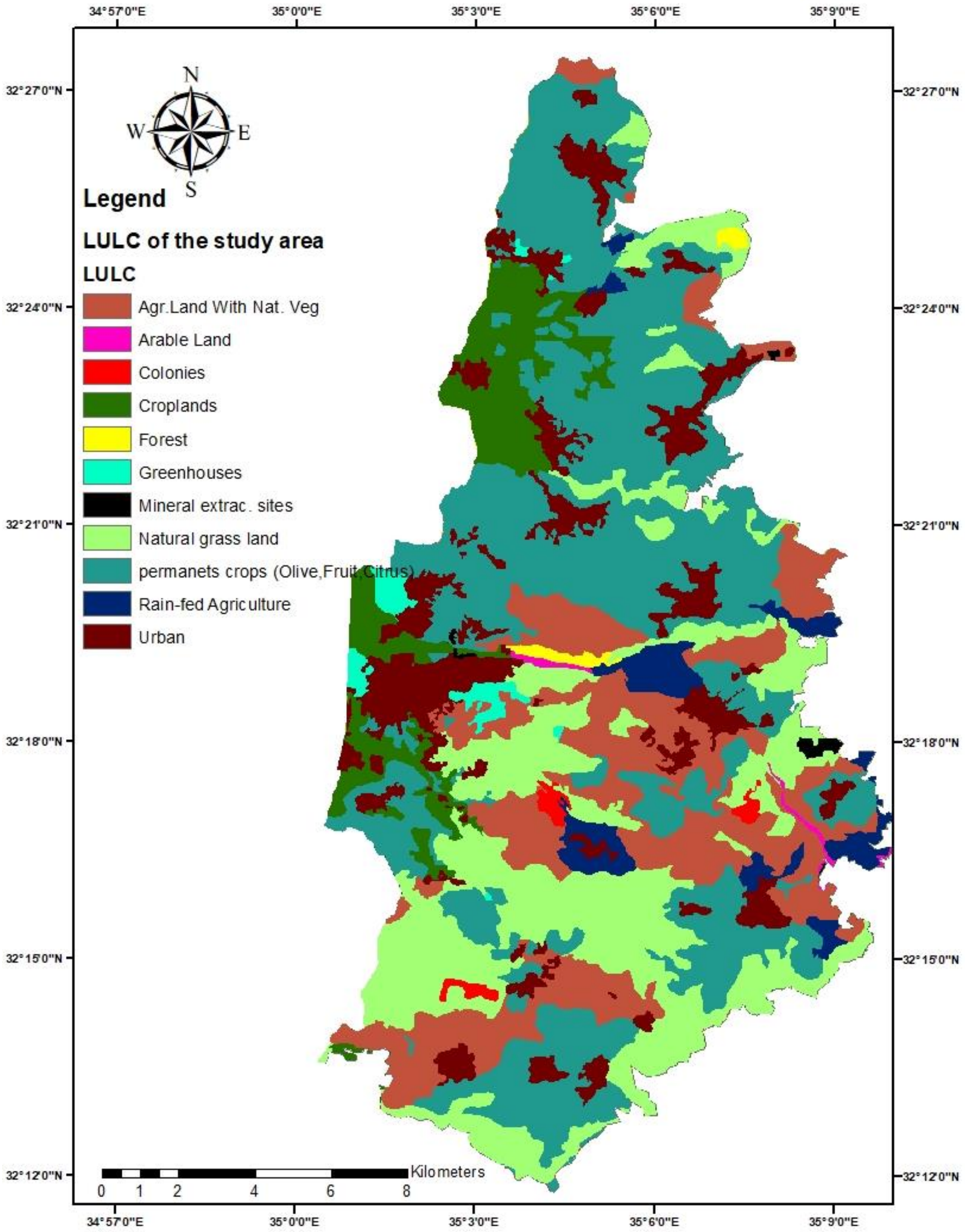
There are three types of vegetation cover (PCBS, 2012):

- **Field crops**: a group of temporary crops, including cereal crops (e.g., wheat and barley), leguminous crops (e.g., chickpeas and beans), oil crops (e.g., sunflowers and sesame), and tuber crops (e.g., potatoes and onions), medicinal crops (e.g., anise, sage, and mint), spice crops (e.g., cumin and black seed), and fodder crops (e.g., alfalfa).
- **Vegetables**: a group of temporary crops that are mainly used for fresh consumption (e.g., pumpkin, eggplant, okra, and green legumes), root vegetables (e.g., carrots, radishes), and leafy vegetables (e.g., lettuce and spinach), in addition to strawberries, melons, and watermelons.
- **Perennial crops**: crops whose growth cycle exceeds one year and do not need to be replanted after each harvest season and live for several years, such as olive, citrus, and almonds trees.

Figure 10 shows that the distribution of population centers in the study area is consistent with its geographical nature. Field crops are widespread in the west, permanent crops (mostly olive trees) are in the north, and orchards and pastures are in the south.

Figure 10

Land cover / Land use in Tulkarm Governorate



Source: (Geomolg, 2023)

2.9 The Water Situation in the West Bank

Water resources are among the most important natural resources due to their importance in the economic and social development of any human society at all times and places. The following is a summary of the water resources in the occupied West Bank (PHG, 2006):

- **Groundwater "wells"**: There are about 597 wells in the West Bank, with a capacity of 69 million m^3 annually, distributed in the western, northeastern, and eastern reservoirs (Figure 11).
- **Springs**: There are approximately 304 springs in the West Bank, with a 27 million m^3 capacity annually.
- **Surface water**: The wadis contain approximately 70 million m^3 of flood water annually, but they are not exploited due to the lack of infrastructure.

Table 10 shows the amount of groundwater present in each of the three aquifers included in the Oslo Agreement 1993 and the percentage of water used by the Israeli and Palestinian sides.

Table 10

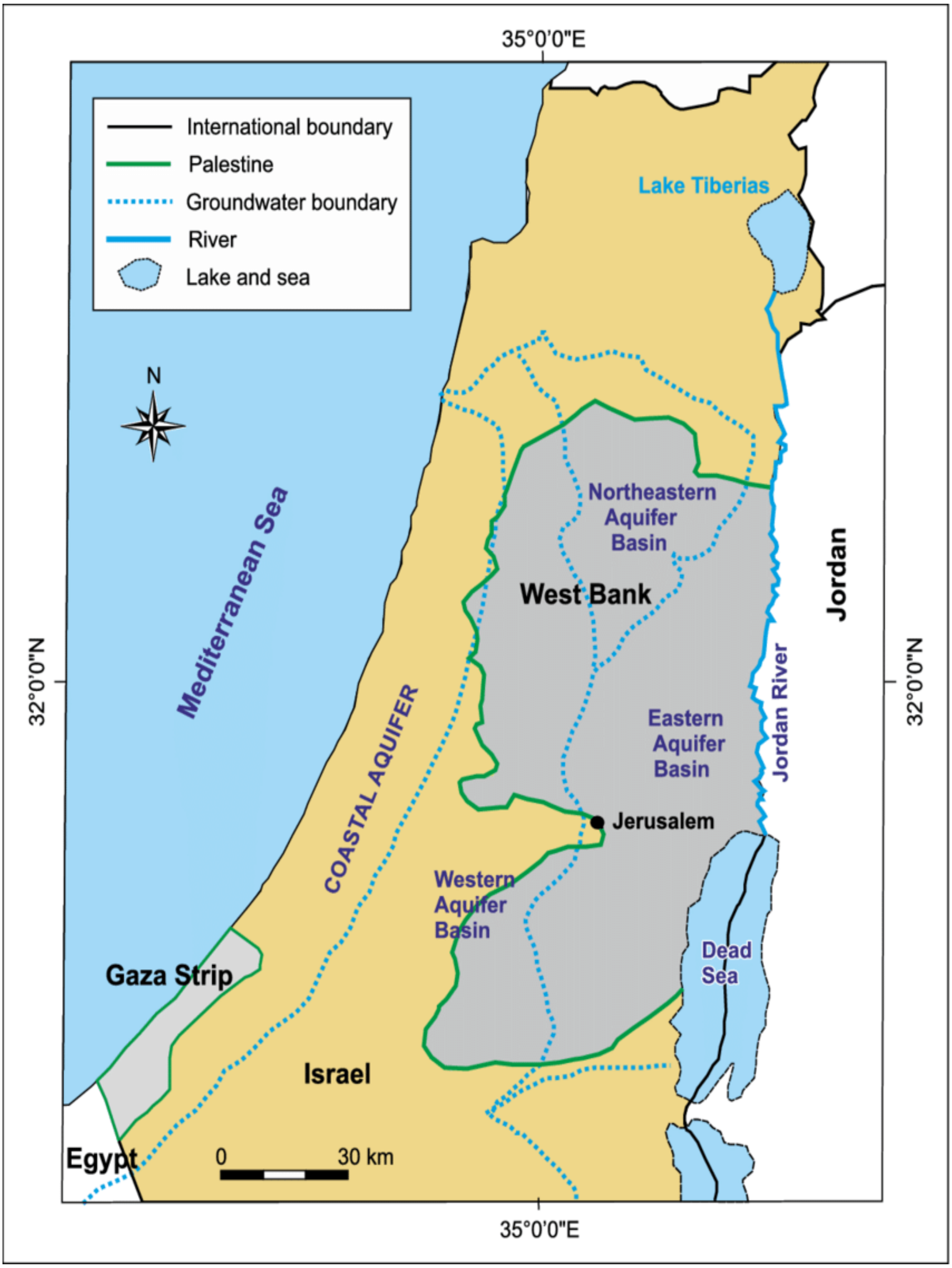
Quantity of water available in ground water aquifer in historical Palestine

Aquifer	***Annual feeding million m^3/year***	***West Bank***	***Israel***	***The rest***
Northeastern	145	42	103	-----
Eastern	172	54	40	78
Western	362	22	340	-----
Total	678	118	438	78

Source: (Abu Amr & Hamouda, 2001).

Figure 11

Groundwater aquifer basins in historic Palestine



Source: (Jebreen, et al., 2017)

Water is one of the most important issues that Palestinians suffer from as a result of military control over Palestinian water resources. The occupation uses security pretexts to prevent Palestinians from using their water resources optimally. The Israeli encroachments extend to direct control over the various water sources in the occupied territory and deprive Palestinians of their water rights in the Jordan River.

Israel's share in the Jordan River is estimated at 23%, but it diverts the waters of the river and its tributaries by building dams and pumps to transport water and digging wells on the border between the Golan Heights and Israel. Israel also controls the water resources in the southern part of the Jordan River, and its withdrawal of water, estimated at approximately 400 m^3 annually, has caused damage to agricultural lands along the river. This amount constitutes 55% of the river's water sources, while Israel did not agree to establish projects for Jordan along the river (Ismail, 2012).

One of the manifestations of the occupation's injustice to the Palestinians' water rights is the huge disparity in consumption. The per capita share of water in Palestine is 70 liters per person per day, much lower than the rates set by the World Health Organization, i.e., a minimum of 100 liters per person per day. In contrast, Israeli settlers in the West Bank receive 394 liters per day. Israel seizes 86.5% of the total Palestinian ground and surface water, while Palestinian consumption does not exceed 13.5% (PCBS, 2000).

In addition, the occupation forces escalated their attacks on the Palestinian water sector as part of their implementation of the apartheid wall. They destroyed 35,000 meters of irrigation networks, about 200 tanks and water ponds, and isolated more than 200 water wells (Applied Research Institute – Jerusalem (ARIJ, 2023).

2. 9. 1 The Water Situation in the Study Area

In the West Bank, in general, and the study area, in particular, the need for water resources is increasing to encourage expansion in various economic sectors, especially agriculture. Because the study area lacks springs, the rainwater harvesting techniques can be used as an alternative water source due to the abundance of rainwater in the governorate.

The Israeli Water Company (Mekorot), collection wells, and the purchase of water tanks from nearby springs and agricultural wells are the only water sources for agricultural lands not connected to public water networks. The price of a cubic meter of water for these tanks ranges between 8 and 14 dollars, approximately five times that of a cubic meter of water obtained from the public water network. Collection wells depend mainly on rainfall throughout the year due to rain fluctuation and its low rates. Water from these tanks has become the only option available to Palestinian farmers (World Bank, 2009).

The water resources in the governorate are divided into two sources:

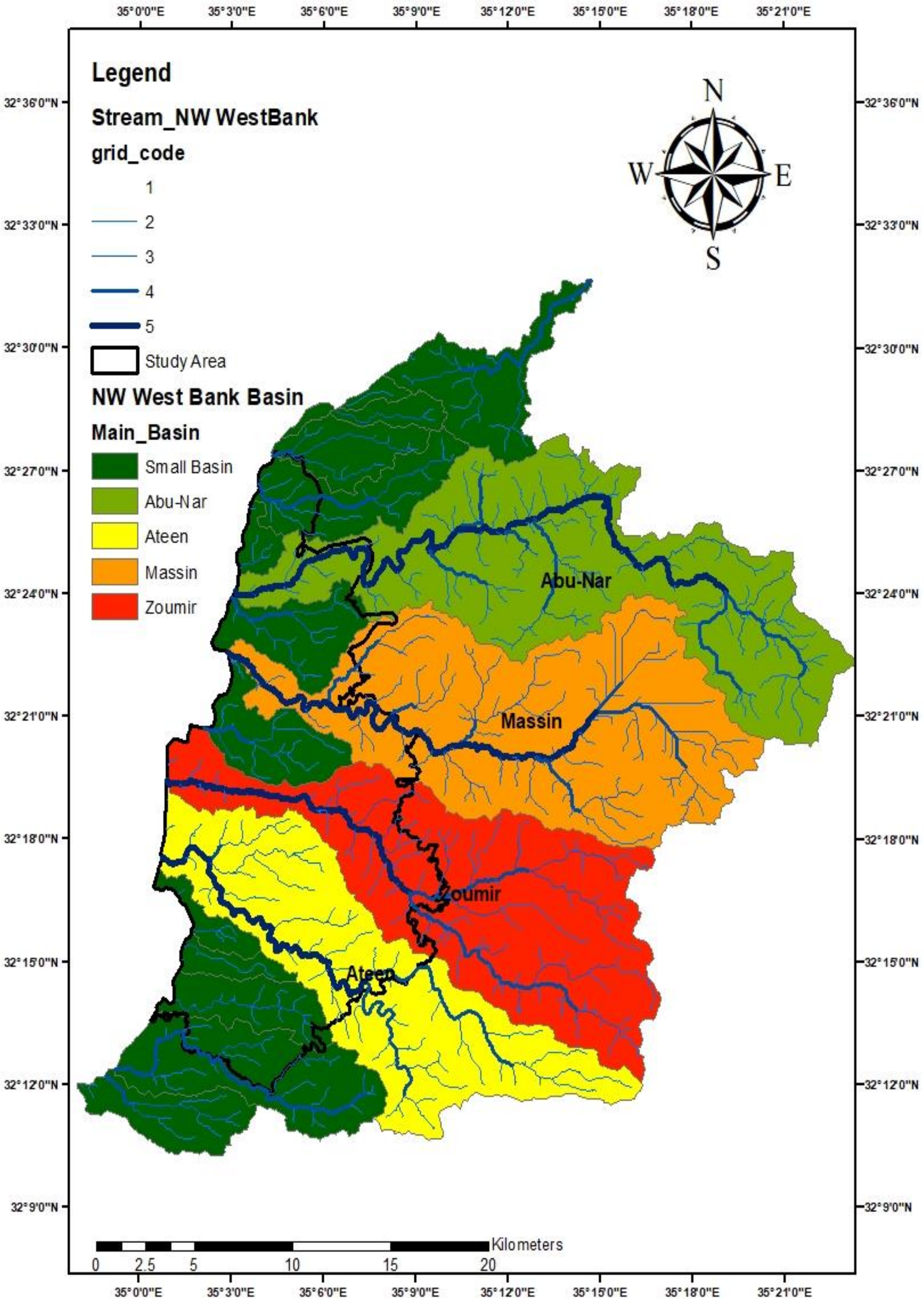
- **Surface water**

The study area lacks sources of surface runoff (wadis and springs). The wadis are seasonal and temporary because there are no permanently flowing wadis. The amount of water flowing in the wadis varies according to the amount of rain that falls from one year to another, and the water flows westward into the Mediterranean Sea (Abu-Farah, 2014) These wadis dry up when winter ends. Figure 12 shows the wadis of the governorate (Abu-Sa, 2014):

1. **Wadi Al-Zoumar** is a tributary of the Alexander River located northwest of Tulkarm. It comes from the north of Burqa from the mountains of Nablus, passing through the villages of Beit Amrin, Deir Sharaf, and Bizaria, passing through the center of the town of Anabta to Nour Shams camp and Iktaba, which is known as Wadi Al-Shaer in those areas. It meets the end at Wadi Qalanswa and has transformed from a source of fresh water into a source of health hazards in the form of a dumping ground for waste and sewage.
2. **Wadi Ateen** starts at the foothills of Mount Al-Tur, east of Nablus, and meets another wadi in Kafr Qaddum. Then, its path turned towards Tulkar, and its flow changed from northwest to south, passing through the villages of Far’un and Artah towards the coastal plain and flowing into the Mediterranean Sea.
3. **Wadi Al-Barq** is one of the dry wadis in the governorate. It floods in the winter and flows into the Mediterranean Sea.
4. **Wadi Qana** passes near Qalqilya, starts south of the Nablus Mountains, and flows into the Mediterranean Sea.
5. **Wadi Al-Mafjar (Wadi Abu Nar)** starts from the Talfeet and Zababdeh Heights, passes through Qabatiya and the Arraba Plain, and flows into the Mediterranean Sea.
6. **Wadi Alexandaronih** flows into the Mediterranean Sea, where it ends with rainwater carried by Wadi Qalansuwa and Wadi Ateen.

Figure 12

Water basins in the northwestern West Bank extracted from a digital elevation model (DEM)



- **Underground water**

The nature of the surface formation helps surface water seeps into the aquifers, it is estimated that 40% to 50% of the surface water finds its way into the aquifers before it is exploited for irrigated agriculture. The fragile, chalky limestone components that form the surface layers of the governorate and its westward inclination helped increase rainwater infiltration, compensating for the loss of surface water and solving problems resulting from rainfall fluctuations (Hassan, 2008).

Unfortunately, these reservoirs are under the control of the Israeli occupation army. Therefore, taking advantage of the remaining amount of wasted surface runoff water that did not find its way into these reservoirs is necessary.

Chapter Three

Rainwater Harvesting

3.1 Introduction

The Mediterranean region suffers from irregular and poorly distributed rainfall throughout the year, so cultivated plants, especially trees, suffer from a lack of water in the soil. For example, about 75% of winter precipitation falls between December and February, and occasional dry spells can occur in April and May (Atawneh & Awadallah, 2002).

Water reserve in the soil greatly affects the success of rain-fed crops. The amount of water stored depends on the quality and depth of the soil. Consequently, the productivity of rain-fed crops increases with increased rainfall. The shallowness of the soil and low depth in the slopes of the study area increases the rate of rainwater loss that is not stored in the soil, which harms plants during the hot summer season. In addition to poor rain distribution and its small amounts, these factors contribute to rainwater misuse in the governorate. Therefore, two of the most important factors affecting agriculture in the region are the amount of annual rainfall and the ability of the soil to retain water. Although the amount of rainfall cannot be controlled, it is possible to use water harvesting to raise soil water content and reduce runoff.

Water harvesting is a collection of surface runoff water for useful, productive purposes. It is a method of collecting and storing rainwater and runoff in a specific location. The main component of rainwater harvesting techniques is the ratio between the runoff and catchment areas. The runoff area is ideal if it has a high runoff coefficient and the catchment area is sufficient to collect water. The collected water is usually stored near agricultural areas provided the soil has sufficient water holding capacity to supply the grown crop until rainfall occurs (Junad, 2005).

Rainwater harvesting refers to any morphological, chemical, or physical process on land to utilize rainwater. It is achieved: 1) directly by enabling the soil to store the largest possible amount of rainwater and reducing the speed of excess runoff, or 2) indirectly by collecting surface runoff water in a drainage and storage area that is not susceptible to erosion (Al-Sheikh, 2006). The collected water is used for supplementary irrigation of crops, drinking, watering animals, or groundwater recharge. The morphological method involves constructing water collection areas such as ponds. The chemical method involves using chemicals to reduce water permeability into the soil, such as using biopolymers produced by bacteria or a bio-enzyme responsible for reducing permeability and swelling and improving the soil. The physical method involves preparing the land by clearing and smoothing it and then paving or covering it with minerals or plastic sheets, which is possible in impermeable areas (Verma, 2021; Mendonça et al., 2021; Gaafer et al., 2015).

General water harvesting is collecting and storing rainwater for later use, usually after winter. On the other hand, agriculture harvesting uses tools and techniques to collect runoff water to raise soil moisture content and increase its water reserves, which in turn enhances plant productivity during the dry season (Libiszewski, 1995).

The amount of rain that falls on the Earth's surface is distributed as follows:

- The portion absorbed by the soil increases its moisture content and benefits crops throughout the year.
- The portion penetrating the rock and soil layers is stored in the aquifers below the Earth’s surface.
- Surface runoff is the portion that flows over the surface of the Earth and is not exploited.
- Evaporation that reaches the atmosphere.

3. 1. 1 Components of the Hydroponic Harvesting System

The system consists of several components, the most important of which are (Al-Dhoeb, 2012):

- **Rainwater catchment area** is a piece of land with a suitable slope towards the rainwater catchment where rainwater collects during rainfall. This area may be wide or limited and not exceed a few square meters. There is a path to transport the collected water if the collection site is far from the area that will use it for agriculture.
- **Storage area** is where rainwater is stored, i.e., in reservoirs such as ponds, pits, aquifers, or soil.
- **Beneficiary Area** should be irrigated with collected rainwater.

3. 1. 2 Benefits of Water Harvesting

- Water harvesting helps prevent environmental degradation and improves vegetation.
- Agriculture is made possible in the region through water harvesting despite acceptable and poorly distributed rainfall.
- Water sustainability can sometimes be achieved through water harvesting technology.
- Stabilizing rural communities and reducing rural migration to cities.
- Improving the social and economic conditions of residents in water harvesting areas.
- Rainwater harvesting can help in places without enough water for human use and animal husbandry (FAO, 1991).

3.2 The Importance of Water Harvesting in the Development of Water Resources

In general, water harvesting is one of the best techniques for obtaining water when other water sources are not available, especially in areas where there are no permanent running water sources, or if water is available, it is in the form of non-renewable groundwater (AOGD, 1999).

Note that numerous techniques for harvesting rainwater and preserving soil moisture vary from one site to another, depending on the characteristics of the natural soil, rain intensity, and optimal land exploitation. Water harvesting techniques also depend directly on the slope, shape, and direction of the earth's surface, as well as the depth and quality of the soil, which determine the direction and intensity of the works and the type of technology that will be established.

From the above, it can be concluded that the most important factors that must be considered when designing water harvesting systems are as follows (Al-Sheikh, 2006):

- Rainfall distribution throughout the agricultural season,
- Precipitation intensity,
- Surface soil runoff characteristics and soil permeability,
- Topography of the study area in terms of inclination and direction,
- Soil water holding capacity (soil depth and texture).

The importance of water harvesting for collecting runoff water and establishing supplementary irrigation systems to support agricultural production is based on the following principles (FAO, 1994):

- Water harvesting should be a supplementary source for crops with high water needs, not the main source due to the scarcity of water resources,
- Increasing opportunities to save water to enhance the productivity of rain-fed crops,
- Improving the efficiency of exploiting wasted land resources.

Exploiting water harvesting techniques and utilizing rainwater as much as possible is crucial, especially in growing local varieties (Goish, 2008), to mitigate plant extinction due to drought or farmers dispensing these plants due to their low productivity caused by drought and low rainfall rates. Therefore, exploiting water harvesting techniques and ideas will contribute greatly to maintaining the sustainability of these plants in the region, increasing their productivity and their survival and preservation.

Water harvesting is very important on the economic and social levels because using water harvesting technology to provide and collect water is low-cost and easy to provide to the residents of the study area. The collected water is used for agricultural and domestic purposes, as its use in agriculture increases production by reducing soil erosion. It also combats desertification resulting from surface runoff by growing crops that can withstand long drought and water shortages. Moreover, it provides animals with drinking water, which increases the wealth of livestock, especially if it is used to grow suitable fodder for the animals, increasing family income and improving the standard of living. It also reduces unemployment and labor migration to cities.

3. 3 Water Harvesting Techniques in Palestine

The following is a review of Palestine's most important water harvesting techniques. Note that these techniques are not limited to Palestine but have been applied in different regions of the Arab Levant and the world (Al-Dhoeb, 2012; Al-Lawzi, 2002; Prinz et al., 1998).

1. Small Pits

Soil digging techniques go back a very long time. The goal was to create a group or series of small pits distributed among trees to collect some water runoff and rain to benefit plants. The diameter ranges from 0.5 to 2 meters, and their depth ranges from 5 to 15 centimeters. It is excellent for reviving degraded agricultural lands.

2. Contour Ridges

Earthen walls are erected parallel to the contour lines, and the distance between one wall and the other ranges from 10 to 20 meters. The field is divided into small areas for harvesting, and a hole is made around each plant to absorb the collected rainwater. This technique is suitable for planting trees.

3. Eyebrow Terrace

Dirt barriers in the shape of a semicircle, crescent, or trapezoid face directly up the slope. They are created at distances that allow a sufficient catchment area to prepare the required runoff water so it collects in front of the barrier, where the plants grow. These barriers are usually created in different rows. The diameter or distance between two barrier ends ranges from 1 to 8 m, while its height ranges between 30-50 cm.

4. Contour Plow System

The land is plowed in longitudinal furrows corresponding to the contour lines, and the distance between the furrows ranges from 0.5 to 1 meter. This system is applied in low-slope lands with a slope of 3% to 8% and deep soil. This technique is often used to grow crops and shrubs; cultivation is done on both sides of the furrows.

5. Stone Terraces

It is one of the well-known techniques for collecting rainwater in mountain slope areas. Terracing is one of the most efficient techniques to maintain and protect soil from erosion, especially on slopes between 10% and 35%. The distance between the terraces is a few meters. It is the best way to transform agricultural lands on slopes with poor productivity into highly productive lands.

6. Earthen Terraces

Earthen terraces are built along the ground, usually 5 to 15 meters apart. Creating these terraces is a simple technique for growing trees and fodder. It is used in areas with a slight slope, such as where it is difficult to make stone terraces due to the lack of stone.

7. Roof Top Systems

Roof systems collect and store rainwater from the roofs of homes, large buildings, greenhouses, and similar impermeable spaces and surfaces, including streets, allowing most rainwater to be collected and stored. Using water after harvesting depends on the type of surface used to collect it and its degree of cleanliness, in addition to the users' needs.

8. Small Reservoirs

Small reservoirs are created in lands near valleys or in flood courses, such as ponds. The location is suitable for storing some or all surface runoff water that flows down the valley so that this water can be used to irrigate crops or consumed. These ponds are usually small, varying from 1,000 to 500,000 m^3. The assistance of engineers is required to plan, design, and implement these facilities (Hutchinson, Garduño, & Dutt, 1981).

3.4 Potentials of Adopting Rainwater Harvesting Techniques in Palestine

The amount of water shared with the occupying state (Israel) from ground and surface water sources, is estimated at 2,989 million m^3 annually. The amount of water flowing from torrents is about 215 million m^3. The amount of water resulting from the natural flow of Jordan's waters is estimated at 1320 million m^3, and the rest is from groundwater. The total amount of water consumed is about 2570 million m^3 annually, of which the Palestinians consume 271 million m^3 (11%), while Israelis exploit the remaining 89%. The Palestinian people are deprived of access to and benefit from the waters of the Jordan River (Palestinian Water Authority, 2010).

Surface water sources constitute an important water source in Palestine because heavy seasonal rains usually fall for limited and intermittent periods in the winter. Climate fluctuations greatly affect these water quantities, especially since rain is the main source of surface and groundwater.

Palestine has recently witnessed climatic fluctuations, manifested in the variation of the average amount of rain from year to year. The water harvesting project aims to store water, reuse it, raise the efficiency of rainwater use, improve the environment, increase technical efficiency, and develop specialized personnel qualified to work in this field (Abu Amr & Hamouda, 2001).

Examples of water harvesting projects in Palestine include the construction of 51 wells in the Gaza Strip to collect rainwater using stone terraces and cement ponds. However, this project only lasted for two years due to the events that took place in the Gaza Strip during the Al-Aqsa Intifada in 2000, which led to the destruction of the wells and any other water sources (Abu Dhaher, 2000). In addition, Palestine strives to increase the amount of water using simplified traditional technologies to effectively prevent water resource loss. Most of these systems are built on the concept of rainwater harvesting.

Israel has seized Palestinian waters because it was able to access and control the water basins during its occupation of the West Bank and Gaza Strip in 1967. In addition, the occupying authority forcibly deports Palestinians from their homes and lands near water springs. It prevents them from building dams or digging wells unless they obtain a special permit under specific conditions (Center for Palestinian Studies, 1990).

Accordingly, Palestinians are prohibited from establishing any new water facilities without a license. Israel has the right to refuse any license without giving reasons. At the same time, Israel has drilled many wells and built dams that the Palestinian people desperately need (Gaza Center for Rights and Law, 1990).

Chapter Four

Water Budget

4. 1 Introduction

Thornthwaite was the first to use “water balance” in climate studies in 1948. He believes that the climate water balance is the relationship between the quantities of water entering an area represented by precipitation, what is lost through evaporation and transpiration, and any change in soil moisture (Thornthwaite & Mather, 1957). Calculating the water budget is the basic step in finding the potential and actual values of evapotranspiration, and the evapotranspiration element is the controlling element in the values of water surplus and deficit. Water deficit means lower water potential, while high potential evaporation and transpiration values mean more pressure on water resources. Therefore, it was necessary to calculate the water balance in the study area to estimate the water surplus and deficit values based on the Thornthwaite method of calculating the potential elements of evaporation and transpiration (Al-Rawi & Al-Samerai, 1990).

The modified Thornthwaite equation (1955) was also used to calculate potential evapotranspiration based on monthly temperature averages, taking into account that other climatic elements that affect evaporation and transpiration change automatically with temperature (Shehadeh, 1983). Several studies have indicated that the Thornthwaite method is suitable for calculating potential evapotranspiration over long periods (Alananzeh, 1996). Using it to calculate variables related to soil water balance gives a good impression of precipitation, temperature, soil moisture, and runoff (Calvo, 1986). This chapter focuses on evapotranspiration and changes in soil moisture storage during 2011-2020.

The soil water balance in the study area was also calculated using the modified Thornthwaite equation (1955), which is the most common equation in climate studies and is used to calculate water loss through evaporation and transpiration in any area depending on the average monthly temperature and precipitation (Mather, 1961; Thornthwaite & Mather, 1957).

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4. 2 Evapotranspiration

Evaporation is the release of water in the form of vapor from water bodies and soil into the atmosphere. At the same time, transpiration is the water vapor that plants release into the air from openings on their leaves and the steam emitted from the bodies of animals and humans (Al-Saadi, 2013). Both types of evaporation and transpiration are collectively called evapotranspiration, and several factors affect the evaporation process:

- Climatic factors (Al-Saadi, 2013; Al-Shamrati & Al-Salim, 2011; Al-Janabi):

1. **Temperature**: It is the climatic element that most influences the evaporation process. The higher the temperature, the more heat the water or land surface is exposed to, and thus, the faster water molecules are released into the air.
2. **Solar radiation**: It is the primary energy source influencing the evaporation process. Therefore, it contributes to increasing evaporation values, whether from exposed water, soil, or plant surfaces after exposure to solar radiation. The light energy transforms into thermal energy, releasing water molecules into the air. Solar radiation values vary depending on the angle of the sun's position to the Earth. The evaporation values increase in areas where the sun's rays fall vertically.
3. **Wind**: It is a major factor in the evaporation process. An increase in air speed leads to the movement and mixing of moist air when it comes into contact with the surface of the soil, tree leaves, and bodies of water, which is replaced by relatively dry air, leading to accelerated evaporation and transpiration processes. Evaporation values are directly proportional to the wind movement, direction, and speed when all other factors are constant.
4. **Atmospheric pressure**: At high atmospheric pressure, there is a greater opportunity for water vapor molecules emerging from the water surface to collide with air molecules. When atmospheric pressure increases, evaporation decreases, and the number of air molecules per unit volume increases.
5. **Humidity**: The quantity of evaporation/transpiration increases in low relative humidity and decreases or stops in saturated atmospheres with very high relative humidity. Therefore, the evaporation and transpiration values in the air increase when air humidity decreases, meaning that air saturated with water vapor cannot hold more water vapor. Thus, evaporation stops when the air becomes saturated with moisture.

- The ground factors affecting the evaporation process were obtained from a lecture by Dr. Hameed Rajab Al-Janabi (Al-Janabi):

1. **Soil Moisture**: The evaporation process and its values are affected by the nature of the soil, characteristics, texture, and moisture content. For example, sandy soil does

not retain water, unlike clay soil. The greatest amount of evaporation is from saturated soil. When soil moisture decreases, the evaporation amount also decreases. There is usually lower or no evaporation in desert areas due to the soil's lack or absence of moisture.

2. **Slope Direction**: The incoming energy and duration of sunlight vary depending on the slope direction. Southern slopes receive more energy and a longer bright period than northern slopes in the Northern Hemisphere, and vice versa. Therefore, since the study site is located in the northern hemisphere, evaporation is greater on the southern slopes than the northern slopes despite the same height above sea level.
3. The amount of solar radiation the soil absorbs varies depending on its color. Therefore, dark and light soils differ due to the ability of dark soil to absorb a greater amount of solar radiation during the day.

4. 2. 1 Potential Evapotranspiration (PE)

PE is the largest possible evaporation process from water bodies and soil saturated with water, which is affected by climatic factors, especially solar radiation (Al-Janabi). There are several ways to calculate it statistically. Still, the most common method is the Thornthwaite equation (1931), which is the simplest and most widely used soil moisture equation because it uses an accurate table showing the interaction between solar radiation with temperature to calculate the elements in the equation (Al-Hallaq, 2003). It makes it easy to divide the world into climatic regions because it does not need any climatic elements except the average monthly temperature of the station (Al-Saadi, 2013). It is as follows (WMO, 1961):

$$PEx = 16\left(\frac{10Tm}{I}\right)^{a} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ(1)$$

PEx: Potential monthly evapotranspiration (mm/month)
Tm: Mean temperature of the month (°C)
I: annual heat coefficient, which is calculated as follows

$$I = \sum_{12} i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ(2)$$

i: monthly heat coefficient, calculated from the following equation (WMO, 1961).

$$i = \left(\frac{Tm}{5}\right)^{1.514} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \dots \; equ(3)$$

$$a = (6.75 * 10^{-7})I^{3} - (7.71 * 10^{-5})I^{2} + (1.792 * 10^{-2})I + 0.49293 \dots equ\ (4)$$

The PEx value assumes that the number of days in a month is 30 and the number of hours from sunrise to sunset is 12. Therefore, the potential evaporation value can be corrected in each month with the following relationship:

$$PE = PEx\left(\frac{DH}{360}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \; equ(5)$$

PE: corrected potential monthly evapotranspiration (mm/month)
D: number of days in the month
H: average number of sunrise hours (hours/day)

Table 11

Average monthly potential evapotranspiration (mm) for the study area from 2011 to 2020

Month	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Ann*
Tm	12.85	13.42	15.31	18.03	21.88	24.71	26.93	27.51	26.39	23.63	19.15	14.99	20.40
i	4.17	4.46	5.44	6.97	9.34	11.24	12.80	13.22	12.41	10.50	7.64	5.27	103.47
PEx	24.34	27.01	36.87	54.36	85.92	114.67	140.55	147.80	133.95	103.14	62.69	35.07	966.38
factor	0.89	0.86	1.03	1.08	1.19	1.20	1.21	1.15	1.03	0.98	0.88	0.87	
PE	21.66	23.23	37.97	58.71	102.25	137.60	170.07	169.97	137.96	101.08	55.17	30.52	1046.19
P	150.60	91.20	52.10	24.01	7.28	0	0	0	0.55	21.93	78.72	131.67	558.06

4. 2. 2 Actual Evapotranspiration (AE)

AE is the amount of water lost from a specific area in a certain period and under a certain soil moisture level. It equals potential evapotranspiration as long as precipitation is higher than potential evapotranspiration. However, when the amount of precipitation is less than potential evapotranspiration, effective evapotranspiration equals precipitation plus change in soil moisture (ΔST), even if negative (Zeitoun, 2014). If precipitation is equal to zero, then the effective evapotranspiration is equal to the change in soil moisture. However, if the change in soil moisture equals zero, the effective evapotranspiration remains equal to precipitation.

$$AE = PE \qquad\qquad if \quad P > PE$$

$$AE = P + |\,\Delta\, ST\,| \qquad\qquad if \quad PE > P \ldots\ldots\ldots\ldots\ldots\ldots\ldots \; equ(6)$$

4. 2. 3 Total Evapotranspiration (TE)

Total evapotranspiration equals the sum of potential and actual evapotranspiration if the rain is less than the potential evapotranspiration. If the rain is greater than or equal to the potential evapotranspiration, the total evapotranspiration equals the potential evapotranspiration (Al-Saadi, 2013).

$$TE = PE + AE \qquad\qquad if \quad PE > P$$
$$TE = PE = AE \qquad\qquad if \quad P \geq PE \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ equ(7)$$

4. 3 Change in Soil Moisture Storage (ΔST)

Soil moisture storage is the amount of water held in the soil at any given time. Thornthwaite assumed that soil moisture has a storage capacity of 100 mm (4 in). When rainfall is higher than potential evaporation, soil moisture is filled up first, and then excess water flows out. When potential evaporation exceeds rainfall, the soil begins to dry out first. The change in ΔST is the amount of water recharged or utilized from what was stored (Al-Hallaq, 2003).

4. 4 Water Budget

The climate water budget is the relationship between the amount of precipitation (imports) and amount of water loss. Its calculation depends on the amount of evaporation, considering the climatic factors affecting it (Ahmed, 2019). Thornthwaite believes that the climate water balance is “the relationship between what water enters an area in the form of precipitation and what is lost in water through evaporation and transpiration, as well as any changes in water from soil moisture, groundwater, and water bodies, etc., which determines drought in any place.”

Water deficit occurs when the potential amounts of evaporation and transpiration are greater than the amount of precipitation, leading to the drying out of the area. Conversely, water surplus occurs when precipitation exceeds the potential amount of evaporation and transpiration. So, many components, terms, and concepts in the water budget equation must be known (Al-Saadi, 2013; Al-Hallaq, 2003).

$$\boldsymbol{P = PE - WD + WS \pm \Delta\, ST} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ equ(8)$$

Where: P: Precipitation (mm)
PE: Potential Evapotranspiration (mm)
WD: Water Deficit (mm)

WS: Water Surplus (mm)
| Δ ST |: Change in soil moisture (mm)

4. 4. 1 Water Surplus Periods (WS)

This period is characterized by precipitation exceeding potential evaporation rates and the soil being at its field capacity and “saturated.” Any increase in the amount of precipitation after that is considered an increase in humidity, and then surface runoff begins as long as the temperature is higher than -1°C (Zeitoun, 2014; Maidment et al., 1997; Reed, 1997) The following relationship determines this period:

$$WS = P - PE \quad if \quad P > PE \quad \& \quad ST = 100$$
$$else \;\; WS = 0 \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \ldots\ldots \; equ(9)$$

4. 4. 2 Water Deficit Periods (WD)

This period is characterized by potential evaporation rates exceeding rainfall rates because it equals the difference between potential evaporation and actual evaporation (Al-Saadi, 2013; Al-Hallaq, 2003; Critchfield, 1974). The following relationship determines this period:

$$WD = PE - P \;\; if \quad P < PE \quad \& \quad ST = 0$$
$$else \quad WD = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; equ(10)$$
$$OR \quad WD = PE - AE \; \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \ldots \; equ(11)$$

Figure (13) and Figure (14) in appendix (B) show the average annual water deficit and surplus (mm/year) in the study area for the years 2011 to 2020.

Table 12

Average water budget (mm/month) for the study area from 2011 to 2020

Month	*PE*	*P*	*P-PE*	*P+Δ ST*	*Δ ST*	*ST*	*AE*	*WS*	*WD*

Jan	21.66	150.60	128.94	150.60	0	100	21.66	128.94	0
Feb	23.23	91.20	67.97	91.20	0	100	23.23	67.97	0
Mar	37.97	52.10	14.13	52.10	0	100	37.97	14.13	0
Apr	58.71	24.01	-34.70	58.71	-34.70	65.30	58.71	0	0
May	102.25	7.28	-94.97	72.58	-65.30	0	72.58	0	29.67
Jun	137.60	0	-137.60	0	0	0	0	0	137.60
Jul	170.07	0	-170.07	0	0	0	0	0	170.07
Aug	169.97	0	-169.97	0	0	0	0	0	169.97
Sep	137.96	0.55	-137.41	0.55	0	0	0.55	0	137.41
Oct	101.08	21.93	-79.15	21.93	0	0	21.93	0	79.15
Nov	55.17	78.72	23.55	102.27	23.55	23.55	55.17	0	0
Dec	30.52	131.67	101.15	208.12	76.45	100.00	30.52	24.70	0
Annual	1046.19	558.06			0		322.32	235.74	723.87

Table 13

Average annual and monthly water budget (mm) for Tulkarm Governorate from 2011 to 2020

Month	***P =***	***PE***	***- WD***	***+ WS***	***+ Δ ST***
Jan	150.60	21.66	0	128.94	0
Feb	91.20	23.23	0	67.97	0
Mar	52.10	37.97	0	14.13	0
Apr	24.01	58.71	0	0	-34.70
May	7.28	102.25	29.67	0	-65.30
Jun	0	137.60	137.60	0	0
Jul	0	170.07	170.07	0	0
Aug	0	169.97	169.97	0	0
Sep	0.55	137.96	137.41	0	0
Oct	21.93	101.08	79.15	0	0
Nov	78.72	55.17	0	0	23.55
Dec	131.67	30.52	0	24.70	76.45
Annual	558.06	1046.19	723.87	235.74	0

4.5 Drought

Drought is a topic of interest to geographers because it is a bioclimatic phenomenon linked to humans, the surrounding nature, and their economic and environmental capabilities. Therefore, climate studies involve studying its causes and effects within the framework of the desertification concept, such as global warming, agriculture, irrigation, famine, food security, water sufficiency, etc. Droughts occur in almost all climate zones, such as areas with high and low rainfall, and are often associated with a decrease in rainfall over a long period, such as a season or a year (Mishra & Singh, 2010). Drought is defined as the inability of atmospheric or ground moisture to cause germination, meaning insufficient moisture for germination. (Al-Saadi, 2013).

4. 5. 1 Types of Droughts

Thornthwaite defined four types of droughts (Mohammed, 2020; Al-Amoud, 2018; Vittal et al., 2010):

1. **Permanent Drought**: The amount of rain is so little that moisture in the soil or air does not enable germination on most days of the year. Only plants that can tolerate a shortage of moisture and water grow, such as spiny plants. This type appears in hot and cold deserts.
2. **Seasonal drought**: This type appears in a specific season of the year, where the increasing water is limited to one, two, or three seasons, except the dry season. Agriculture depends on rainfall in the rainy season, but in the dry season, it depends on irrigation.
3. **Contingent Drought**: This type results from irregular rainfall and fluctuating seasons. It is limited to humid and semi-humid areas, such as the study area, where drought may extend for a long period without precipitation, destroying plants and decreasing their production. This drought is one of the most dangerous types because it is unpredictable and rain cannot be compensated for with irrigation, as had happened in many countries when they were struck by drought waves, e.g., countries in the northern Mediterranean, whose forests were exposed to fires as a result of sudden droughts.
4. **Invisible Drought:** This type occurs when the atmospheric humidity or soil moisture is below the minimum necessary for plants to survive, causing them to harden and die, leading to sudden forest fires. It affects the humid areas of the world.

- **These are secondary types of droughts:**

1. **Hydrological drought**: This type is widespread in areas where it is impossible to supply water to the low plains (Al-Saadi, 2013). It also represents a decrease in the

water level in water bodies and underground reservoirs, leading to the drying up of reservoirs and lakes and a decrease in flow in waterways (Vittal et al., 2010).

2. **Agricultural drought**: It represents the lack of rainfall and its insufficiency for growth and production, whether winter or summer crops. It is when the amount of water in the soil is insufficient. Therefore, it occurs when the amount of water needed for evaporation and transpiration is greater than in the soil (Ndayiragije & Li, 2022; Al-Amoud, 2018).

4. 6 Climate Classification Indicators

Six indices are used to determine differences in climate categories (Thornthwaite, Lang, De Martonne, Minar, UNPI, Pinna Combinative).

4. 6. 1 Thornthwaite Index

The Thornthwaite's precipitation effectiveness index (TWI) depends on temperature and precipitation, given by the following formula:

$$TWI = \sum_{12} 1.65\left(\frac{Pm}{Tm + 12.2}\right)^{10/9} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\; equ(12)$$

Pm = monthly precipitation (mm)
Tm= monthly temperature (°C)

Thornthwaite divided the world into five climate categories according to the adequacy of rainfall, as shown in Table 14, appendix (C)

Thornthwaite's climate classification equation was applied to the study area, and its value was 38.72. The study area is classified as a semi-humid region according to his table of climate categories in Table 14.

4. 6. 2 Lang Index

Richard Lang expressed drought in terms of rain coefficient (LI), which is based on the following equation (Mendez, 2006):

$$LI = \frac{P}{T} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\; equ(13)$$

P = annual average precipitation (mm)

T = annual average temperature (°C)

The world is divided into four climate categories based on the Lange precipitation factor, as shown in Table 15, appendix (C)

The Lang's precipitation factor was applied to the study area, and its value was 27.35. The study area is classified as an arid region according to his table of climate categories in Table 15.

4. 6. 3 De Martone Index

De Marton divided the world into five climate categories based on his drought index (DMI), which is expressed by the following equation (Nikolova & Yanakiev, 2020; De Martonne, 1923):

$$DMI = \frac{P}{T+10} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots.\ equ(14)$$

P = annual average precipitation (mm)

T = annual average temperature (°C)

DMI was applied to the study area, and its value was 18.35. According to his table of climate categories (Table 16, appendix (C)), the study area is classified as a semi-arid region.

4. 6. 4 Minar's Index (MI)

MI divides the world into seven categories according to the degree of drought using the following equation (Chowdhury, 2018):

$$MI = \frac{P - 30\,(T-7)}{T} \dots\dots\dots\dots\dots\dots\dots\dots.\dots\dots.\ equ(15)$$

P = annual average precipitation (mm)

T = average annual temperature (°C)

MI was applied to the study area, and its value was 7.65. According to his table of climate categories (Table 17, appendix (C)), the study area is classified as a semi-arid region.

4. 6. 5 UNEP Arid Index (UNPI)

UNPI is defined as follows (Gabriels, 2007; UNEP, 1993):

$$UNPI = \frac{P}{PET} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\ equ(16)$$

P = annual average precipitation (mm)

PET = annual average Potential Evapotranspiration (mm)

The UNPI drought index was applied to the study area, and its value was 0.53. According to (Table 18, appendix (C)), the study area is classified as a semi-humid dry area.

4. 6. 6 Pinna Combinative Index (PCI)

PCI is defined as follows (Baltas, 2007):

$$PCI = \frac{1}{2}\left(\frac{P}{T+10} + \frac{12\,pd}{td+10}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; equ(17)$$

P = annual average precipitation (mm)
T = annual average temperature (°C)
pd = average precipitation in the driest month (mm)
td = average temperature in the driest month (°C)

The PCI value of the study area is 9.17, classifying it as an arid region, according to (Table 19, appendix (C)).

The study area is considered semi-humid (Ayed & Alwishahy, 1999). Table 20 shows that the most accurate indicators to describe the study area are the Thornthwaite Index and UNPI.

Table 20

Classification of climate in the study area according to different indicators

Indicator	***Value***	***Climate Categories***
Thornthwaite	38.72	Semi-humid
Lang	27.35	Arid
De Martone	18.35	Semi-arid
Minar	7.65	Semi-arid
UNEP	0.53	Dry sub-humid
Pinna Combinative	9.17	Arid

Chapter Five

Surface water harvesting methodology in the study area

5.1 Introduction

Obtaining field readings to calculate surface runoff using traditional methods may be difficult. It requires special measuring devices to collect, store, and measure rainwater over time. It is difficult to provide these methods directly, especially in developing countries like the study area. Therefore, GIS technology was used to simplify obtaining the data needed to analyze rainwater harvesting data.

Modeling rainwater drainage in arid and semi-arid areas is no less important than in humid areas. Hydrological modeling in the West Bank did not receive sufficient attention, and no extensive studies were conducted (ARIJ, 1996). Therefore, Palestinian researchers and hydrologists have made great efforts to develop these hydrological models and have completed many research projects in this field. Hence, using GIS allows the processing and analyzing of hydrological data with great efficiency.

This study focuses on a few modern technologies used in this field to benefit from them. The most important of these techniques is GIS and their role in processing DEMs, which are used to determine the rainwater network and calculate the amount of surface runoff.

Surface runoff is the portion of precipitation that falls on a specific area, flows over the earth's surface, and follows several paths depending on the area's topography until it reaches a stream that confines water in its course. Surface runoff occurs due to water saturation of the soil after heavy rains and the steep slope of the ground surface, which exceeds the ability of the ground to absorb water. Hence, rainwater flows down the slopes towards the main channel (Abdel Aziz, 1996).

The amount of runoff is affected by soil composition and properties, which control the amount and time of water infiltration into the soil. Therefore, coarse soil (e.g., sandy soil) is characterized by its large porosity and is classified as permeable soil. On the other hand, soft, loose soil is characterized by its small porosity (e.g., clay soil), which resists and prevents seepage. Surface runoff is also affected by vegetation density and land slope. High plant density allows water to seep into the soil because plant roots create larger voids between soil particles, allowing water to pass through them. Ground slopes have an inverse relationship with water seepage because the speed of water flow over the surface increases with the slope of the ground, reducing the amount of seepage into the soil (Khudair, 1998).

The efficiency of the results depends on many factors, such as multiple processing methods, reducing fieldwork, and managing a large amount of information. Therefore, GIS technology was adopted to estimate surface runoff in the study area due to its ability to deal with all these factors. GIS is key in enhancing the rainwater harvesting system and providing the necessary data to enable its large-scale implementation. Subsequently, a model has been proposed to consider the different hydrological conditions prevailing in the region using the analytical capabilities of GIS. The available data was processed, analyzed, and combined into mathematical equations to choose suitable sites for building water collection ponds.

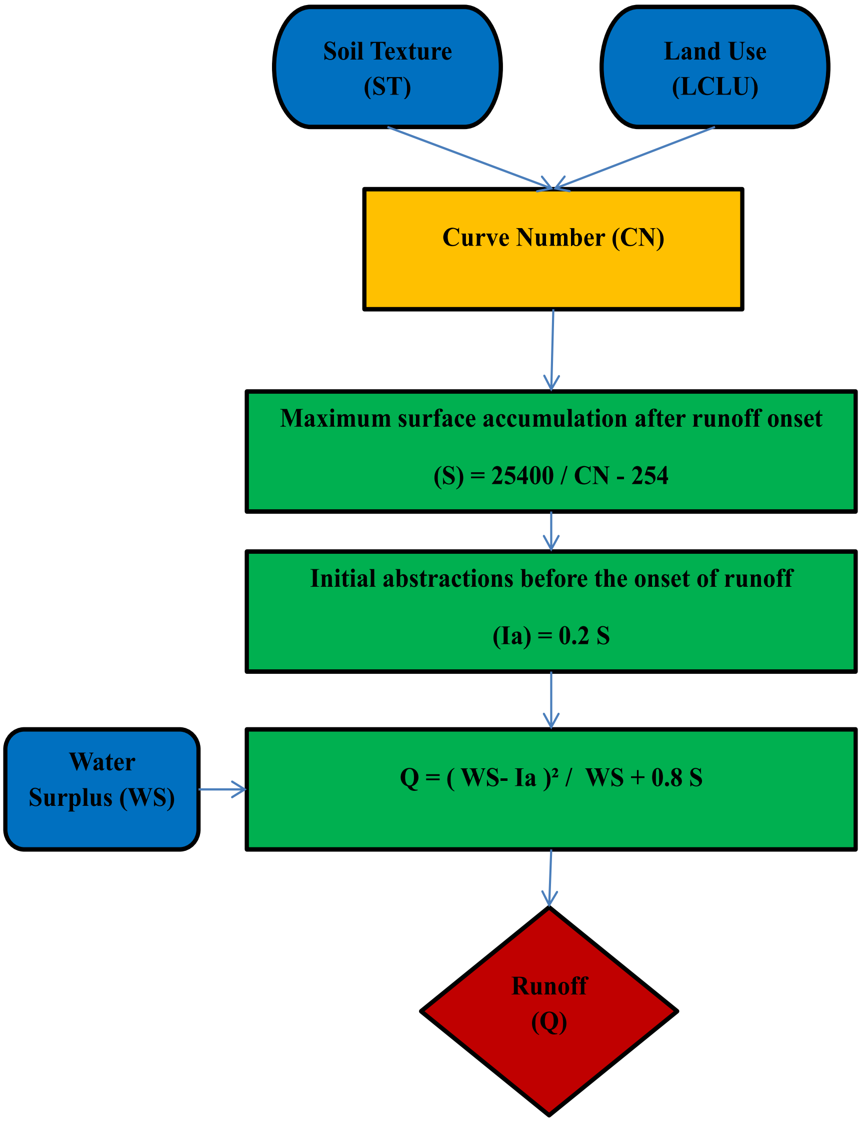
5.2 Surface Runoff Model

The surface water runoff model was created in the ArcGIS environment using mathematical equations. Numerical CN values are calculated based on land use/cover types and soil texture.

Figure 15 summarizes the runoff calculation process using the numerical CN method with the help of models to calculate the maximum water retention factor (S) and initial abstractions (Ia) using GIS.

Figure 15

***Surface** Runoff Model*



5. 2. 1 Curve Number (CN)

Runoff curve number (also called curve number) is an empirical parameter used in hydrology to predict direct runoff or infiltration from excess precipitation. The CN method was developed by the Natural Resources Conservation Service of the United States Department of Agriculture (USDA), formerly called the Soil Conservation Service (SCS). The value is still widely known as the "SCS runoff curve number." The CN method has gained widespread acceptance in the USA, and no flow hydrological study will be accepted unless this method is applied (Al-Ghamdi & Abu-Ras, 1991). This model has also been widely used outside the USA by many researchers in developing countries, especially India (Al-Jabari, 2007). It is a series of mathematical equations that depend on the availability of information about land use/cover, soil hydrology, vegetation type, and rainfall amounts. The calculation of surface water runoff requires determining CN values, and the value depends on four elements (Gupta & Panigrahy, 2008). The factors affecting surface runoff are summarized as follows (Stone, 2014):

- Precipitation (amount, intensity, and duration),
- Soil type and topography,
- Antecedent soil moisture condition,
- Land use /Land cover.

CN values range from 0 to 100, and the practical range is from 40 to 98. They are used as an integer value only, reflecting water's response to land cover components. Their values were obtained through thousands of measurements in different natural and urban environments in the USA. Lower values indicate lower runoff potential, while higher values indicate higher runoff potential. Thus, lower values indicate that the soil is permeable (USDA-TR55, 1986).

5. 2. 2 Preparations of the CN Model Layers and Calculation of Surface Runoff

The water balance represents all water entering and leaving the system.
Rainfall = Runoff + Losses

- Types of surface runoff and their characteristics according to the hydrology training series, module 205:

- **Channel runoff**: Precipitation that falls on a watercourse, which is generally a small amount.
- **Surface runoff**: It occurs when the rate of precipitation exceeds the rate of infiltration.
- **Subsurface flow**: The horizontal movement of water seeping into the soil. Subsurface flow may reappear as runoff shortly after rainfall (through seeps or springs). It may also be called the "quick return flow" or "interflow."
- **Direct runoff**: An umbrella term that includes all the runoff types listed above.
- **Base flow**: The continuous release of water from natural or artificial storage areas, such as lakes, swamps, or aquifers. The flow continues after the direct impacts of a surface runoff event occur.

- Losses include precipitation interception, soil infiltration, surface storage, and evapotranspiration (hydrology training series, module 205).

- **Interception**: Precipitation that does not reach the ground due to contact with something (plants or buildings in general).
- **Infiltration**: Water that reaches the ground and permeates the soil. The seeping water may become part of subsurface flow or groundwater.
- **Surface storage**: Water that reaches the ground and collects in depressions (low zone) along the flow path or in an enclosed basin.
- **Evapotranspiration**: Water that returns to the atmosphere.

The mathematical formula for the flow CNs model (USDA, 1972) is as follows:

$$\boldsymbol{Q = (WS - Ia)^2 / [\,WS - Ia + S\,] \qquad if \qquad WS > Ia}$$
$$else\ \boldsymbol{Q = 0} \qquad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ(18)$$

Q: Surface runoff depth (mm)

WS: Surplus rainwater (mm)

Ia: Initial abstractions before the onset of runoff, such as seepage plant uptake.

S: Maximum surface accumulation after runoff onset.

It has been found that Ia is generally equal to one-fifth of the S value. It is calculated as follows:

$$Ia = 0.2\,S \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ(19)$$

Combining Equations 2 and 1 yield:

$$Q = \frac{(WS - Ia)^2}{WS + 0.8\,S} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; \mathrm{equ}(20)$$

for WS > 0.2 S

S is calculated using the following mathematical formula:

$$Sx = \frac{1000}{CN} - 10 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ(21)$$

Note that the input units for the previous equation (S) are in inches. Therefore, the equation was reformulated to comply with the metric standards, where the fixed numbers in the (Sx) equation were multiplied by (25.4) to convert it to millimeters, and thus the formula becomes:

$$S = \frac{25400}{CN} - 254 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \; equ\ (22)$$

5. 2. 2. 1 Method of Extracting CN values

The CN value depends on several factors, including soil moisture, land cover, and soil hydrological groups.

- **Antecedent Moisture Condition (AMC)**

The soil moisture condition in the drainage basin before surface runoff occurs is another important factor affecting the final CN value. In the CN Method, soil moisture status is categorized into three AMC Classes (USDA, 1972, Soil Conservation Service):

- **AMC I**: The soil in the drainage basin is dry (soil moisture content at the wilting point).
- **AMC II**: Moderate moisture condition.
- **AMC III**: The soil in the drainage basins is saturated from a previous rainfall (soil moisture content at maximum field capacity).

Table 21

Antecedent moisture conditions

AMC	*Antecedent 5-day rainfall (mm)*	
	Active growing season (mm)	Dormant season (mm)
AMC I (Dry)	< 35.6	< 12.5
AMC II (Moderate)	35.6-53.4	12.5-27.5
AMC III (Moisture)	> 53.4	> 27.5

Source: (Deshmukh et al., 2013; Chow et al., 1988)

The following equations are used to find the values of each condition according to (Asmar et al., 2020):

$$\mathrm{CN\ I} = \frac{4.2\ \mathrm{CN\ II}}{[10 - 0.058\ \mathrm{CN\ II}]} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \ \mathrm{equ}(23)$$

$$\mathrm{CN\ III} = \frac{23\ \mathrm{CN\ II}}{[10 + 0.13\ \mathrm{CN\ II}]} \ldots\ldots\ldots\ldots\ldots\ldots..\ldots\ldots \ \mathrm{equ}(24)$$

Or by using this table:

Table 22

Conversion between Antecedent moisture conditions

CN for Condition II	*fcn I*	*fcn III*
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Source: (Stone, 2014)

$$AMC\ \mathrm{I} = fnc\ \mathrm{I} * \mathrm{CN\ II} \dots\dots\dots\dots\dots..\dots\dots\dots\dots..\ \mathrm{equ}(25)$$

$$AMC\ \mathrm{III}\ = fnc\ \ \mathrm{III}\ * \mathrm{CN\ II} \dots\dots\dots\dots\dots\dots\dots\dots.\ \mathrm{equ}(26)$$

In this study, soil moisture was not considered when calculating the CN value due to a lack of data, and the possibility of calculating CN values with a reasonable degree of accuracy, as reported in USDA studies on calculating the CN without soil moisture (Soil Conservation Service, 1972).

- **Hydrological Soil Group (HSG)**

HSG is classified by the US Soil Service (SCS) into four groups according to the rate of water movement through the soil, graded from A to D, each with its characteristics. Classes A and D represent extreme cases of runoff formation, while Classes B and C represent intermediate cases of runoff formation. These soil groups (USDA-TR55, 1986; USDA–SCS, 1985)are characterized by their soil infiltration levels and, thus, reveal the extent of soil texture influences surface runoff formation. They are described as follows:

- **Soil Class A or Hydrological Group A**: Soils with high percolation rates even when completely wet (>7.62 mm per hour) and high water transport rates in the soils generate low surface runoff. It consists mostly of deep, dry soil. Loamy Sand Soil and Sandy Soil are in this category.

- **Soil Class B or Hydrological Group B**: Soils with moderate percolation rates when fully wet (3.18 - 7.62 mm per hour) and a moderate rate of water transfer. It consists mainly of deep to medium-depth soil with a fine to coarse texture. Silt Loam Soil and Loam Soil are in this category.
- **Soil class C or hydrological group C**: Soils with low filtration rates when fully wet (1.27 – 3.18 mm per hour) and a low rate of water transfer. It consists mainly of soil with a layer that impedes water movement downward. It is dark-colored soil containing iron, manganese, and clay oxides. Sandy Clay Soil is in this category.
- **Soil Class D or hydrological group D**: Soils with very low infiltration rates when fully wet (< 1.27 mm per hour) and a very low rate of water transport, generating high runoff. It consists mainly of silt and clay.

Table 23

USDA soil hydrological group classification

HSG	***Description***	***Water Transmission***	***Runoff Potential***	***Infiltration Rate (mm/h)***	***Soil Taxonomy***
A	Includes deep sands with very little silt and clay.	High	Low	>7.62	Sand, loamy sand, or sandy loam
B	Soils with sandy content, although less than group A	Moderate	Moderate	3.18-7.62	Silt loam, or loam
C	Soils contain considerable clay and colloids, although lower than Group D.	Low	Moderately high	1.27-3.18	Sandy clay loam
D	Includes mostly clays of high swelling percent	Very low	High	<1.27	Clay loam, silty clay loam, sandy clay, silty clay, clay

Source: (Al-Ghobari & Dewidar, 2021; Stone, 2014).

Table 24 shows the soil textures of the study area, derived from the shape files obtained from the Ministry of Local Government (Geomolg, 2023).

Table 24

Definition of soil texture

Soil texture	****Definition***
Terra Rosa	Formed from hard limestone, Clay texture.
Mediterranean Brown	Formed from Nari; Moderate lime content; Clay texture.
Alluvial	Formed from ancient clay alluvial, Moderate lime content, Clay Loam texture.
Colluvial - Alluvial	Formed from recent clay-loam alluvial; Moderate lime content; Clay Loam texture.

* Source: (Ravikovitch & Navrot, 1972).

Based on the previous information, it was found that the soil texture in the study area for all lands falls into hydrological group D.

The land cover and soil hydrological group categories were integrated into a GIS environment to determine the CN values (Merwade, 2019). The CN value was derived by giving different values to each intersection between the hydrological group and land cover (USDA-TR55, 1986; Soil Conservation Service, 1972), as shown in Table 25, Appendix (C). At the end of this procedure, it was found that the study area was represented by 8 CN values, ranging between 77 and 95 as shown in Figure 16, Appendix (B) and Table 26, Appendix (C).

The CN value reflects the state of the land cover and soil hydrology regarding its ability to absorb water. It also indicates the region's response to collecting surface runoff. Higher CN values indicate impermeable surfaces, which generate higher runoff. On the other hand, lower values indicate permeable surfaces, which reduce the ability to generate surface runoff.

According to the SCS measurements, the CN values extend between 0-100. The value of 100 is for a completely impermeable surface that does not allow water to infiltrate the soil. Rainfall on this surface flows directly over it. The value of zero indicates that the surface is permeable and can absorb all rainwater it receives. Between these two extremes, there is an average value of 50, which expresses that the surface has moderate permeability, and therefore, soil seepage rates are equal to surface runoff rates.

5.2.2.2 Calculation of the Coefficient (S)

The maximum potential retention factor (S) describes the state of soil completely saturated with water after surface runoff has begun and seepage has stopped. The thickness of saturated soil varies depending on the soil type and its ability to absorb more water during the rainy season. Therefore, the coefficient S is related to the type and depth of soil and land cover, which is reflected in the CN values.

S values close to zero indicate that the ability of the soil to hold water above the surface decreases after the onset of surface runoff, resulting in a large amount of runoff at the surface. On the contrary, when the water retention rate in the soil is equal to the water flow rate on the surface, the S value approaches 254 mm, i.e., the median value, which is a fixed number obtained through several experiments conducted by the USDA. The ability of soil to hold water at the surface increases when the S values are above the median value, decreasing the amount of surface runoff (USDA-TR55, 1986).

The S values were calculated using the ArcGIS raster calculator by entering all CN values into Equation 22. Figure 17, Appendix (B), shows the result.

5. 2. 2. 3 Calculation of Coefficient (Ia)

The initial abstraction coefficient (Ia) reflects the amount of rainwater lost before surface runoff begins through seepage or exposure to vegetation. Ia is related to the soil texture and land uses and can be calculated from the maximum water retention potential (S) coefficient. The Ia value equals one-fifth of the S value, as shown in Equation 19. It was derived from the field work conducted by the US Department of Agriculture (USDA-TR55, 1986).

On the other hand, when Ia approaches zero, there is little rainwater loss before surface runoff begins, which helps accelerate runoff generation. When the initial extraction rate becomes equal to the water flow rate on the surface, the Ia value equals 50.8 mm, i.e., the median value. Therefore, an Ia value greater than the median indicates increased rainfall loss and decreased runoff amount (USDA-TR55, 1986).

The Ia of the study area was calculated using the ArcGIS raster calculator by entering all S values into Equation 19. Figure 18, Appendix (B), shows the result.

5. 2. 2. 4 Calculation of Runoff Depth (Q)

Surface water runoff summarizes the interaction of a particular rain event with the components and characteristics of the surface runoff area (Al-Nubani, 2000). When the precipitation rate is constant, the CN value controls the runoff value because the relationship between CN and Q is positive. Thus, the Q value increases as the CN value increases.

Runoff depth was calculated using the Raster Calculator in the Spatial Analyst menu in the ArcGIS environment based on Equation 20. Figure 19, Appendix (B), shows the runoff amounts of the study area for WS > 0.2 S.

5.3 Site Selection Criteria for Rainwater Harvesting Ponds

Table 27 shows nine criteria used to determine the best sites for collecting surface water in the study area through collection ponds. Each criterion was weighed according to its contribution to surface water runoff in the GIS environment. Figure 20, Appendix (B), shows the site selection methodology.

Table 27

Conditions and criteria for choosing water harvesting ponds

***Criteria**	***Weight (%)***
Run off (Q)	20
Stream Density	15
Slope	15
Basin area	12
Agricultural land value	12
Land use	10
Elevation	8
soil texture	5
Geology	3

* Source: (Fealy, et al., 2010); (Faisal & Abdaki, 2020); (Preeti et al., 2022) Adapted.

The RWH structure model was developed using the weighted overlay process (WOP) for all criteria. WOP allows data from multiple input grids to be aggregated by converting their cell values into a common scale, assigning a weight to each grid, and then summing the weighted cell values (Store & Jokimäki, 2003). It is also known as a multi-criteria assessment, a commonly weighted linear method used in ArcGIS-based decision-making (Shadeed, 2011).

Each layer is multiplied by its weight, and the results are summed according to the following equation (Shadeed, 2011; Malczewski, 1999):

$$Aj = \sum_{n} Wi.Sij \dots\dots\dots\dots\dots\dots\dots. \; equ(27)$$

Where Aj is the final cell suitability score index, Sij is the suitability of the ith cell concerning the jth layer, and weight Wi is a normalized weight so that ΣWi = 1.

5.4 Applying Selection Criteria in a GIS Environment

5.4.1 Runoff

Potential runoff indicates a potential water supply for collection and storage through the RWH structure. Areas with high runoff potential are more suitable for the RWH system (Setiawan & Nandini, 2022; Asmar et al., 2020; Faisal & Abdaki, 2020) Table 28, Appendix (C) and Figure 21, Appendix (B) shows the scoring structure for surface water runoff in the study area

5.4.2 Slopes

Slope information was extracted from DEM and obtained from the ASF Data Search website (ASF, 2023)

The slope map included 5 classes: flat terrain (0%–5%), moderate slope (from 5%–10%), rolling slope (10%–15%), mountainous terrain (15%–30%), and steep terrain (>30%), as shown in Figure 22, Appendix (B).

Slope affects surface water runoff, recharge, and flow, and is one of the most important factors to consider when selecting and implementing RWH structures (Setiawan & Nandini, 2022). Areas with steep slopes are more suitable for runoff, but areas with lower slopes are more suitable for RWH (Preeti et al., 2022; Shadeed et al., 2022). 25.98% of the study area is classified as a steep slope, which is the least suitable for RWH structures. A slope of less than 5% is considered ideal for RWH ponds, and 30.86% of the study area is very suitable. Table 29, Appendix (C) shows the scoring structure for the slope of the study area.

5. 4. 3 Basin’s Runoff Volume

Basins that contain a large amount of surface runoff are best suited for RWH ponds (Asmar et al., 2020), Figure 23, Appendix (B). The total drainage area of the northwestern basins of the West Bank is 772.39 km^2, and the average volume of surface rainwater runoff is 147,120 MQM/year from 2001-2020. The total drainage area of the study area is 246.12 km^2, and the average volume of surface rainwater runoff is 45.78 MQM/year during the same period, as shown in Table 30, Appendix (C). This amount of rainwater can be used to increase the area of irrigated land in the study area.

5 4.4 Land Agricultural Value

High agricultural value land is highly suitable for RWH ponds. Table 31, Appendix (C) and Figure 24, Appendix (B) shows the scoring structure of lands in terms of their agricultural value.

4.4.5 Stream Density

Areas with high stream density tend to have large amounts of water runoff harvested by collection ponds (Preeti et al., 2022; Adham et al., 2016). Table 32, Appendix (C) and Figure 25, Appendix (B) shows the scoring structure of the stream density in the study area.

5. 4. 6 Land Use/ Land Cover

The LULC map of the study area was divided into eleven categories: built-up areas, forests, permanent crops, grasslands and pastures, croplands, rain-fed, greenhouses, agricultural land with natural vegetation, arable land, mineral extract sites, and Israeli settlements (Figure 26, Appendix (B)). Lands suitable for collecting rainwater must be close to the agricultural lands to benefit from rain to irrigate crops (Shadeed et al., 2022; Faisal & Abdaki, 2020; Mbilinyi et al., 2007). The lands were arranged according to their suitability for collecting rainwater in the study area, as shown in Table 33, Appendix (C).

5.4.7 Elevations

Rainwater falling on the ground flows with the terrain, so the water goes to low plains. Thus, low-lying areas are more suitable for collecting rainwater (Faisal & Abdaki, 2020). Elevation directly correlates with water harvesting because high elevations are less suitable because they require many excavations (Adham et al., 2016). Table 34, Appendix

(C) and Figure 27, Appendix (B) shows the distribution of land elevations regarding suitability for collecting rainwater.

5.4.8 Soil Texture

Soil permeability is the key parameter in determining the infiltration rate and the amount of water stored in the soil (Preeti et al., 2022). Therefore, the degree of suitability of each soil type for surface runoff was determined. The different soil types were divided into soil hydrological groups according to the speed of water movement through them, which depends on the soil texture. Fine to medium soil texture is more suitable for water harvesting due to its high water-holding capacity (Setiawan & Nandini, 2022; Faisal & Abdaki, 2020; Mbilinyi et al., 2007). as shown in Table 35, Appendix (C) and Figure 28, Appendix (B).

5.4.9 Geology Formations

The ideal location for RWH should preferably be in areas with ancient geological ages because the composition of ancient geological ages consists of solid materials that reduce the soil permeability (Al-Aqeel, 2020; Khader, 2012). Accordingly, the geological eras were arranged from oldest to newest, as shown in Table 36, Appendix (C) and Figure 29, Appendix (B).

Chapter Six

Results and Recommendations

6.1 Results

The average annual water surplus in the study area between 2011 and 2020 ranges between 220.47 and 249.97 mm, while the average annual water deficit for the same period ranges between 709.65 and 739.14 mm. The water surplus period extends from December to March, and the water deficit period from May to October. January is the highest month in terms of water surplus, reaching 129 mm. July and August are the highest in terms of water deficit, reaching 170 mm (Al-Hallaq, 2003), which is consistent with the climate features of this region during that period.

The composite CN value varied from one watershed to another due to land use changes in the study area. The composite CN value for the main watersheds in the study area is greater than 82, which is an appropriate value for surface runoff generation. Therefore, it is suitable for rainwater harvesting because CN values reflect the runoff depth from a certain rainfall amount (Asmar et al., 2020).

The annual average surface water runoff depth for the study area between 2011 and 2020 ranged between 159.88 and 234.29 mm. The main factors that affected the runoff depth values were the spatial distribution of rainfall amounts and the size of the sub-watershed areas (Khader, 2012). The average runoff depth changed within the main watersheds, with higher runoff depths dominating the northern watersheds, where higher rainfall amounts were recorded compared to the southern watersheds.

The average surface runoff volume in the main watersheds in the northwestern West Bank between 2011 and 2020 was 119.824 MQM/year. Abu Al-Nar Watershed, the highest in terms of quantity, reached 35.259 MQM/year. Massin Watershed was 33.274 MQM/year, Zoumar Watershed was 28.376 MQM/year, and Ateen Watershed was 22.915 MQM/year.

An RWH pond suitability map was created based on WOP. The selected areas supporting the rainwater harvesting structure were divided into sub-areas based on suitability. The suitability ratings range from 0 to 9, with 9 indicating the most suitable locations and 0 indicating unsuitable/restricted locations, as shown in Table 37.

The results indicated that 0.1% (0.25 km^2), 2.72% (6.70 km^2), and 9.15% (22.52 km^2) of the study area showed excellent, very good, and good suitability for rainwater harvesting, respectively. 20.78 % (51.14 km^2) and 46.79 % (115.17 km^2) of the site were classified as moderately high and moderate suitability for rainwater harvesting, respectively. 19.16% (47.15 km^2), 0.32% (0.79 km^2), and 0.98% (2.40 km^2) of the site were classified as poor, very poor and unsuitable suitability, respectively, for rainwater harvesting, as shown in Table 37.

Figure 30 shows that 14 sites received the highest score (8), but it is possible to re-select the best sites for collecting rainwater using ponds. The sites closest to the water stream outlets are considered the best among the fourteen sites. Therefore, sites 7, 8, 10, and 12 best establish rainwater harvesting ponds for agricultural use in the study area, as shown in Appendix (A).

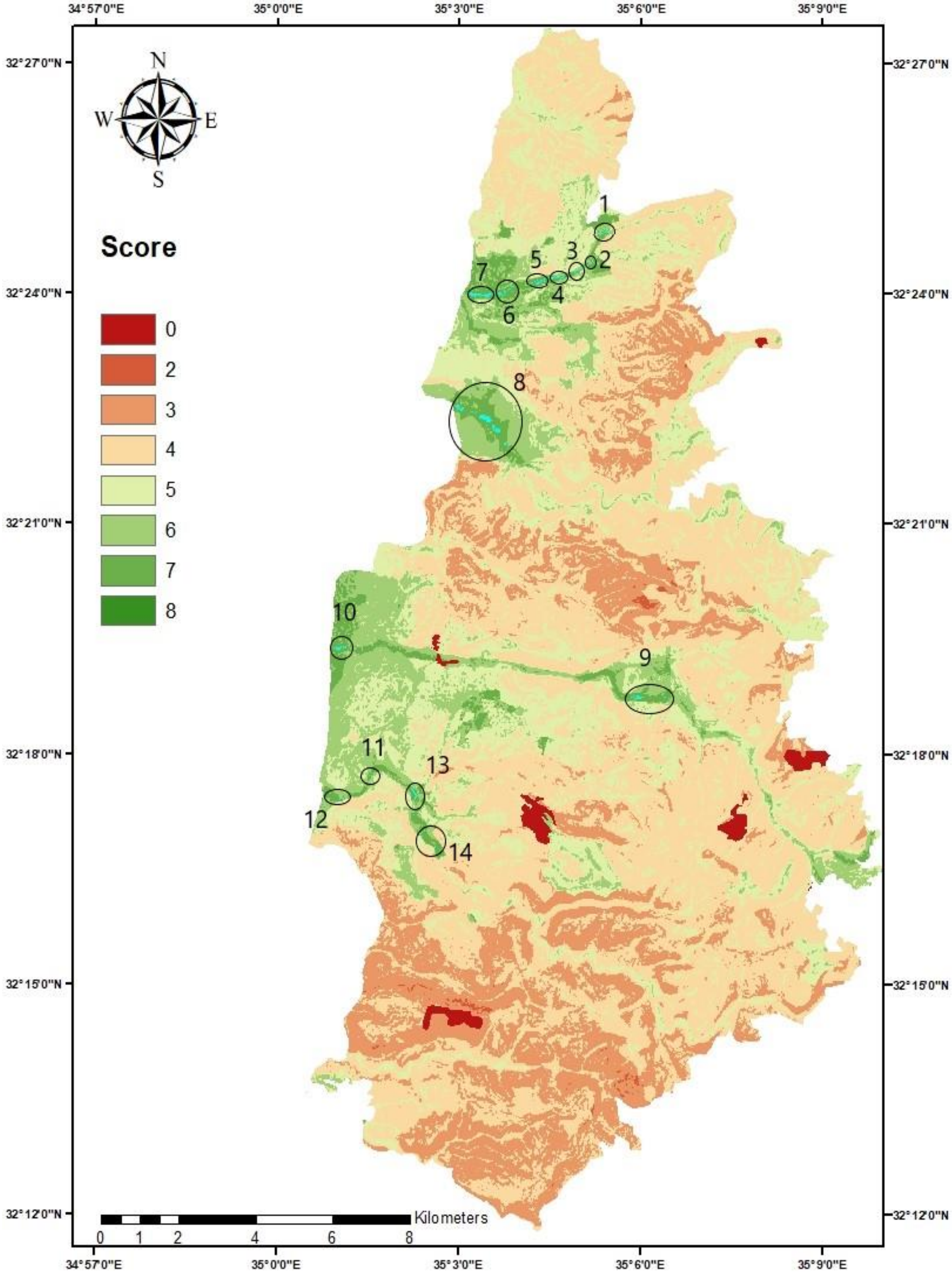
Table 37

Suitability scores for rainwater harvesting ponds in the study area

Score	*Coverage (km2)*	*Suitability*	*Coverage (%)*
0	2.40	Unsuitable	0.98
2	0.79	Very poor	0.32
3	47.15	poor	19.16
4	115.17	Moderate	46.79
5	51.14	Moderately high	20.78
6	22.52	Good	9.15
7	6.70	Very good	2.72
8	0.25	Excellent	0.10

Figure 30

Final suitability map of rainwater harvesting



6. 2 Recommendations

This study recommends the following:

- Water resources must be managed efficiently considering indicators of climate change in the Mediterranean region, such as decreased rainfall, delayed and irregular rainy seasons, and rising temperatures.
- Integration of water and climate studies to focus on problems related to water, rainfall, drought, environment, and climate change.
- Future studies must focus on developing early warning systems for drought periods.
- Conduct further studies on the impact of water harvesting on the economic and social aspects of the study area.
- Establish water harvesting ponds to store rainwater to serve the area during drought.
- Integrating water harvesting into the integrated development plan for land and water resources.

List of Abbreviations

Abbreviations	Meaning
AE	Actual evapotranspiration
CN	Curve Number
D	Number of days in the month
DMI	De Martone index
H	Average number of sunrise hours
I	Annual heat coefficient
i	Monthly heat coefficient
Ia	Initial abstractions
LCLU	Land cover and land use
LI	Lang index
MI	Minar index
P	Annual average precipitation
PCI	Pinna Combinative Index
pd	Average precipitation in the driest month
PE	Corrected monthly potential evapotranspiration
PET	Annual average Potential Evapotranspiration
PEx	Potential monthly evapotranspiration
Pm	Monthly precipitation
Q	Surface runoff depth
S	Maximum surface accumulation after runoff onset
ST	Soil texture
Δ ST	Change in soil moisture storage
T	Annual average temperature
Td	Average temperature in the driest month
TE	Total evapotranspiration
Tm	Mean temperature of the month
TWI	Thornthwaite index
UNPI	UNEP Arid Index
WD	Water Deficit
WS	Water Surplus

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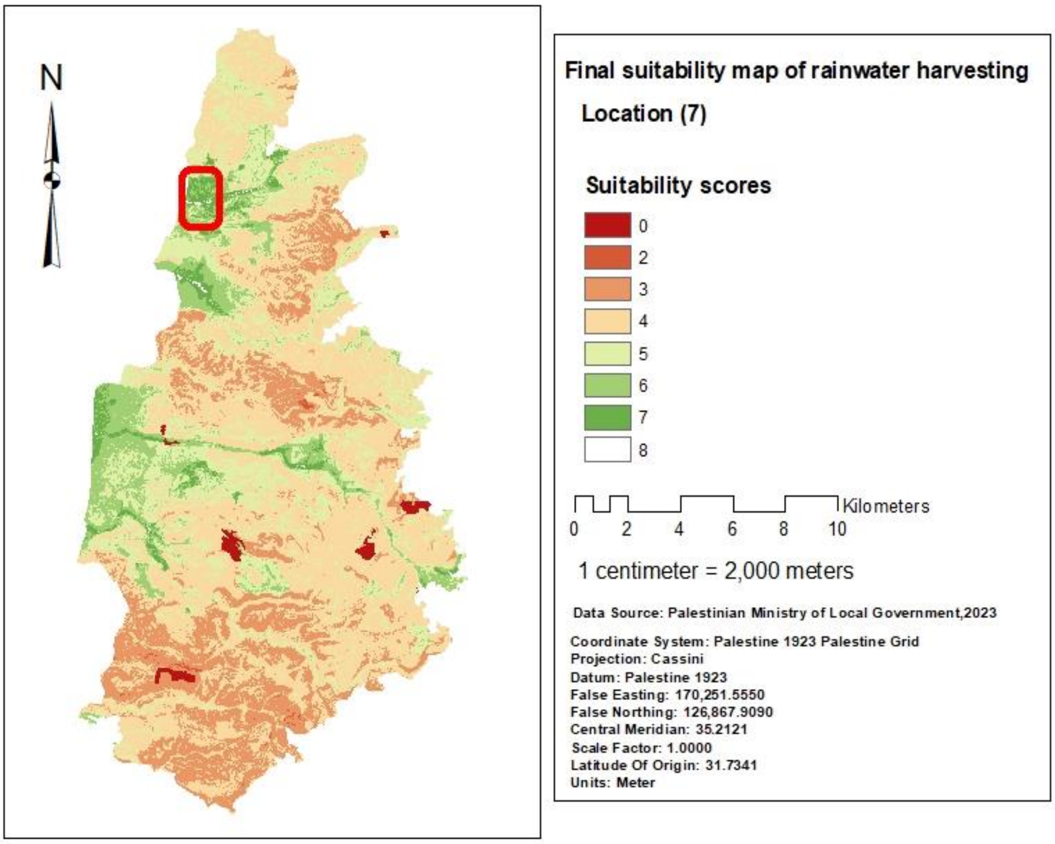
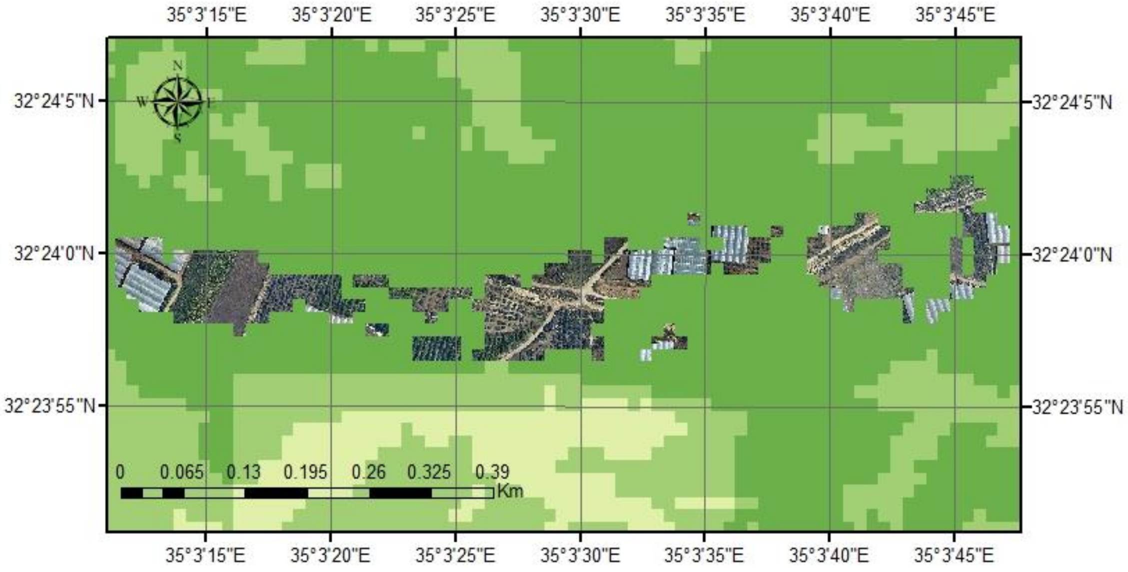
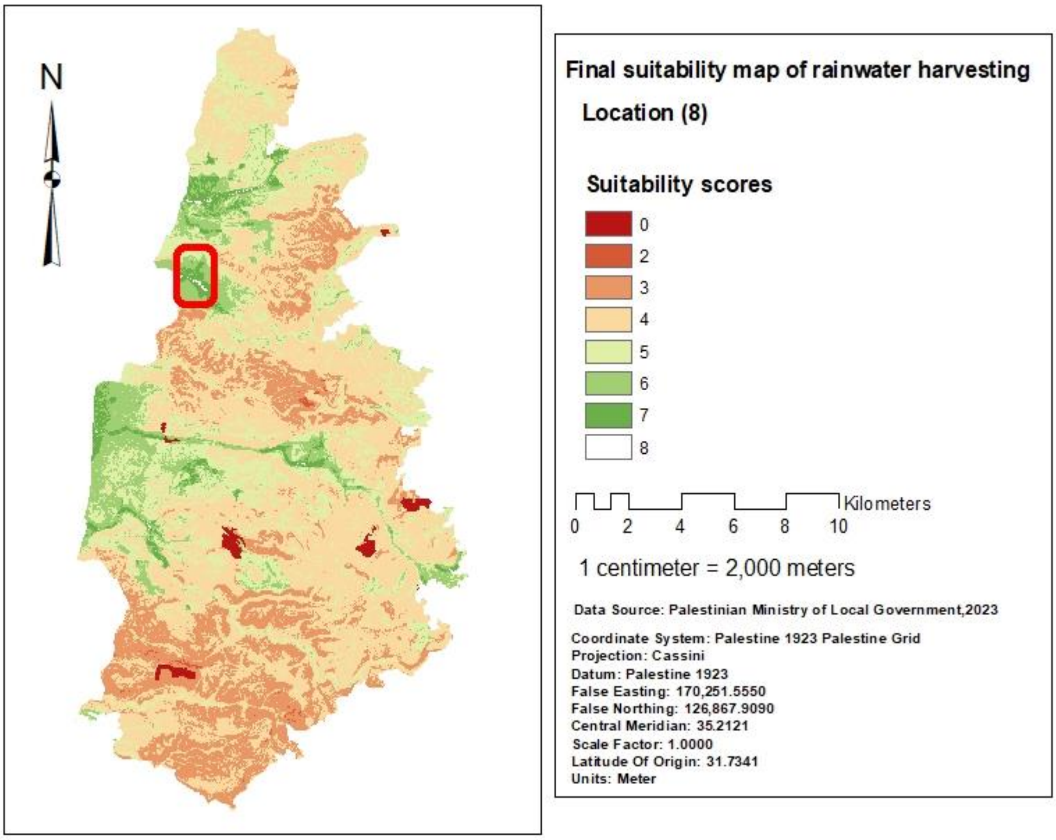
Appendix

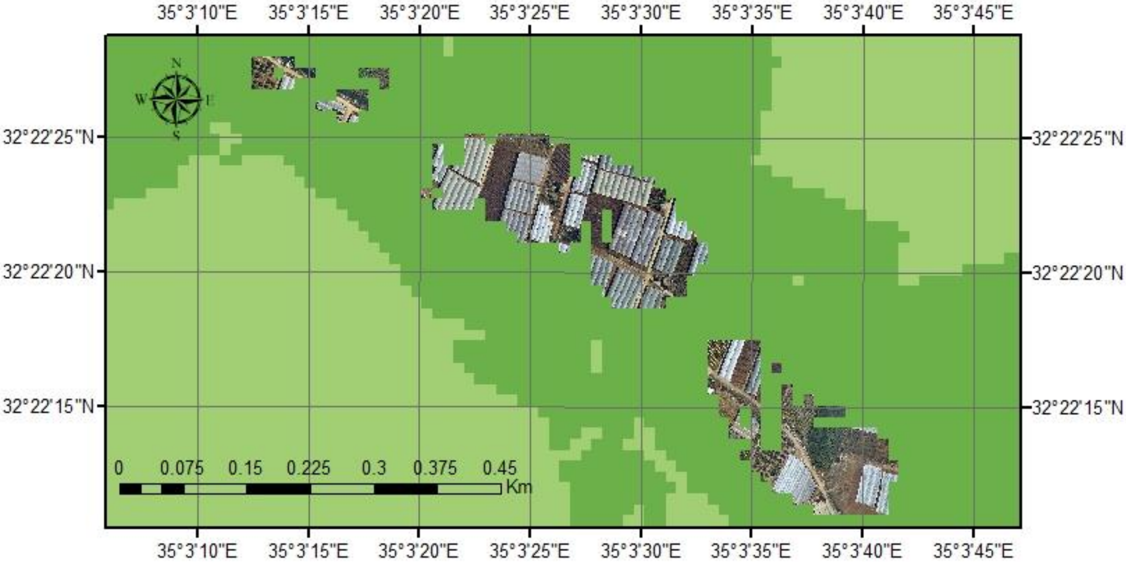
Appendix (A)

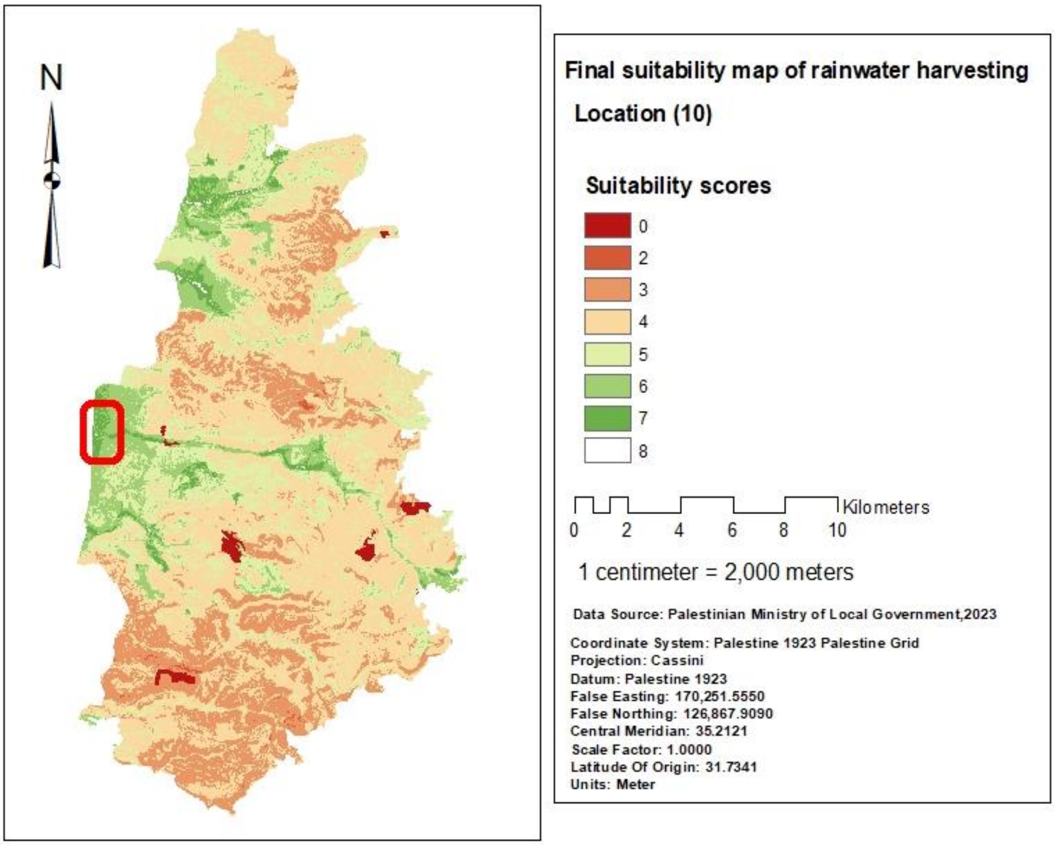
Final suitability Map

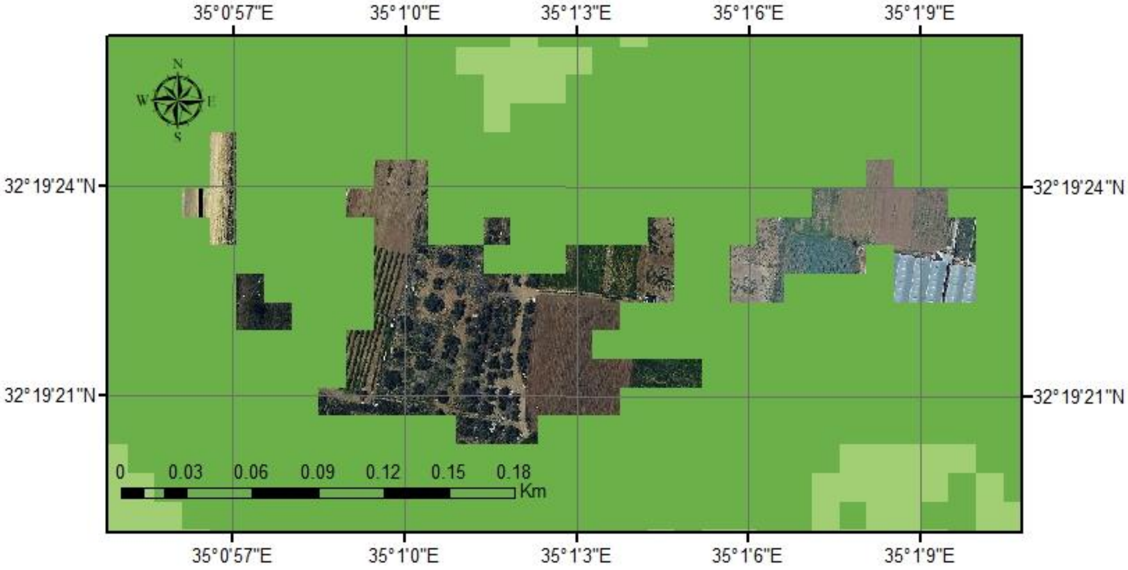


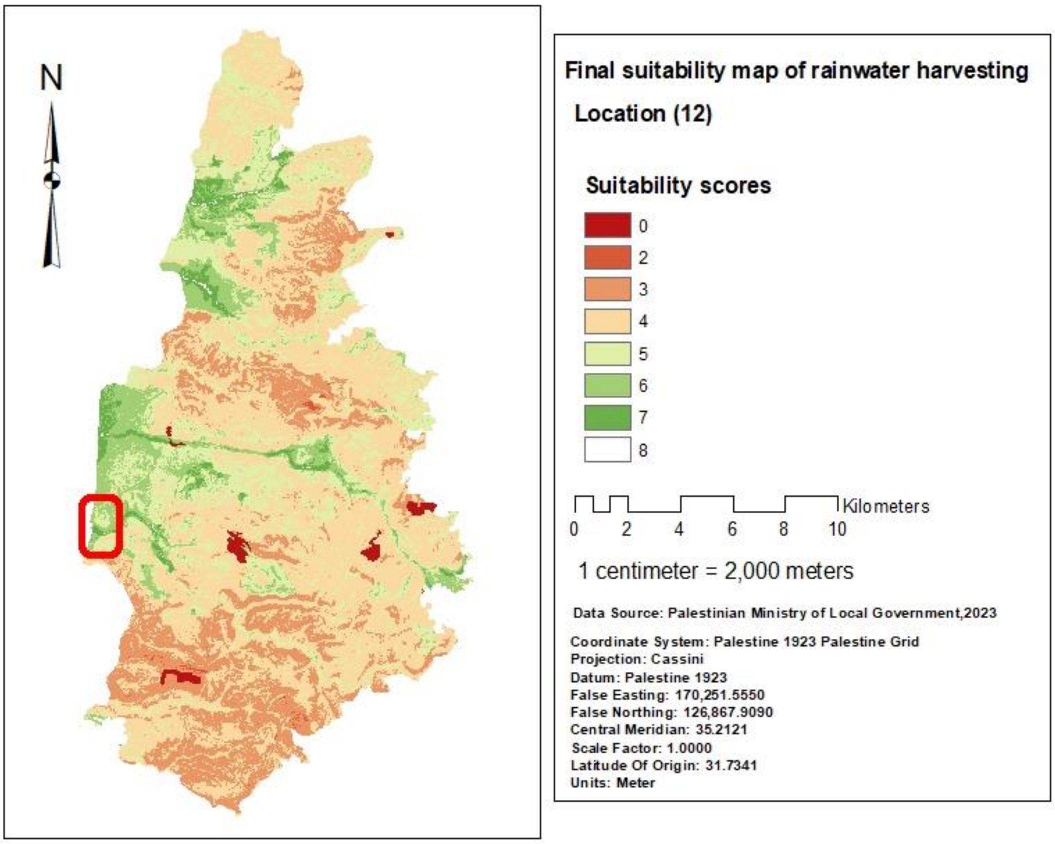



N
Final suitability map of rainwater harvesting
Location (8)
Suitability scores
0
2
3
4
5
6
7
8
0
2
4
6
8
10
Kilometers
1 centimeter = 2,000 meters
Data Source: Palestinian Ministry of Local Government,2023
Coordinate System: Palestine 1923 Palestine Grid
Projection: Cassini
Datum: Palestine 1923
False Easting: 170,251.5550
False Northing: 126,867.9090
Central Meridian: 35.2121
Scale Factor: 1.0000
Latitude Of Origin: 31.7341
Units: Meter


35°3'10"E
35°3'15"E
35°3'20"E
35°3'25"E
35°3'30"E
35°3'35"E
35°3'40"E
35°3'45"E
32°22'25"N
32°22'20"N
32°22'15"N
N
W
E
S
0
0.075
0.15
0.225
0.3
0.375
0.45
Km


N
Final suitability map of rainwater harvesting
Location (10)
Suitability scores
🟥 0
🟥 2
🟧 3
🟧 4
🟩 5
🟩 6
🟩 7
⬜ 8
0 2 4 6 8 10 Kilometers
1 centimeter = 2,000 meters
Data Source: Palestinian Ministry of Local Government,2023
Coordinate System: Palestine 1923 Palestine Grid
Projection: Cassini
Datum: Palestine 1923
False Easting: 170,251.5550
False Northing: 126,867.9090
Central Meridian: 35.2121
Scale Factor: 1.0000
Latitude Of Origin: 31.7341
Units: Meter


35°0'57"E
35°1'0"E
35°1'3"E
35°1'6"E
35°1'9"E
32°19'24"N
32°19'21"N
N
W
E
S
0 0.03 0.06 0.09 0.12 0.15 0.18 Km


N
Final suitability map of rainwater harvesting
Location (12)
Suitability scores
0
2
3
4
5
6
7
8
0 2 4 6 8 10 Kilometers
1 centimeter = 2,000 meters
Data Source: Palestinian Ministry of Local Government,2023
Coordinate System: Palestine 1923 Palestine Grid
Projection: Cassini
Datum: Palestine 1923
False Easting: 170,251.5550
False Northing: 126,867.9090
Central Meridian: 35.2121
Scale Factor: 1.0000
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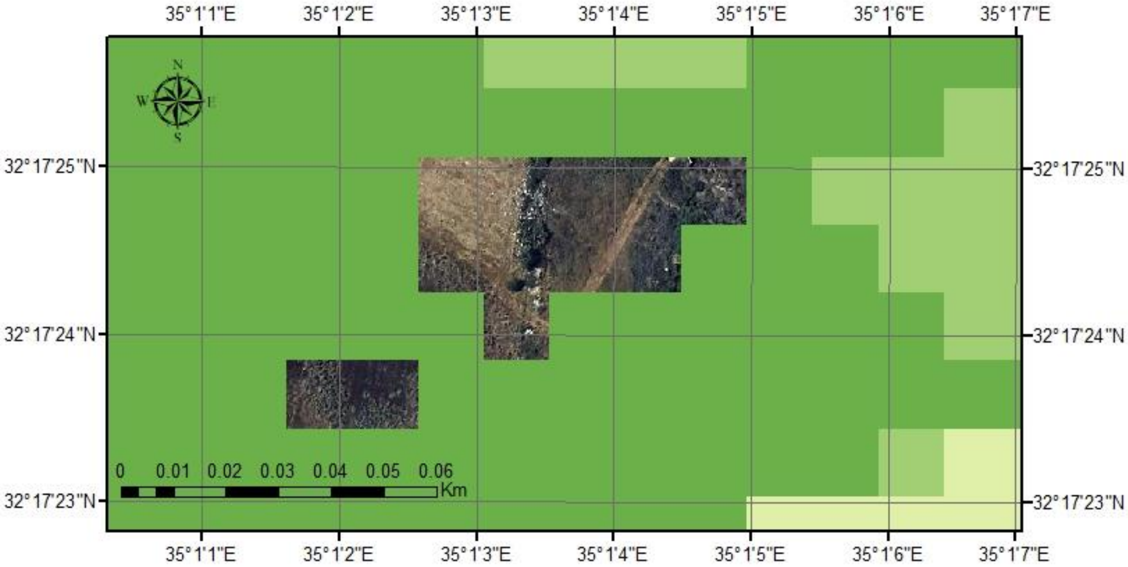
Units: Meter


35°1'1"E
35°1'2"E
35°1'3"E
35°1'4"E
35°1'5"E
35°1'6"E
35°1'7"E
32°17'25"N
32°17'24"N
32°17'23"N
N
W
E
S
0 0.01 0.02 0.03 0.04 0.05 0.06 Km

Appendix (B)

Figures

Figure 13

Average annual water surplus (mm/year) in the study area for the years 2011 to 2020

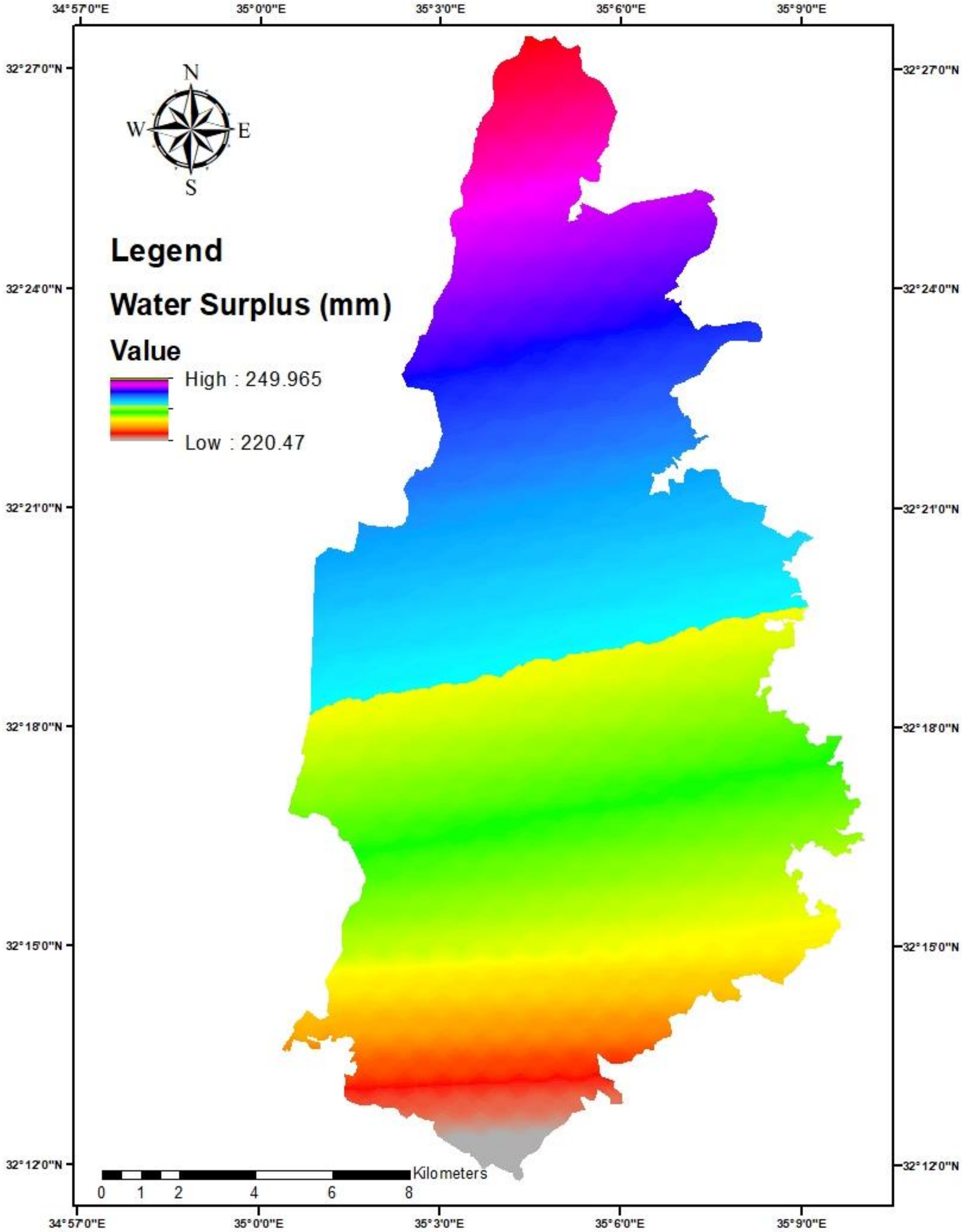


Figure 14

Average annual water deficit (mm/year) in the study area for the years 2011 to 2020

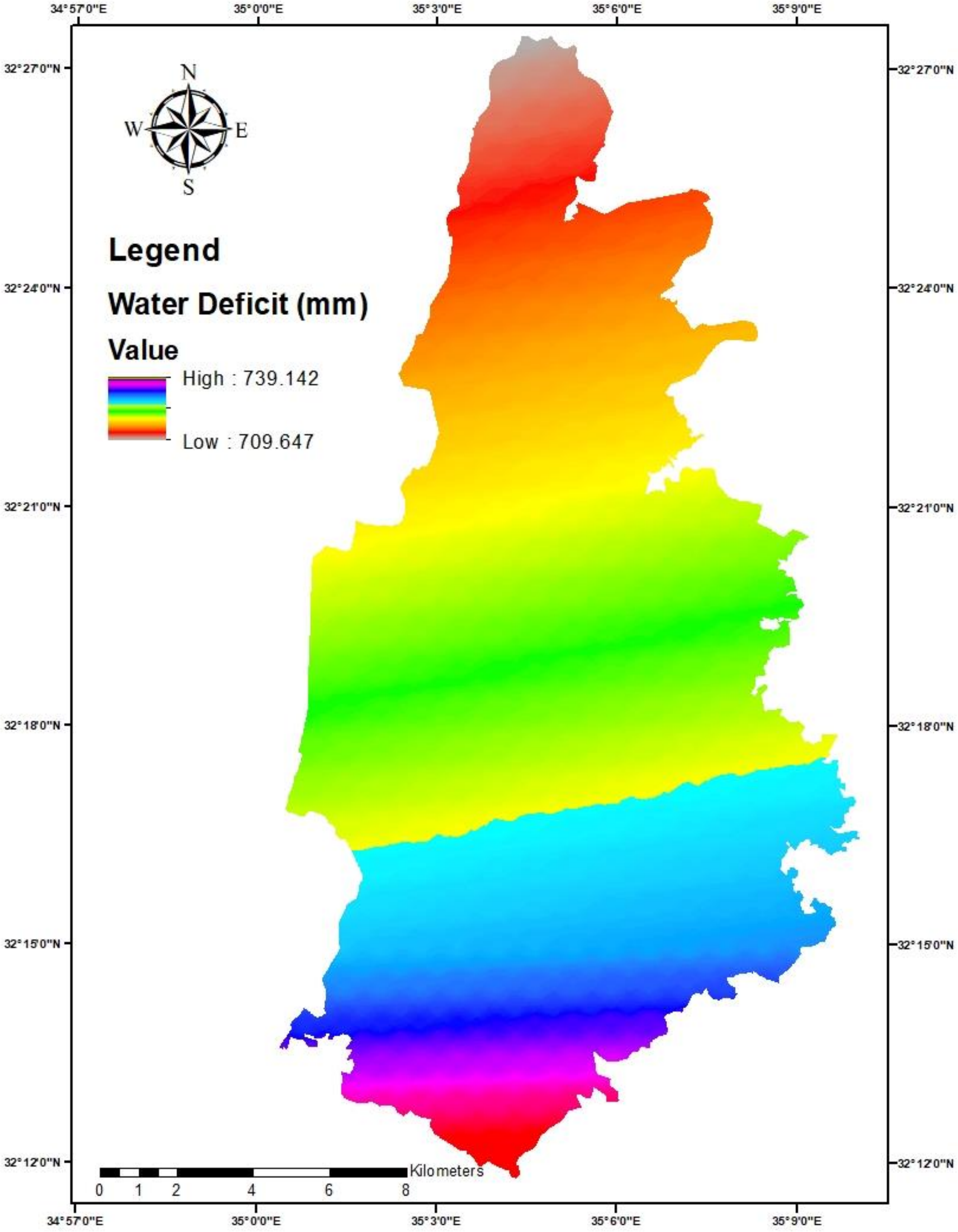


Figure 16

Distribution of CN values in the study area

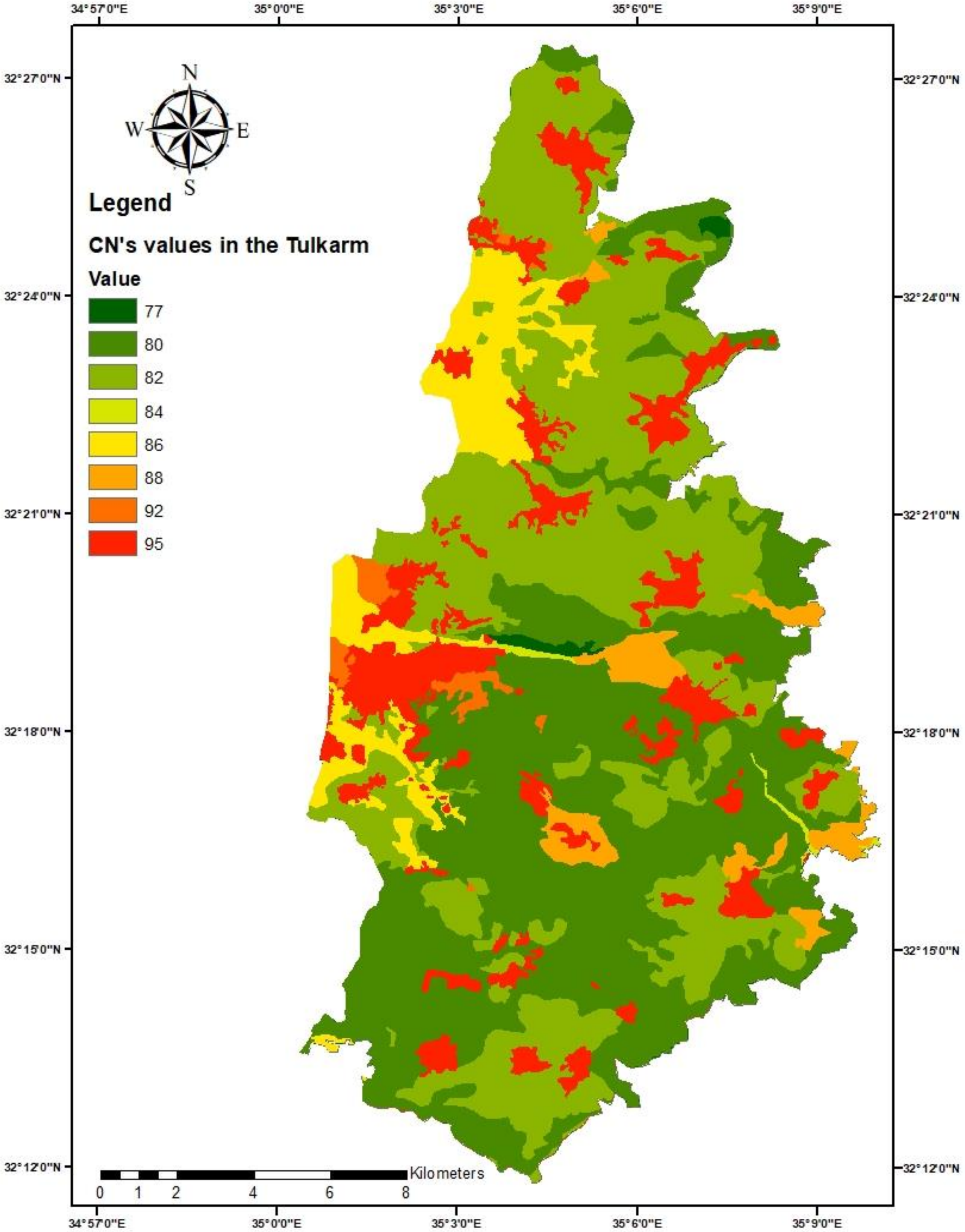


Figure 17

Distribution of S coefficient value in the study area

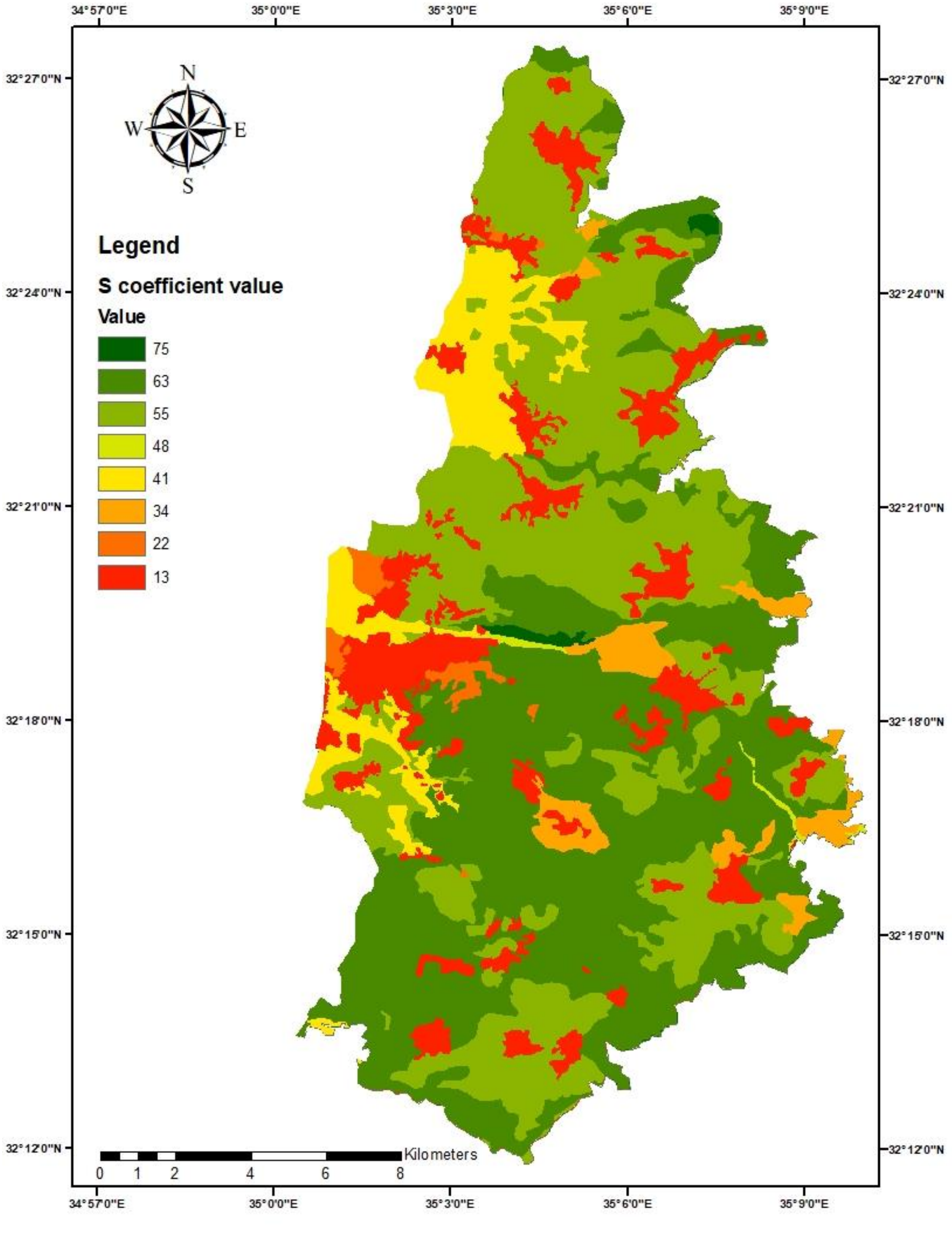


Figure 18

Distribution of Ia coefficient value in the study area

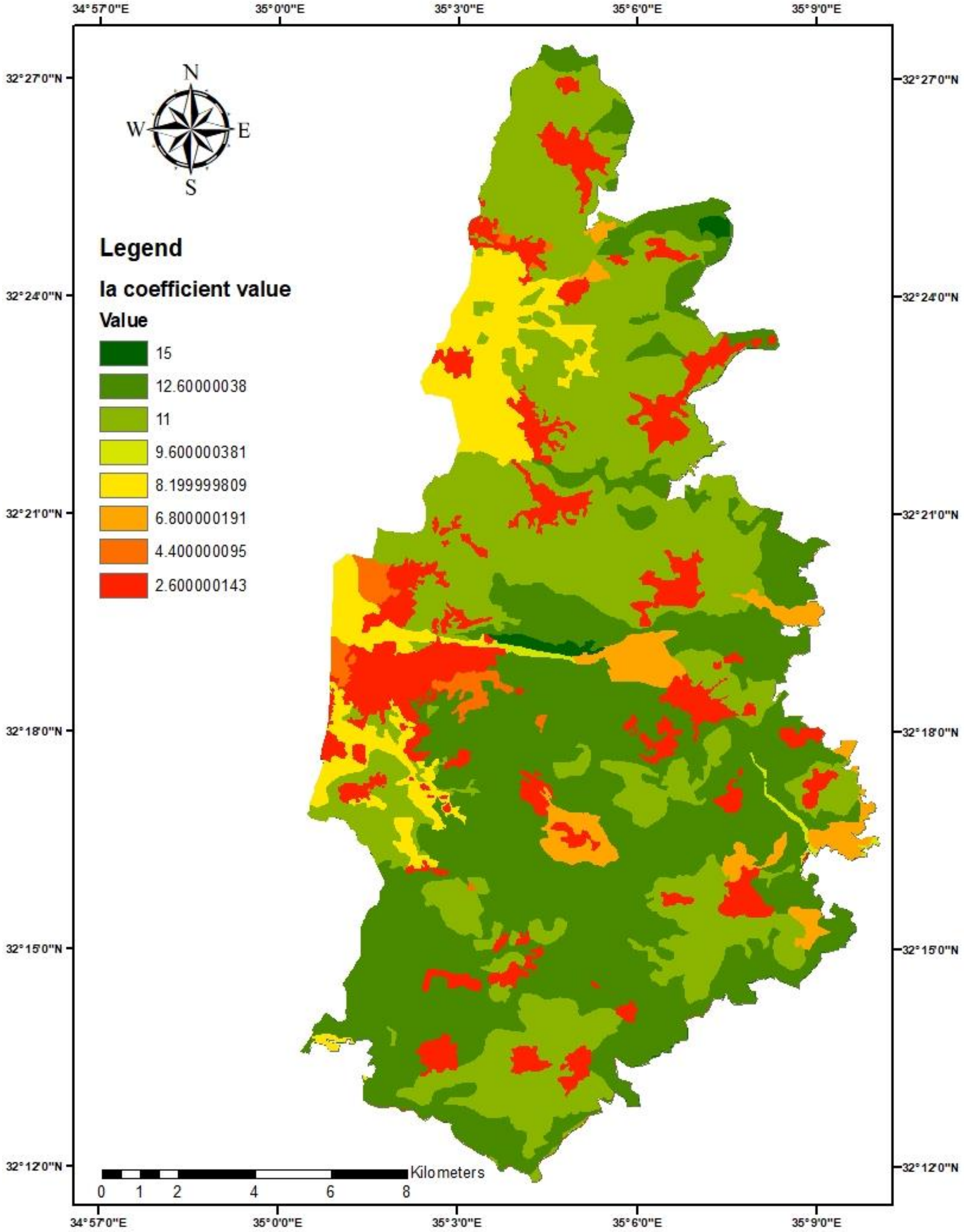


Figure 19

Average annual surface runoff (mm/year) in the study area for the years 2011 to 2020

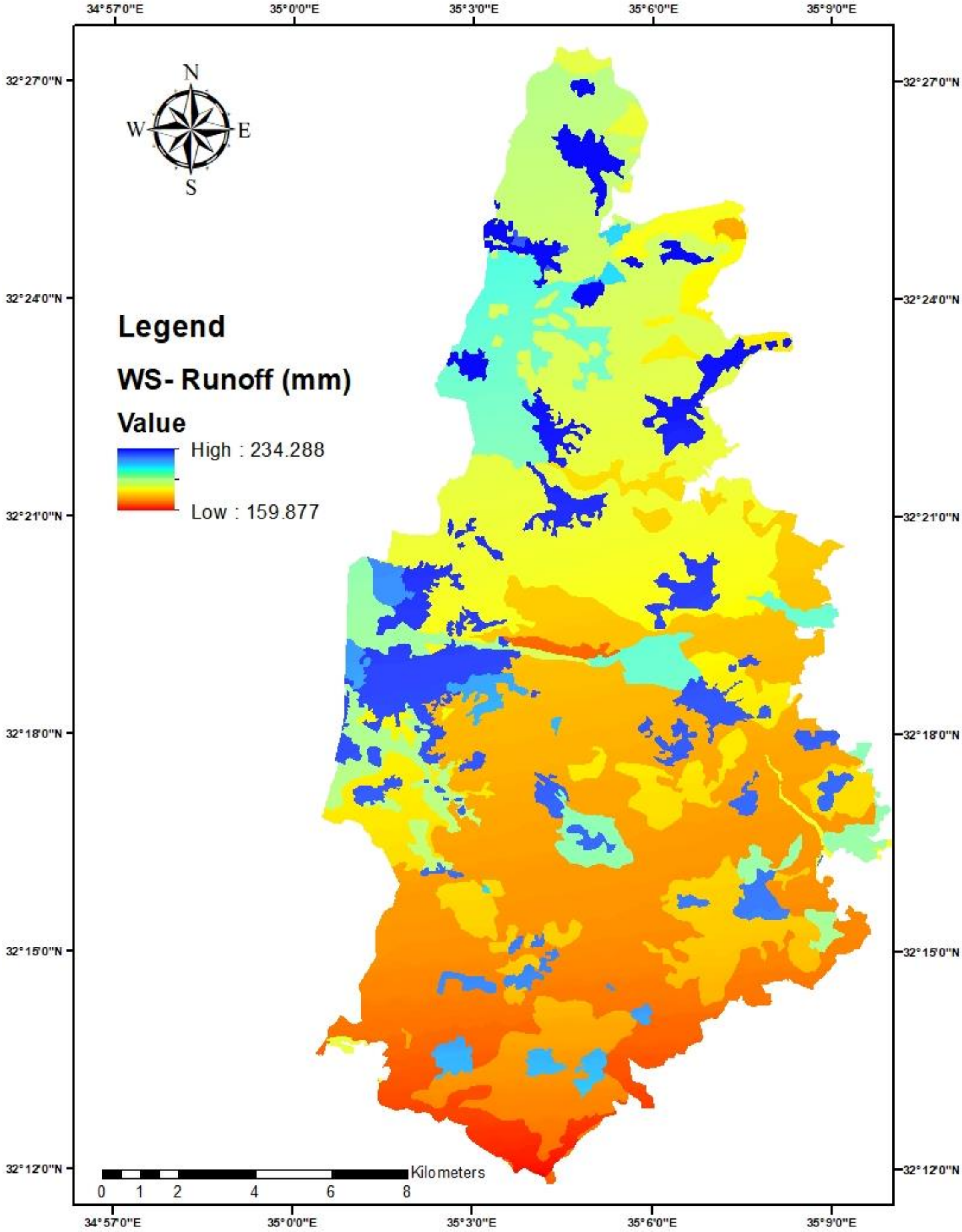


Figure 20

Flowchart for defining a suitable map for rainwater harvesting ponds

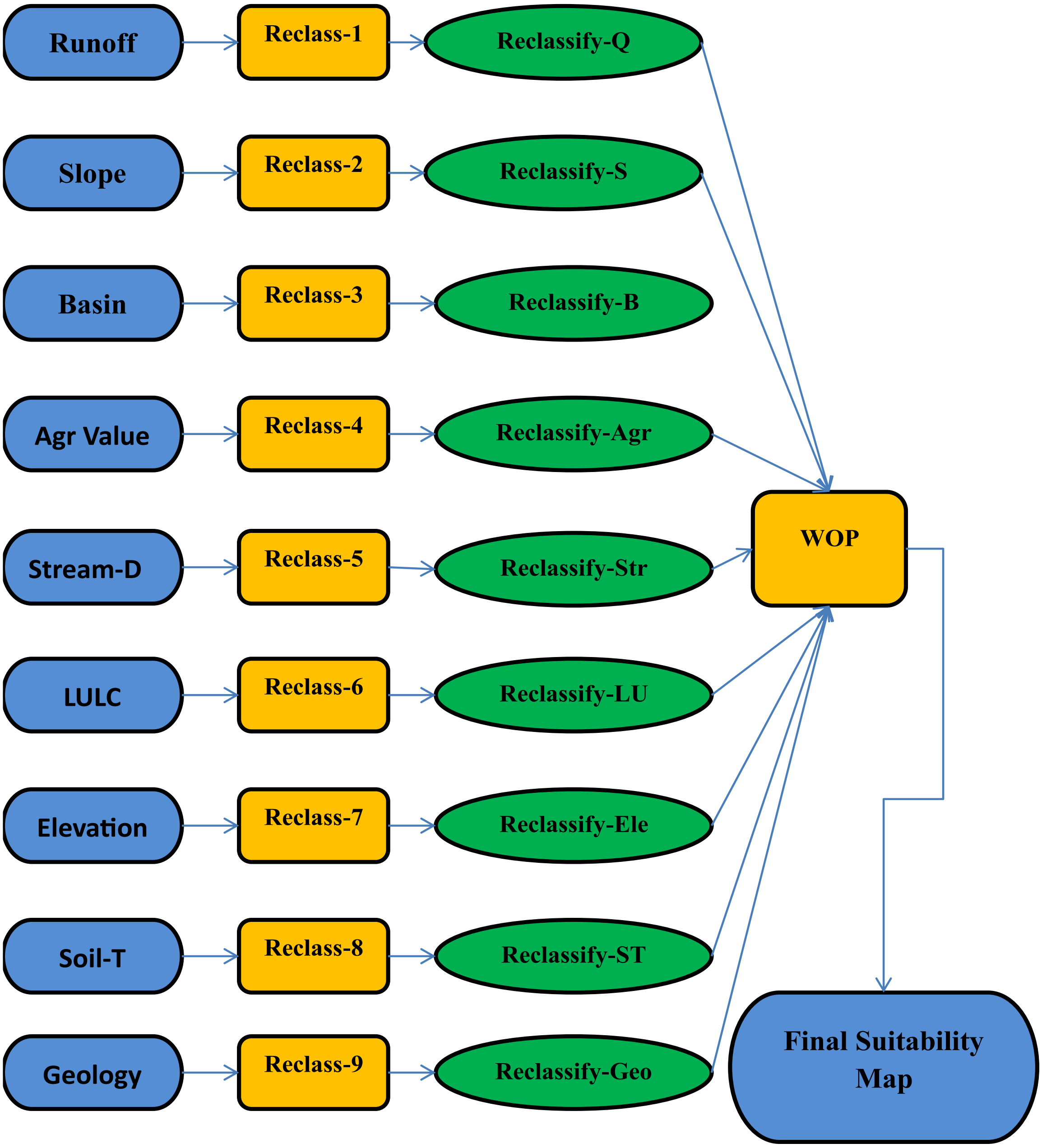
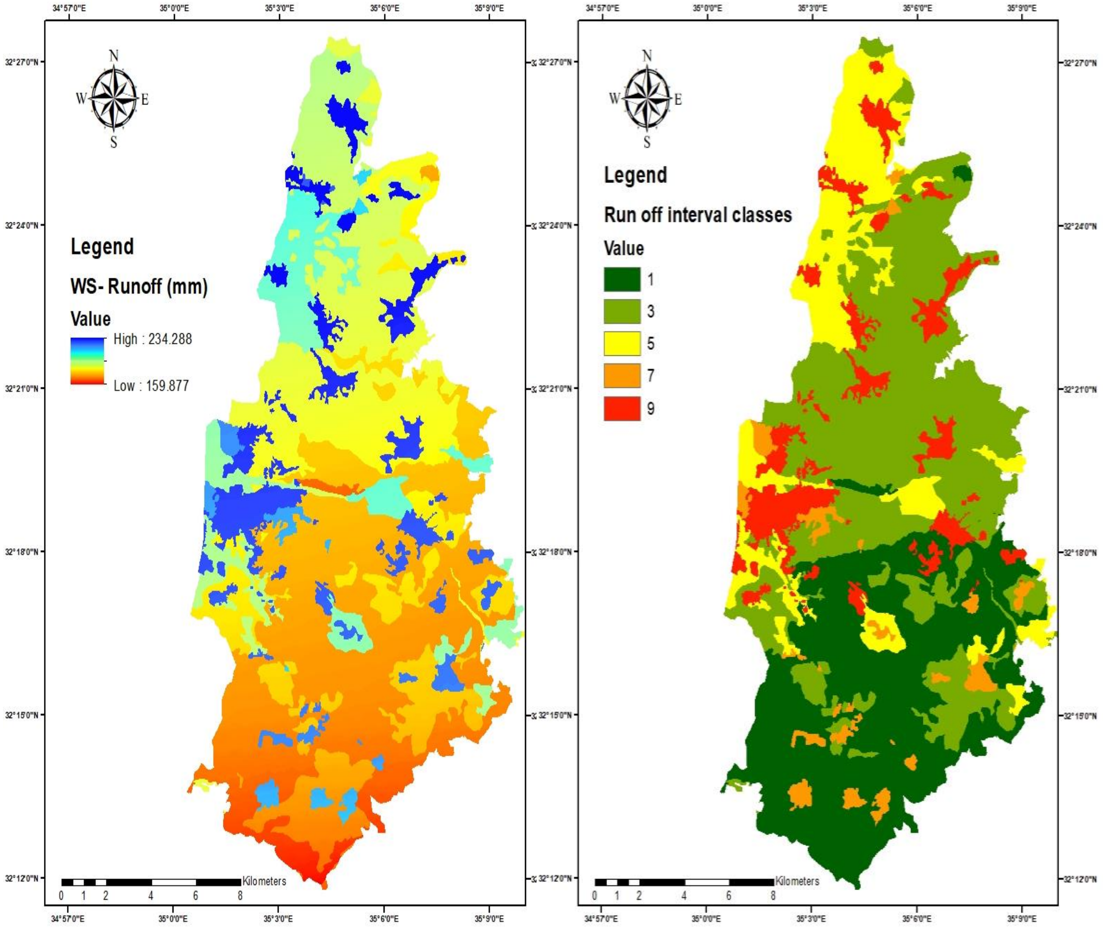


Figure 21

Average annual runoff of the study area (left); reclassified runoff interval (right)

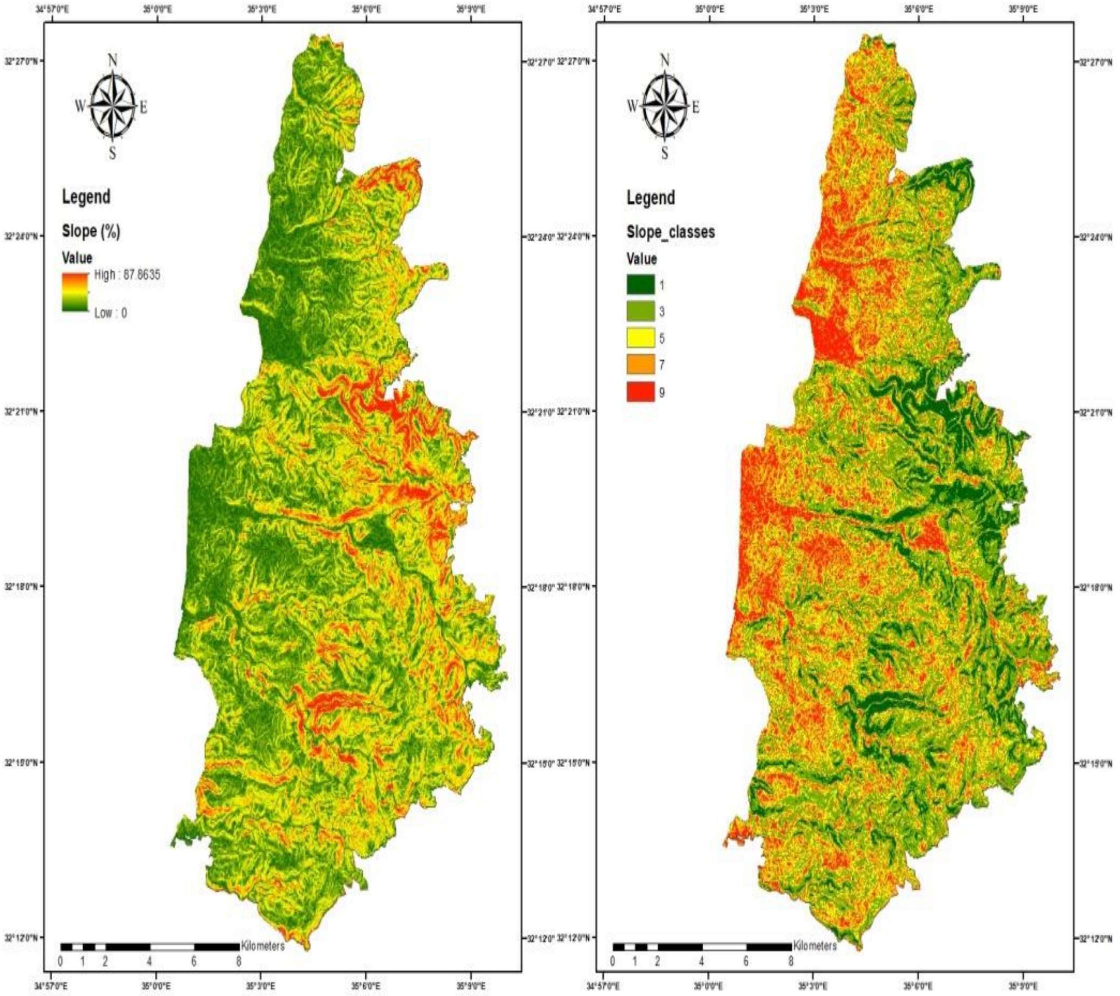


Run off

Reclassify

Figure 22

Slope of Tulkarm governorate lands (left); reclassified slope (right)

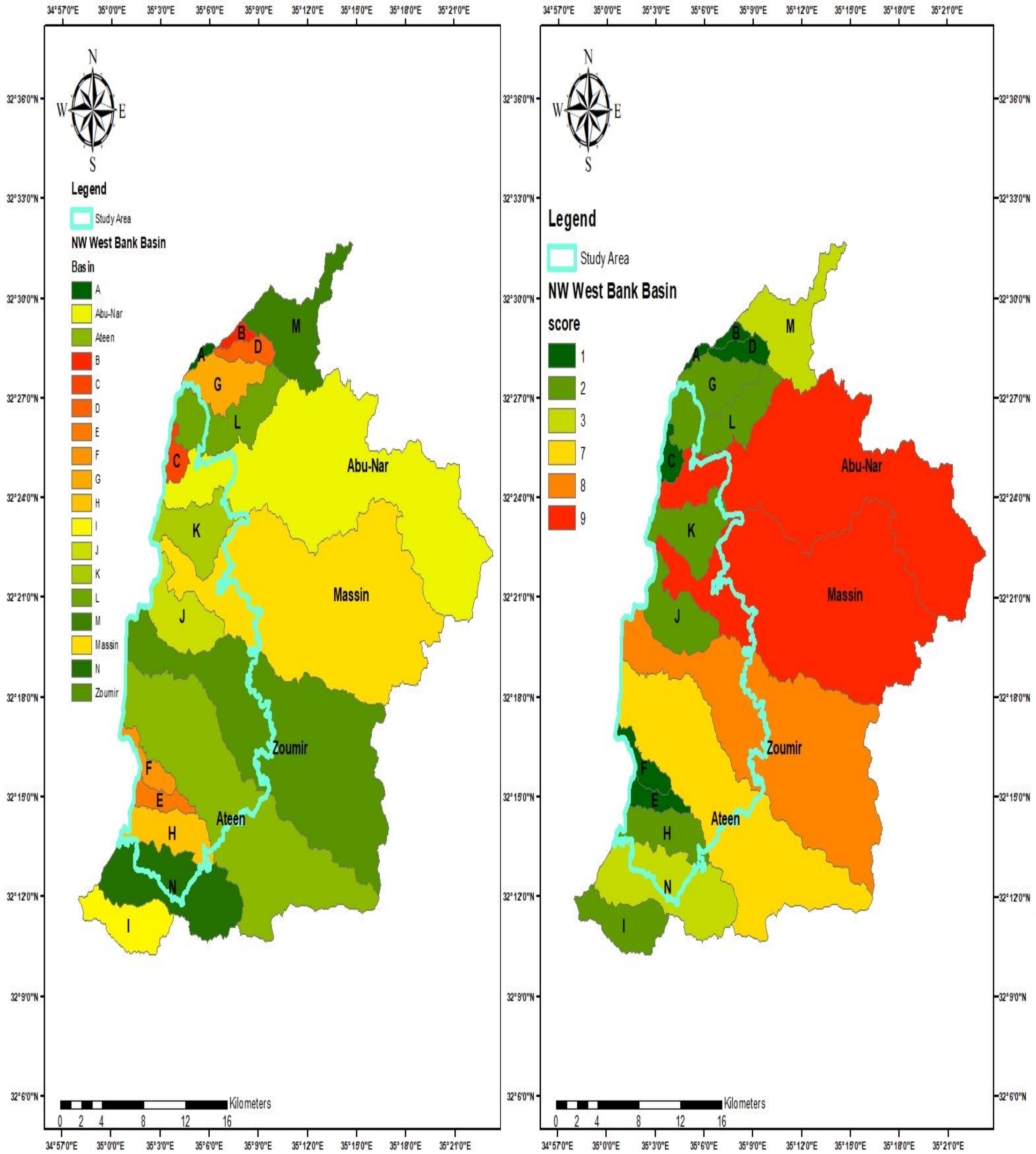


Slope

Reclassify

Figure 23

Basins of the study area (left); reclassified basins (right)

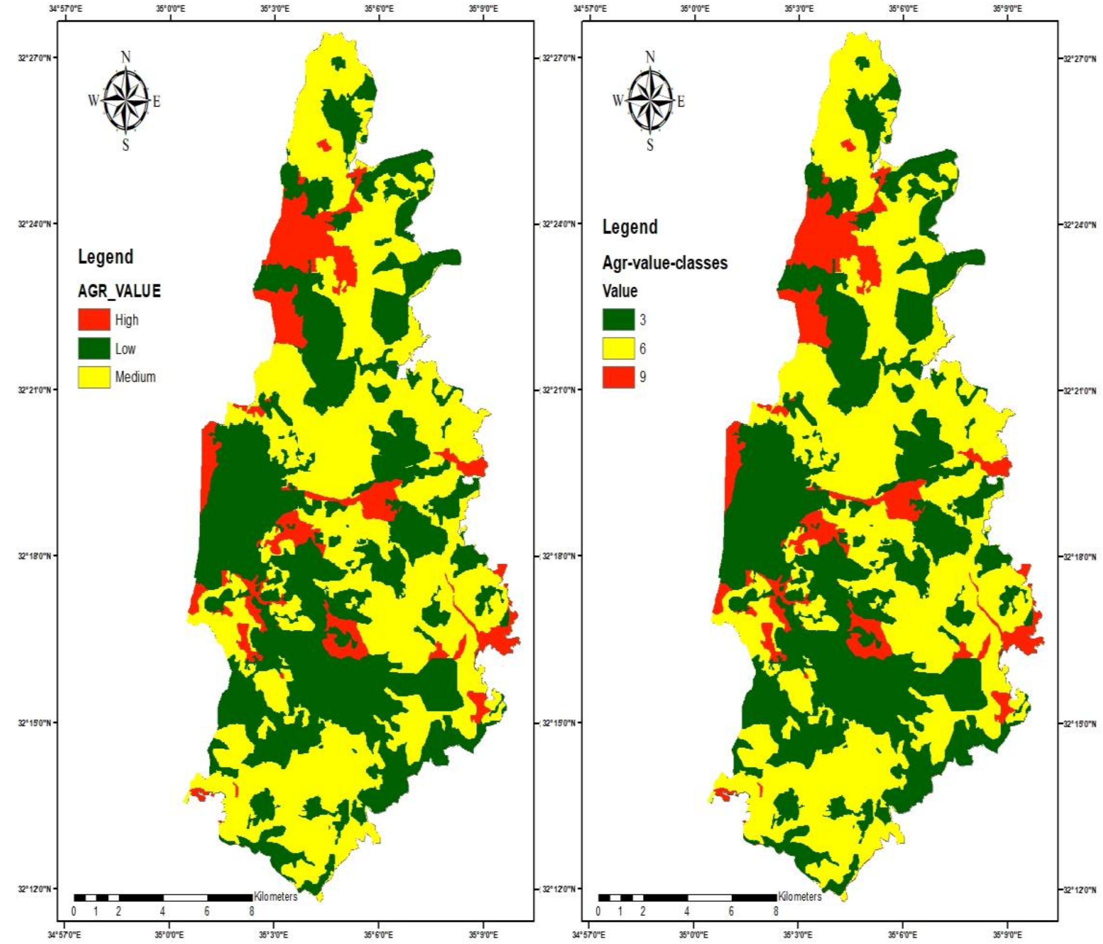


Basin

Reclassify

Figure 24

Agricultural value of lands (left); reclassified agricultural value (right)

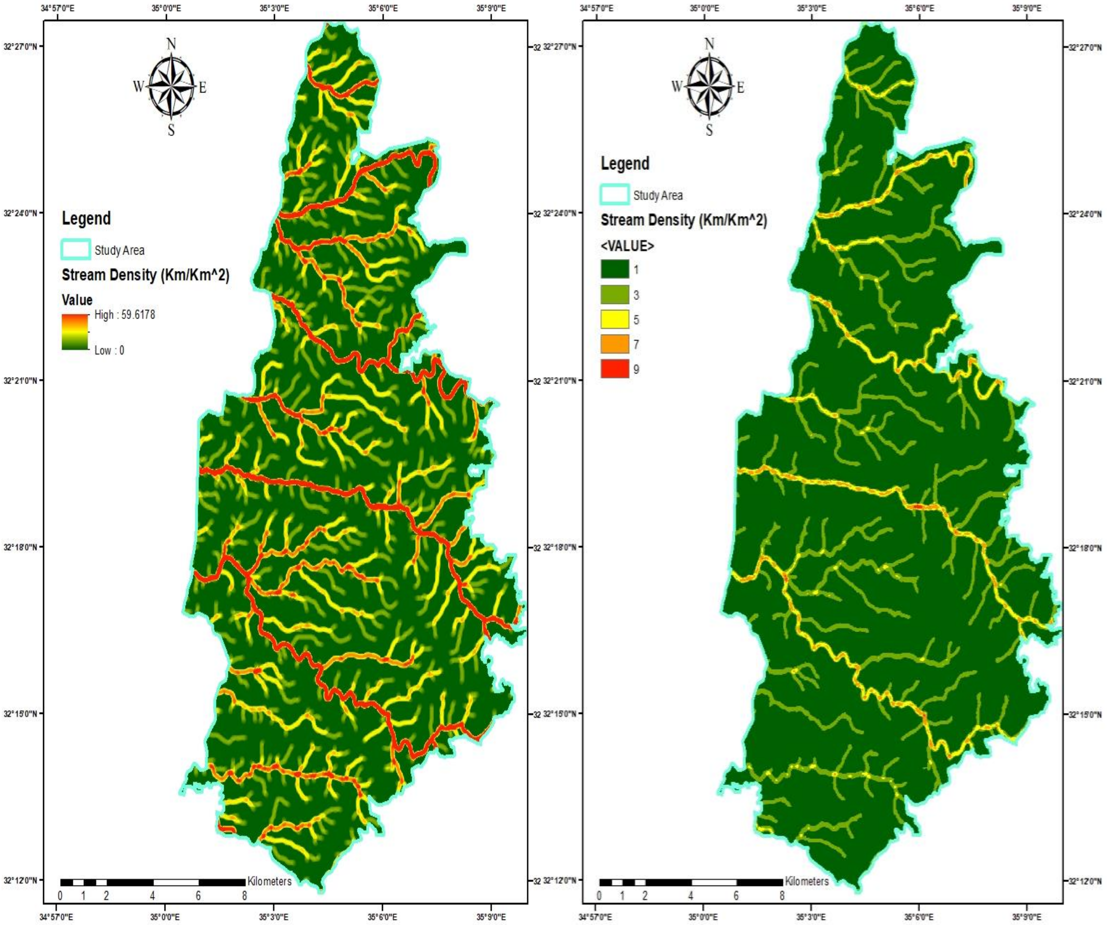


Agriculture Value

Reclassify

Figure 25

Stream density of the study area (left); reclassified density (right)

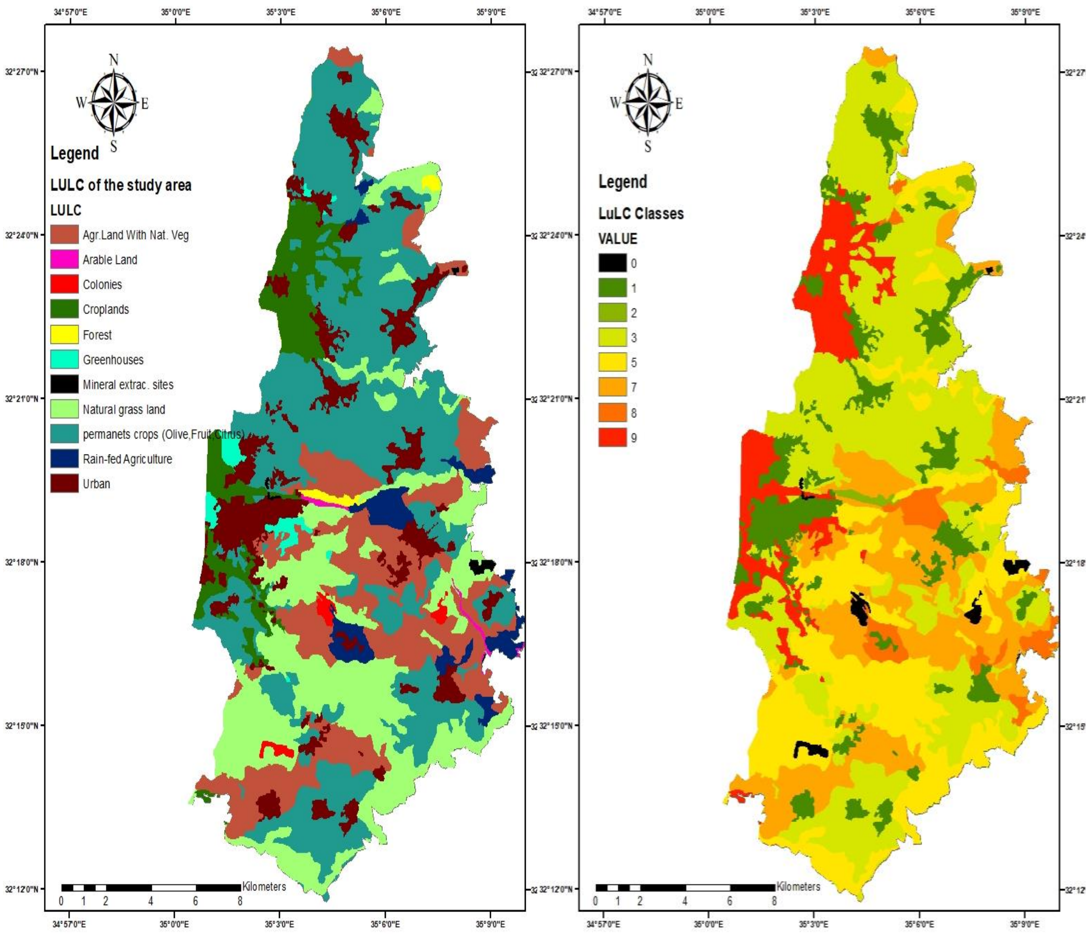


Stream Density

Reclassify

Figure 26

LULC of the study area (left); reclassified LULC (right)

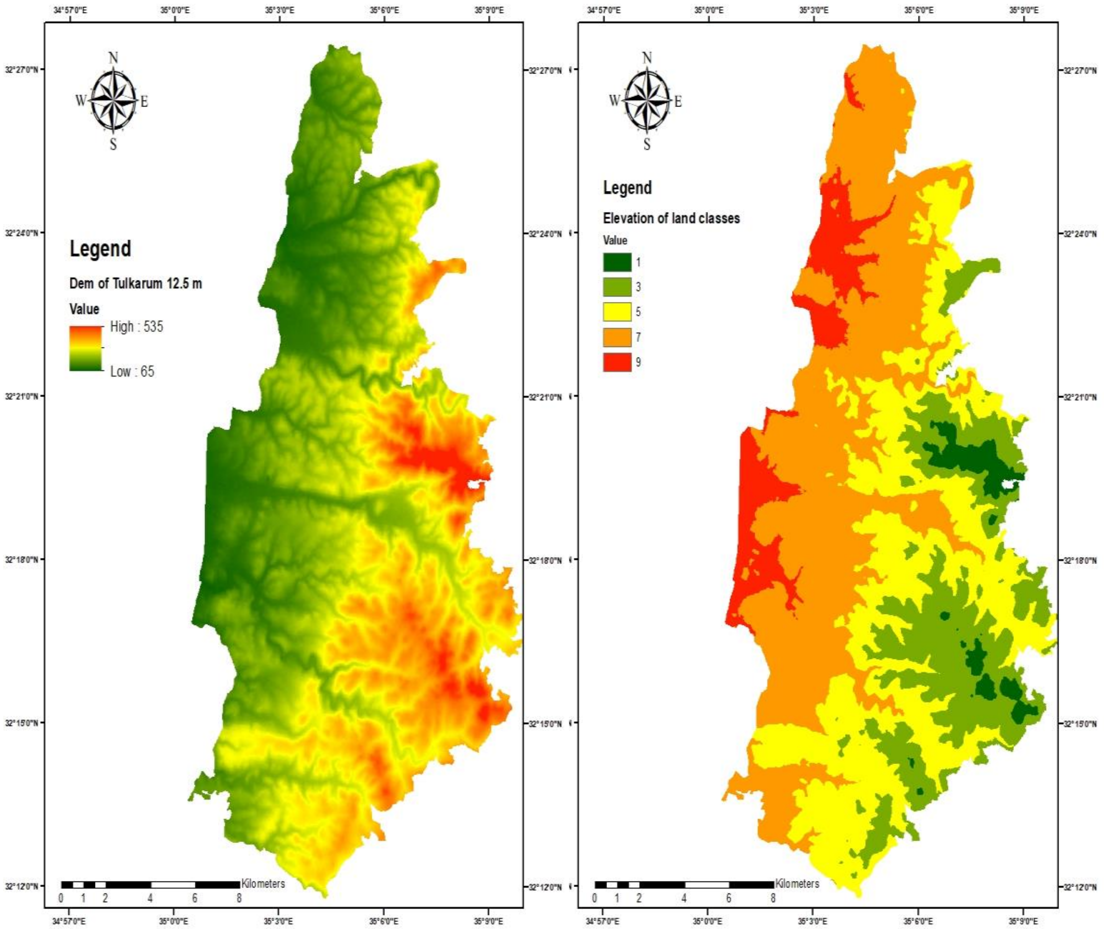


LCLU

Reclassify

Figure 27

DEM of the study area (left); reclassified DEM (right)

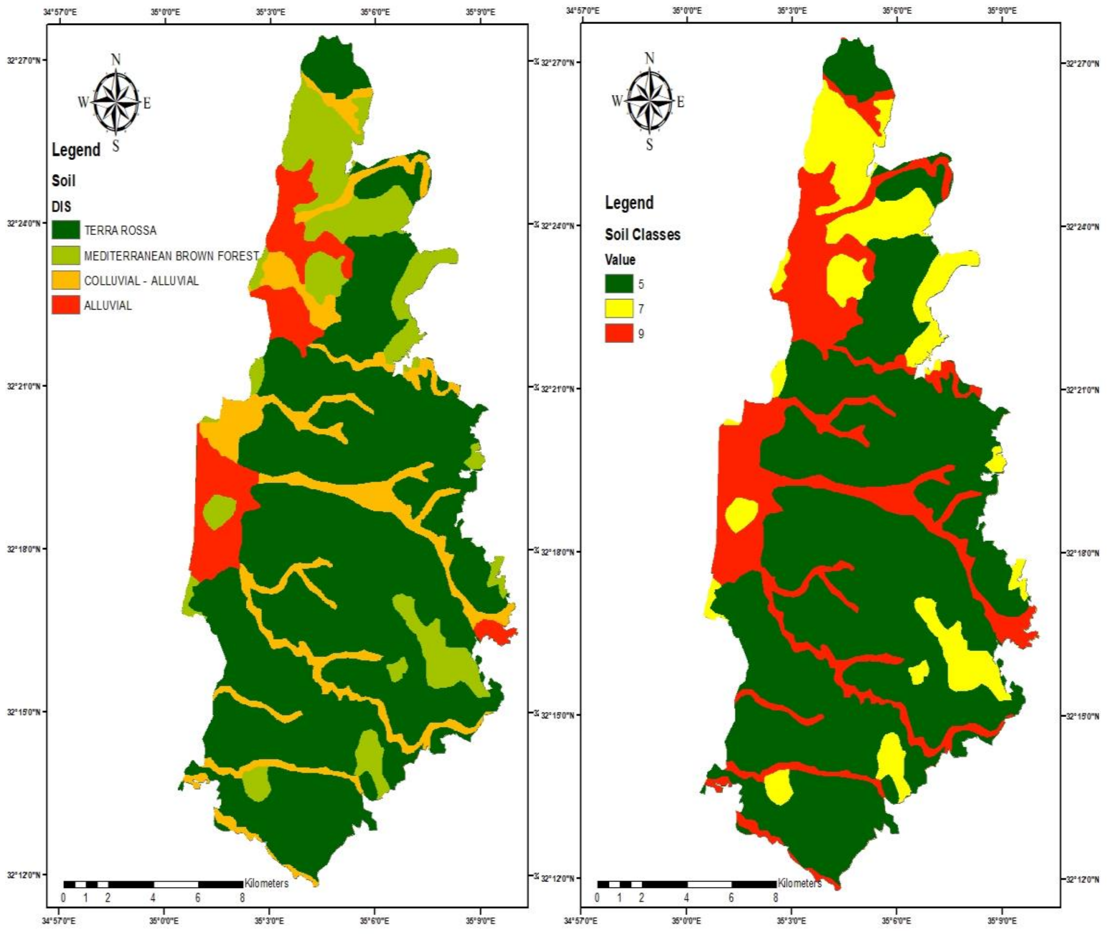


DEM

Reclassify

Figure 28

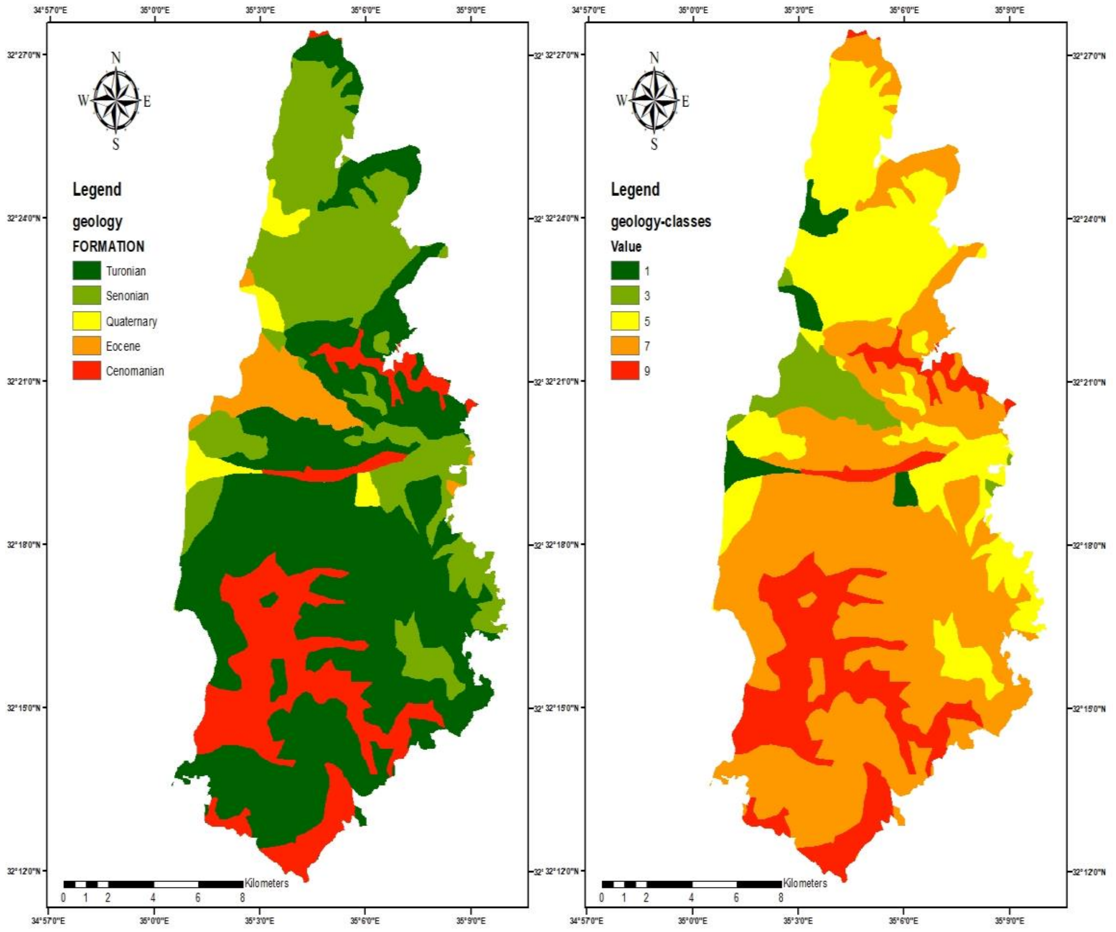
Soil Texture of Study Area (left); reclassified Soil (right)



Soil Reclassify

Figure 29

Geology of Study Area (left); reclassified Geology (right)



Geology

Reclassify

Appendix (C): Tables

Table 2

Geopolitical division of the study area

Geopolitical division	***Area (Km^o)***	***Percentage (%)***
A	55.04	22.36
B	87.20	35.43
C	103.88	42.21
Total	246.12	100

Table 3

Slope distribution (%) in the study area

Slope (%)	***Coverage (Km^o)***	***Percentage (%)***
< 5	30.86	12.53
(5-10)	54.78	22.26
(10-15)	47.55	19.32
(15-30)	86.95	35.34
> 30	25.98	10.55
Total	246.12	100

Table 4

Average monthly temperatures (C) in the study area for the years 2011-2020

Month	***Max***	***Min***	***Average***
Jan	21.282	5.205	12.845
Feb	23.916	5.723	13.422
Mar	26.742	7.452	15.307
Apr	32.190	9.980	18.034
May	35.747	14.507	21.879
Jun	34.796	17.930	24.714
Jul	35.470	20.892	26.932
Aug	35.063	22.539	27.510
Sep	35.188	20.609	26.390
Oct	34.381	16.296	23.633
Nov	29.671	11.046	19.153
Dec	24.469	7.502	14.988
Annual	*30.718*	*4.338*	*20.400*

Table 5

Monthly wind speed and direction in the study area for the year 2020

Month	***Wind Speed at 10m Max (km/hour)***	***Wind Speed at 10m Min (km/hour)***	***Average Wind Speed at 2m (km/hour)***	***Wind Direction (degrees)***
Jan	32.220	1.440	8.820	252.56
Feb	35.676	0.720	8.028	266.50
Mar	37.728	0.648	7.272	251.25
Apr	26.388	0.504	6.300	281.31
May	26.388	0.576	7.128	311.38
Jun	24.084	0.468	6.480	282.75
Jul	20.880	1.476	6.336	288.88
Aug	22.536	0.396	7.020	280.06
Sep	21.528	1.584	6.876	318.19
Oct	22.428	0.216	7.416	335.31
Nov	24.444	0.864	7.380	295.62
Dec	25.920	0.288	8.532	114.88

Table 6

The monthly average of relative and specific humidity in the study area for the years 2011-2020

Month	***Specific Humidity (g/Kg)***	***Relative Humidity (%)***
Jan	6.768	73.632
Feb	6.978	73.137
Mar	7.769	72.857
Apr	8.612	69.400
May	10.42	66.481
Jun	12.799	67.756
Jul	14.833	68.431
Aug	15.576	69.161
Sep	14.282	67.850
Oct	11.585	64.974
Nov	8.785	64.318
Dec	7.324	69.418
Annual	10.477	68.951

Table 7

Average monthly rainfall (mm) in the study area for the years 2011-2020

	Jan	***Feb***	***Mar***	***Apr***	***May***	***Jun***	***Jul***	***Aug***	***Sep***	***Oct***	***Nov***	***Dec***	***Annual***
2011	101	124	68	52	6.76	0.0	0.0	0.0	2.00	5.40	111.10	57.25	527.51
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2012	180	102	88	1.50	2.43	0.0	0.0	0.0	0.50	10.30	125.30	114.20	624.23
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2013	262	71	4	27	8.23	0.0	0.0	0.0	1.10	4.00	31.65	197.60	605.58
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2014	67	28	77	0.65	22.30	0.0	0.0	0.0	1.70	31.20	155.55	109.75	493.15
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2015	163	103	34	37	0.63	0.0	0.0	0.0	0.00	69.00	66.75	99.25	572.63
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2016	94	66	48	22	4.53	0.0	0.0	0.0	0.00	31.00	9.83	242.85	518.21
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2017	54	63	27	16	1.83	0.0	0.0	0.0	0.00	10.55	26.00	40.85	239.23
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2018	184	112	9	37	12.80	0.0	0.0	0.0	0.00	31.45	64.00	203.25	653.50
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2019	149	145	80	25	0.0	0.0	0.0	0.0	0.20	26.40	6.63	145.15	577.38
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2020	252	98	86	22	13.33	0.0	0.0	0.0	0.00	0.00	190.45	106.50	768.28
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Average	150.60	91.20	52.10	24.02	7.28	0.0	0.0	0.0	0.55	21.93	78.73	131.66	558.07

Table 8

Distribution of geological formations in the study area

Geological cover	***Area (Kmº)***	***Percentage (%)***
Quaternary	6.33	2.57
Eocene	10.18	4.13
Senonian	63.17	25.66
Turonian	125.72	51.10
Cenomanian	40.72	16.54
Total	246.12	100

Table 9

Distribution of Soil texture in the study area

Soil Type	*Area (Km^2)*	*Percentage (%)*
Terra Rosa	160.43	65.20
Rendzina	34.13	13.86
Alluvial	19.51	7.92
Colluvial - Alluvial	32.05	13.02
Total	246.12	100

Table 14

Climatic categories according to the Thornthwaite Index

Thornthwaite Index (TWI)	*Climate Categories*
> 16	Arid
16 - 31	Semi-arid
31 - 63	Semi humid
63 - 127	Humid
> 128	Wet

Table 15

Climate categories according to the Lang's Rainfall Index

Lang Index (LI)	*Climate Categories*
< 20	Desert
20- 40	arid
40 - 60	Semi-arid
60-100	Humid
> 100	Per-Humid

Table 16

Climate categories according to De Martone's Index

De Martone Index (DMI)	***Climate Categories***
< 10	Arid
10-20	Semi-arid
20-24	Mediterranean
24-28	Semi-humid
28-35	Humid
35-55	Very-humid
> 55	Extremely humid

Table 17

Climate categories according to Minar's Index

(MI)	***Climate Categories***
-4-0	Extremely arid
0-7	Arid
7-14	Semi-arid
14-21	Stable
21-28	Semi-humid
28-35	Humid
> 35	Per-humid

Table 18

Climate categories according to UNPI

UNPI	***Climate Categories***
< 0.05	Hyper-arid
0.05-0.2	Arid
0.2-0.5	Semi-Arid
0.5-0.65	Dry sub-humid
0.65-1	Sub-humid
> 1	Humid

Table 19

Climate categories according to PCI

PCI	*Climate Categories*
< 10	Arid
10-20	Mediterranean semi-dry
> 20	Humid

Table 25

CN values for different types of land cover

Land Cover	**CN values according to hydrological group D*
Forest	77
Pastures and grass land	80
permanent crops	82
Arable land	84
Irrigated crops	86
Rain-fed crops	88
Green Houses	92
Built up	95

* Source: Soil Conservation Service, 1972; USDA, 1986. (Tables 2 a, b, c, d)

Table 26

CN values extracted for the study area

CN's value	*Coverage (km2)*	*Coverage (%)*
77	1.19	0.48
80	96.83	39.35
82	89.47	36.36
84	0.70	0.28
86	17.83	7.24
88	8.25	3.35
92	2.79	1.13
95	29.06	11.81

Table 28

Scoring structure for surface water runoff in the study area

Runoff (mm/year)	*Score*	*Suitability*	*Coverage (km2)*	*Coverage (%)*
159.87-175	1	Unsuitable	80.11	32.55
175-190	3	Low suitability	95.92	38.97
190-205	5	Moderate suitability	37.58	15.27
205-220	7	High suitability	9.18	3.73
> 220	9	Very high suitability	23.33	9.48

Table 29

Scoring structure for the slope of the study area

Slope (%)	*Score*	*Suitability*	*Coverage (km^2)*	*Coverage (%)*
> 30	1	Unsuitable	25.98	10.55
15-20	3	Low suitability	86.95	35.34
10-15	5	Moderate suitability	47.55	19.32
5-10	7	High suitability	54.78	22.26
< 5	9	Very high suitability	30.86	12.53

Table 30

Scoring structure for basin runoff of the study area

Basin	*Mean runoff depth (mm/year)*	*Area of basin (km^2)*	**Volume of runoff (MQM/year)*	***Composite CN*	*Score*
C	210.77	4.920	1.037	84.86	1
E	170.85	6.209	1.060	81.57	1
F	171.66	6.522	1.119	81.83	1
H	172.59	17.645	3.045	82.13	2
J	178.23	20.756	3.699	83.32	2
K	207.72	20.830	4.326	83.91	2
L	204.46	26.794	5.478	82.90	2
N	167.65	44.930	7.532	82.08	3
Ateen	182.22	125.763	22.915	83.67	7
Zoumar	188.41	150.612	28.376	84.10	8
Massin	188.72	176.322	33.274	82.80	9
Abu-Nar	206.10	171.076	35.259	83.41	9
Total		**772.379**	**147.120**		

*Volume of runoff = depth of runoff * area of basin

$$** \text{ Composite CN } = \frac{CN1 * A1 + CN2 * A2 + \cdots + CNn * An}{\sum_n Ai}$$

Table 31

Scoring structure for the land agricultural value of the study area

Agricultural Value	*Score*	*Suitability*	*Coverage (km²)*	*Coverage (%)*
Low	3	Low suitability	106.35	43.21
Moderate	6	Moderate suitability	115.87	47.08
High	9	High suitability	23.90	9.71

Table 32

Scoring structure of stream density in the study area

Density (km/km²)	*Score*	*Suitability*	*Coverage (km²)*	*Coverage (%)*
<10	1	Unsuitable	204.63	83.15
10-25	3	Low suitability	31.12	12.64
25-35	5	Moderate suitability	7.57	3.08
35-50	7	High suitability	2.73	1.11
>50	9	Very high suitability	0.06	0.02

Table 33

Scoring structure of land use/ land cover in the study area

LULC	*Score*	*Coverage (km2)*	*Coverage (%)*
Mines and Settlement	restricted	2.04	0.82
Urban	1	27.14	11.03
Forest	2	1.12	0.45
Permanents crops	3	89.44	36.34
Grass land &Pasture	5	52.95	21.51
Agricultural & Arable Land	7	44.58	18.13
Rain-fed	8	8.25	3.35
Crop land & Green Houses	9	20.60	8.37

Table 34

Scoring structure of land elevations in the study area

Elevation (m)	*Score*	*Suitability*	*Coverage (km2)*	*Coverage (%)*
> 400	1	Unsuitable	7.22	2.93
300-400	3	Low suitability	44.73z	18.17
200-300	5	Moderate suitability	76.19	30.96
`100-200	7	High suitability	98.54	40.04
< 100	9	Very high suitability	19.44	7.90

Table 35

Scoring structure for soil texture in the study area

Soil Texture	** HSG*	*Suitability*	*Score*
Terra Rosa	D	Moderate suitability	5
Rendzina	D	High suitability	7
Alluvial	D	Very high suitability	9
Colluvial - Alluvial	D	Extreme high suitability	9

Source:* (USDA-TR55, 1986) Adapted.

Table 36

Scoring structure for geology in the study area

Geological age	*Score*	*Suitability*	*Coverage (km2)*	*Coverage (%)*
Quaternary	1	Unsuitable	6.31	2.56
Eocene	3	Low suitability	10.18	4.14
Senonian	5	Moderate suitability	63.17	25.67
Turonian	7	High suitability	125.74	51.09
Cenomanian	9	Very high suitability	40.72	16.54

جامعة النجاح الوطنية

كلية الدراسات العليا

تحديد المواقع المناسبة لإنشاء برك تجميع مياه الأمطار باستخدام نظم المعلومات الجغرافية في محافظة طولكرم

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الملخص

تركز هذه الدراسة على استخدام نظم المعلومات الجغرافية في دراسة حصاد مياه الأمطار وسبل استغلالها في محافظة طولكرم، وهدفت الدراسة إلى حساب كميات الجريان السطحي وتحليل الميزانية المائية في منطقة الدراسة للتعرف على فترات الفائض والعجز المائي مما له من فائدة كبيرة للقطاع الزراعي من خلال استغلال فترات الفائض المائي التي تكون فيها التربة مشبعة ولا تعاني من نقص في الرطوبة، ومن المفيد أيضاً معرفة فترات العجز و النقص في المياه بسبب أن قلة رطوبة التربة قد تضر بالمحاصيل، ولذلك من الممكن تجنب هذه الفترة عن طريق الري المزروعات خلالها.

تم تبني تصنيف ثورنثويت المناخي (1955) المعدل في حساب الموازنة المائية، وتم استخدام المتوسطات السنوية والشهرية لهطول الأمطار ودرجة الحرارة للفترة ما بين عامي 2011 و2020.أظهرت النتائج أن متوسط كمية الجريان السطحي المباشر في المحافظة يصل إلى 186 ملم سنوياً، وأشارت إلى وجود فترتين من حيث التوزيع المكاني لرطوبة التربة، فترة فائض مائي تمتد من ديسمبر إلى مارس، بحيث يعد شهر يناير هو الأعلى من حيث الفائض المائي حيث يصل إلى حوالي 129 ملم. وفترة عجز مائي تمتد من مايو إلى أكتوبر، بحيث يعتبر شهري يوليو وأغسطس الأعلى من حيث العجز المائي حيث يصل إلى حوالي 170 ملم، وهو ما يبدو منسجما مع الخصائص المناخية التي تتسم بها منطقة الدراسة.

كما أظهرت النتائج ايضا أن المواقع الأقرب إلى مخارج مجاري الأحواض الرئيسية تعتبر المواقع الأكثر ملاءمة لإنشاء بركة تجميع المياه.

ولذلك فأن الجهد الأساسي في هذا البحث يتركز على تجميع مياه الأمطار في مواقع محددة خلال فترة الفائض المائي عن طريق إنشاء برك الحصاد وخاصة خلال فترات هطول الأمطار الأولى.

الكلمات المفتاحية: حصاد مياه الأمطار، الموازنة المائية، محافظة طولكرم، فلسطين، نظم المعلومات الجغرافية.