إقــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

دراسة وتخطيط نظام مترو الأنفاق في قطاع غزة

Studying and Planning for a Metro System in the Gaza Strip

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Date: 31/3/2015

التاريخ: 31/3/2015

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دراسة وتخطيط نظام مترو الأنفاق في قطاع غزة

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering, Infrastructure.

2015

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بسم الله الرحمن الرحيم

الجامعة الإسلامية – غزة

The Islamic University - Gaza

مكتب نائب الرئيس للبحث العلمي والدراسات العليا هاتف داخلي 1150

ج س غ/35/ Ref ....

التاريخ 2015/03/21 Date ....

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بناءً على موافقة شئون البحث العلمي والدراسات العليا بالجامعة الإسلامية بغزة على تشكيل لجنة الحكم على أطروحة الباحث/ **محمد زكريا إبراهيم سكيك** لنيل درجة الماجستير في **كلية *الهندسة*** قسم <u>الهندسة المدنية- البنى التحتية</u> وموضوعها:

دراسة وتخطيط نظام مترو الأنفاق في قطاع غزة

Studying and Planning for a Metro System in the Gaza Strip

وبعد المناقشة التي تمت اليوم السبت 01 جمادى الآخر 1436هـ، الموافق 2015/03/21م الساعة العاشرة صباحاً، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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وبعد المداولة أوصت اللجنة بمنح الباحث درجة الماجستير في **كلية *الهندسة*** / قسم <u>**الهندسة المدنية- البنى التحتية**</u>.

واللجنة إذ تمنحه هذه الدرجة فإنها توصيه بتقوى الله ولزوم طاعته وأن يسخر علمه في خدمة دينه ووطنه.

والله ولي التوفيق ،،،

مساعد نائب الرئيس للبحث العلمي وللدراسات العليا

أ.د. فؤاد علي العاجز

Dedication

This thesis is dedicated to my beloved parents who always inspired me in my life. They have been supportive, encouraging, and generous. The words are limiting me to be more thankful. This work is also dedicated to my dear family who have always accompanied me and have assisted me to overcome the challenges. It is dedicated to my brothers, sisters, colleagues, and friends as well. It is my honor to dedicate this work to you all with all gratitude and respect.

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Acknowledgement

I find myself fortunate to have a group of contributors who are a part of my success. It gives me pleasure to express my deep acknowledgement and to thank Prof. Dr. Shafik Jendia, the supervisor, for his high commitment to the success of this work. He was always positive, generous guide, and supportive. I am grateful for his supervision, and continuous follow up. I have learned from him so much.

The researcher would like to thank the thesis committee, Prof. Dr. Farid Al-Qeeq and Dr. Yahya Sarraj, for their valuable contribution.

I would like to express the deepest gratitude to my family. You have all provided support, encouragement and interest in my thesis work.

The Researcher

Mohammed Z. Skaik

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List of Acronyms

PNA	Palestinian National Authority
WB	The West Bank - Palestine
GS	The Gaza Strip – Palestine
GIS	Geographic Information Systems
SMCA	Spatial Multi Criteria Analysis
DEM	Digital Elevation Model
ES	Expert Systems
MCDM	Multi-Criteria Decision Making methods
ERRAC	European Rail Research Advisory Council
PCBS	Palestinian Central Bureau of Statistics
UNDP	United Nations Development Program.
MOPIC	Ministry of Planning and International Cooperation - Palestine
MoT	Ministry of Transport - Palestine
UITP	International (Union) Association of Public Transport
EU	European Union
AHP	Analytic Hierarchy Process
SMCE	Spatial Multiple Criteria Evaluation
ESRI	Environmental Systems Research Institute
DEM	Digital Elevation Model

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Abstract

This work aims at studying and planning for establishing a metro network in the Gaza Strip as a strategic trend and solution in order to overcome current and future transportation challenges. A wide literature review of previous studies and efforts that analyzed the public transportation situation in Palestine. It investigated the planning process of establishing metro networks for new areas.

The author has reviewed public transportation systems and demand in the Gaza Strip through studying transportation movements and layout and analyzing the road networks in the Gaza Strip. In addition, the thesis studied basic requirements for establishing and running the metro system and its characteristics. The research is based upon a wide data research from the most viable sources. Geographic Information Systems (GIS), Multi-Criteria Decision Making methods (MCDM), and Expert Systems (ES) have extensively been used in solving metro components sites selection problems.

The planning process in this thesis mainly involves identifying the optimal locations for the main components of the system, which are (1) Stations (end and intermediate stations) and (2) the best optimized route. The locations of such components can be classified as the best ones, if they satisfy certain criteria such as engineering, environmental, economic, social, and institutional requirements. In other words, the location that reduces cost, has less impact on the environment, and can be used without any construction or engineering constraints is the favourable one.

The results show that 3 end stations have been chosen to be the origin and destination stations. It also shows that the total proposed metro line length is 51, 759 Km. It covers all the Gaza Strip Governorates. 57 metro stations have been chosen and distributed along the proposed metro route which is branched into two routes starting from Deir Albalah and reaching the two destinations in South Gaza. It also serves the most important intersections and vital places in the Gaza Strip Governorates. The study has concluded that Metro system could be a strategic national project for developing the frame work of public transportation systems in Palestine. It also connects the Gaza Strip with the West Bank and serves the regional connection of the Gaza Strip as a part of the national strategy towards developing the infrastructure in Palestine.

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Abstract

الملخص

تسعى هذه الرسالة العلمية لدراسة وتخطيط نظام مترو الأنفاق في قطاع غزة كحل وتوجه استراتيجي من أجل التغلب على المشكلات الحالية والتحديات المستقبلية في وسائل النقل العام في فلسطين، وفي هذا الشأن فقد تم إجراء مراجعة واسعة للمراجع العلمية والدراسات السابقة التي تناولت أزمة المواصلات في قطاع غزة، ومتطلبات إنشاء شبكات مترو الأنفاق، وطرق وتقنيات تصميمها والتخطيط السليم لها مع الأخذ بعين الاعتبار العوامل الفنية (الهندسية أو الإنشائية) والاقتصادية والبيئية.

حيث تمت دراسة أنظمة المواصلات العامة وحركات المرور عبر الدراسات المتوفرة من حيث الأعداد والنوعيات والاتجاهات في قطاع غزة، وقد تضمن هذا التوزيعات الجغرافية وأماكن التجمعات، وتحليل شبكات الطرق في قطاع غزة، كما تم إجراء دراسة مفصلة حول متطلبات إنشاء وتشغيل شبكات مترو الأنفاق من النواحي الفنية والتشغيلية الخاصة بها، وأهم الطرق والمنهجيات المتبعة لتخطيط وتصميم مرافق شبكات مترو، وقد اعتمد البحث نظم المعلومات الجغرافية لتحليل البيانات الجغرافية والوصول إلى أفضل النتائج من خلال التحليل متعدد المعايير والأنظمة الخبيرة من أجل اقتراح أفضل البدائل والخيارات لمرافق شبكة المترو في قطاع غزة.

وقد هدفت عملية التخطيط إلى اختيار أفضل المواقع لمكونات شبكة مترو الأنفاق الرئيسية وهي: أولا: المحطات الطرفية (بداية ونهاية) للشبكة، ثانيا: أفضل مسار للشبكة مراعيا المعايير الهندسية والاقتصادية والبيئية، ثالثا: المحطات الوسطية داخل المسار، ومن أجل ذلك فقد استخدمت البيانات الجغرافية بأنواعها المختلفة من توزيعات المحافظات والتقاطعات الرئيسية وتوزيعات استخدامات الأراضي، وجداول المياه الجوفية، والكثافة السكانية، والمناطق الهامة التي شملت الجامعات والمستشفيات والمؤسسات الحكومية والأسواق وخلافه، والمناطق الحدودية، وأنواع التربة، وتوزيعات الارتفاعات عن سطح البحر وغيرها، وقد حققت الدراسة أهدافها من خلال الوصول إلى أفضل مسار ومناطق المحطات المختلفة التي تحقق الأهداف الهندسية والاقتصادية والبيئية والاجتماعية والمؤسسية وغيرها.

فيما خلصت الدراسة إلى مجموعة من النتائج أهمها اقتراح محطات انطلاق ووجهة المترو وكذلك المحطات البينية وأفضل مسار يحقق جميع العوامل والمعايير التي تم اعتمادها في الرسالة، وكنتيجة فقد تم اعتماد 3 محطات مترو طرفية فيما بلغ مجموع محطات المترو ٥٧ محطة مترو كما بلغ طول خط (مسار) المترو 51,759 كم الذي بدوره ينقسم إلى فرعين بدءا من محافظة دير البلح وحتى محافظتي خانيونس ورفح، وقد أوصت الدراسة بضرورة اعتماد المترو كمشروع وطني لحل مشكلة المواصلات العامة في فلسطين وتمهيدا لربط قطاع غزة بالضفة الغربية واقليميا ضمن التوجهات المستقبلية لتطوير البنية التحتية في فلسطين، كما أشارت إلى أهمية إجراء أبحاث ودراسات تصميمية لشبكة مترو الأنفاق بهدف البناء على هذا المنجز العلمي.

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Chapter (1)

General Introduction

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1.1 Background

Growing number of vehicular trips by cars and other means which result in traffic congestion, air pollution and traffic accidents has become a major concern in urban areas. Investments in high capacity rail based mass transit systems are being promoted to arrest this trend (Advani and Tiwari, 2005). Metro has to be understood as, "a tracked, electrically driven local means of transport, which has an integral, continuous track bed of its own (large underground or elevated sections)." This results in a high degree of freedom for the choice of vehicle width and length, and thus a large carrying capacity (above 30,000 passengers per hour per direction – pass/h/dir.). Metro systems can be implemented only in large cities where demand justifies the capital cost. (European Rail Research Advisory Council (ERRAC), 2002)

Metro systems have been introduced in many international cities. These systems have limited seating and several doors on each side of the carriage. This design allows a high capacity with a larger number of standing passengers and faster times for passengers to move in and out of the carriages, reducing station dwell times. These metro systems operate in higher density cities in inner metropolitan areas and rely on interchanges with suburban rail systems to serve commuters from further afield. Metro systems operate in higher density cities in inner metropolitan areas and rely on interchanges with suburban rail systems to serve commuters from further afield. Metro systems are typically introduced to cater for high volume, short distance passenger trips. (Australian Department of Infrastructure, Planning, and Natural Resources, 2004).

While the Gaza Strip is suffering from various and deep problems in the public transport systems and road network that are explained widely in the following sections, this thesis seeks to give a general overview of a potential Metro network in the Gaza Strip in order to sketch some general trends for the development efforts. It tries to match current and future transportation challenges and problems in Palestine with a feasible strategic solution that can satisfies the sustainable development aspects to ensure improving the efficiency of the transportation system and its infrastructure that affects economic, social, and environmental parameters of the sustainable development in Palestine.

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1.2 Problem Statement

Since established, Palestinian National Authority (PNA) has rehabilitated and developed a road network, which connects a majority of cities, towns and villages in the West Bank (WB) and the Gaza Strip (GS). Over 1994-99, approximately 2,068 km of roads were constructed. In addition, 338 km of regional or main roads were built. Between1994-2007, road rehabilitation cost around USD 336.7 million, including construction of the Gaza International Airport and Gaza Port. According to 2009 statistics, vehicles total 229,886 in the Palestinian territory, including 175,265 in the West Bank and 54,621 in the Gaza Strip. Private vehicles comprise the highest percentage (67%), followed by commercial vehicles (17.8%), and public vehicles (7.4%). The road network forms the backbone of the transportation system in the Palestinian territories. The current paved road network in the Palestinian territories comprises of 2869 km, of which 2248 are in the West Bank and 621 km in the Gaza Strip. (Abu-Eisheh and Al-Sahili, 2006)

The Palestinian population of the Gaza Strip has a yearly growth rate of about 3.01%, the Gaza Strip has the 9th highest population growth rate in the world (CIA, 2013). It is 41 kilometres (25 mi) long, and from 6 to 12 kilometres (3.7 to 7.5 mi) wide, with a total area of 365 square kilometres (141 sq mi). The population of the Gaza Strip is about 1.76 million people. (Arnon, 2007).

According to Elsobeihi, (2012), Public transport in the Gaza Strip is provided by buses and shared taxis. Public transport service between North Gaza and other Governorates is not available except for Gaza Governorate. Many rural communities do not have any public bus transportation. Elsobeihi, (2012) has mentioned that Bus movements, originated from Rafah Governorate to other governorates in the Gaza Strip as a destination, for example show that, in 2010, the average number of bus riders per week for different destinations is 16,920 rider.

The problem statement of this thesis could be diagnosed in five major features that summarize that current and the futures problems in the transportation system and its infrastructure including the existing and potential road networks in Palestine as a whole

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and in the Gaza Strip Particularly. Figure (1.1) shows the five features of the problem statement of this thesis:

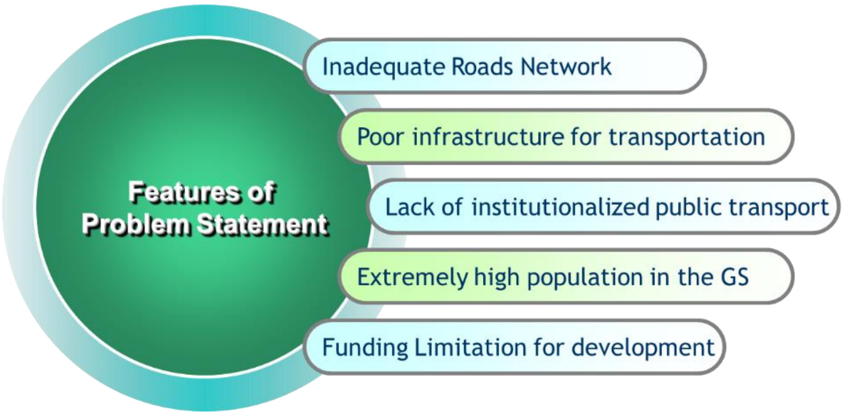

Figure (1.1): Features of Thesis Problem Statement

Taking into consideration the annual increase rate on the demand of the public transport, it can be shown how deep the problem is, since the Gaza Strip has a limited area and it is one of the highest population density in the world this results in in-sufficient transport movement of people and goods throughout the Gaza Strip and the movement in/out of the Gaza Strip. It is highly important to address a wide range of issues associated with the development of a metro system reaching to a recommendation whether the metro system seems a feasible trend to enhance the development of transport in the Gaza Strip and concluding the best practice of establishing and running this national facility.

1.3 Thesis Aim and Objectives

This work aims at studying and planning for establishing a Metro Network in the Gaza Strip as a strategic trend in order to overcome current and future challenges in public transportation. The research seeks to achieve its aim through the following objectives:

1. Evaluating and Analyzing the current and future transportation systems and Road Networks in the Gaza Strip in terms of evaluating the general performance of the systems, the demand, available road networks, the road classification, and traffic surveys.

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2. Studying Metro Networks world-wide, concluding establishment and operational requirements, and assessing the aspects and the potential of establishing a metro network in the Gaza Strip.

3. Planning and designing foe the Metro Network in the Gaza Strip though proposing the best sites location for the network components. This includes end stations, route selection, and intermediate stations taking into consideration engineering, economic, and environmental requirements.

4. Concluding best practices of such a strategic national project for an optimized design, establishment, and operation processes.

1.4 Research Importance and Contribution

The importance of the study comes from seeking for strategies to develop and improve the life style and saving time, cost, and efforts for the Palestinian people in the Gaza Strip. This will be achieved through:

- Reaching a feasible solution for the transportation congestions and other current and future pains while maintaining the sustainable development aspects.
- Providing a trend for new developments of the road network in the Gaza Strip.
- Highlighting current and future transportation needs for the people in the Gaza Strip.
- Contributing to the potential regional connectivity for the Gaza Strip.

In addition, it provides a frame work to relevant agencies to take a role in developing the public transportation systems while sustaining the social, environmental, and economic impacts of such projects. It should be widely noticed that planning for a metro systems as a strategic trend to solve current and future challenges for the region is so important in order to improve the life-style of people.

From previous studies, few of those have provided an integrated framework to develop the transportation systems and road networks in the Gaza Strip.

This study could be the first research that shed light on planning for a metro network as a strategic trend for transportation systems in the Gaza Strip.

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1.5 Methodology

This research depends on wide investigations in order to achieve its aim and objectives. The following brief research methodology has been adopted during the research. Figure (1.2) shows the adopted brief methodology of this thesis:

- A wide literature review of previous studies regarding the trends of planning and establishing a metro system and network for new areas. This also includes the frame work of integrating this system regionally.
- Reviewing the public transportation systems and demands through studying the transportation movements and layout in the Gaza Strip. That includes a Geographic distributions and directions.
- Studying the basic requirements for establishing and running a metro system and its characteristics. This includes minimum criteria for selecting metro facilities.
- Designing and planning a metro network for the Gaza Strip taking into consideration multi criteria analysis tools and standards for identifying the metro lines and site locations including the stations.
- Concluding the research results and suggesting recommendations.

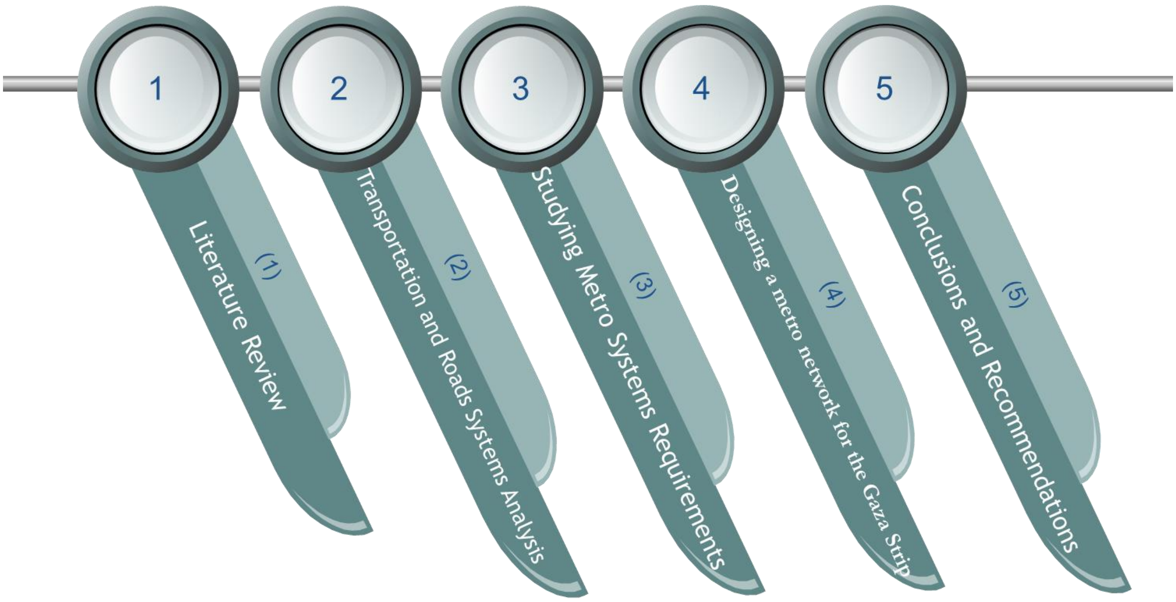

Figure (1.2): Adopted Brief Methodology of the Thesis

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1.6 Thesis Structure

The thesis has been organized in order to achieve its aim and objectives and to apply the research methodology. Starting from analyzing the transportation and road systems in Palestine as a whole and in the Gaza Strip particularly, describing metro networks requirements and characteristics, studying the most well-known methodologies, and then planning and designing metro facilities in the Gaza Strip. This organization is shown according to the following structure:

- Chapter One: introduces a general background, problem statement, aim and objectives of the thesis, thesis importance and contribution, brief research methodology as well as thesis organization.
- Chapter Two: reviews the public transportation systems in the Gaza Strip. That includes a Geographic distributions and directions. It also overviews the available road networks in the Gaza Strip. That includes the capacity of the roads, the performance and the status, road classifications, and national development plans for public transport and road networks in the Gaza Strip.
- Chapter Three: includes the basic requirements for establishing and running the metro system and its characteristics. That includes: definition, components, facilities, stations, the adjacent residential density or the location of employment and commercial and use; and metro planning phases and parameters.
- Chapter Four: describes adopted approaches for an optimal selection process for metro facilities. This includes tools, multi criteria analysis, ideal cases, and principles in order to reach the most optimized route and stations for a metro facility.
- Chapter Five: This chapter introduces the methodology adopted to solve the main problem, which is planning a metro system in the Gaza Strip. The planning process mainly involves identifying the optimal locations for the main components of the system, which are (1) Stations and (2) Routes. The locations of such components can be classified as the best ones, if they satisfy certain criteria such as engineering, environmental, and economical requirements. In other words, the location that reduces costs, has less impact

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on the environment, and can be used without any construction or engineering constraints is the favorable one.

- Chapter Six: Includes the results and proposing a layout of the metro track taking into consideration multi criteria analysis tools and standards for identifying the metro lines and site locations including the stations. In order to improve the performance of the metro system, some criteria have been taken into consideration while choosing metro facilities. Finally it concludes research results and suggests recommendations.

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Chapter (2)

Transportation and Roads Systems in the Gaza Strip

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2.1 Introduction

The Gaza Strip is one of the most densely populated places on earth, with a total area of 365 km^2 (45km long, 7-12 km wide), a population of over 1.7 million and a population growth of 3.37%. The Gaza Strip has been subjected to many external and internal political, economic and social pressures that led to poor socioeconomic conditions for its population. (Al-Wehaidy, 2013)

According to Palestinian Central Bureau of Statistics (PCBS) population will double during the next 21 years (PCBS, 2011). This increase will results in raising the demand for transportation forming traffic congestions in many streets of Gaza City. In addition, it can suspend traffic movement, especially during going to works, schools, universities, and other places. One of the most principal components of the transportation systems is public transportation. (Al-Yazouri, 2013)

After the establishment of the Palestinian National Authority in 1993, the transportation system in the Gaza Strip was extensively improved and a dramatic unprecedented increase in the number of registered vehicles were noticed. In consequence of that, new infrastructure projects especially road networks, were constructed. However, the construction was with little scientific-based planning. This led to shortage in public transport system on several divisions such as economic, social, cultural and service sectors. The Palestinian National Authority did not direct sufficient funds towards the development of public transportation facilities. Modes of public transportation in the Gaza Strip may be limited to buses and shared taxis. The problem facing the public transport sector with regard to buses is that they are few and their stops needed for loading and unloading are rare. Furthermore, there are no clearly indicated bus lines and no timetables which cause long waiting times for passengers. Regarding shared taxis, the problem is that they are a lot but their loading and unloading areas are inadequate that causes obvious traffic congestion in different areas. As a result of that, the public transportation services in the Gaza Strip require to determine future needs and demand of riders. Therefore, there is a need for evaluating existing public transportation and studying the factors that affect current and future public transportation demand. This will help to suggest policies in managing public transport that lead to choosing the feasible and logical solutions. (Elsobeihi, 2012).

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In consequence to this high demand on the public transport in the Gaza Strip, new infrastructure projects especially road networks were constructed to match this high demand. However, the construction was with a little scientific-base planning. This led to shortage in public transport system on several divisions such as economic, social, cultural, and service sectors.

2.2 Road Network in the Gaza Strip

The Gaza Strip road network is divided into three main categories which are Main, Regional, and local road networks. The Ministry of housing and public work as cited by Palestinian Central Bureau of Statistics explained that the total length of the Gaza City network in 2010 was 62 Km for example. Table (2.1) illustrates the road length for each governorate. (PCBS, 2010)

Table (2.1): Paved Road Network Lengths for Gaza Governorates (km)
(Palestinian Central Bureau of Statistics, 2010)

City name	Local	Regional	Main	Total
Rafah	16	20	13	49
Khan Yunis	24	33	20	77
Deir Al-Balah	20	20	16	56
Gaza city	18	31	13	62
North Gaza	21	18	14	53
Gaza Strip	99	122	76	297

Whilst in 2012, United Nations Development Program (UNDP) has estimated the total length of existing paved road network in the Gaza Strip as 690 Km. (UNDP, 2012) This shows the bad need of newly constructed infrastructure projects such as roads construction. The numbers show that the total paved road network length in the Gaza Strip has doubled in two years during (2010-2012).

According to Alokshiya, (2013), the main regional roads of the Gaza Strip are:

1. Salah El-Deen Road: extends from Rafah (South) to Biet Hanoon in the Northern Governorate (North). Salah El-Deen road is 58 kilometers.
2. Al-Karama Road: extends from Rafah (South) to Biet Lahia in the Northern Governorate (North), to the east of Salah El-Deen road. Al-Karama road is 20 kilometers.

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3. Al-Rasheed Road: extends from Rafah (South) to Biet Hanoon in the Northern Governorate (North) along the coastal line of Gaza. Al-Rasheed road is 45 kilometers.

According to Palestinian Ministry of Planning and International Cooperation, the total length of regional roads of the Gaza Strip is 123 Km while the total length of road network in the Gaza Strip is 898 Km (Palestinian Ministry of Planning and International Cooperation, 2012). In contrast, UNDP states that: "it is estimated that the total length of existing road networks in the Gaza Strip is 1390 kilometres. Roads have been severely damaged due to Israeli military invasions and bulldozing while rehabilitation is hindered by the blockade. (UNDP, 2012)

This means that transportation system and road networks in the Gaza Strip should have a more effective national development strategy to ensure the sustainable development of the current and future transportation infrastructure.

2.3 Transportation Systems in the Gaza Strip

The Gaza Strip vehicles composition varies from Private cars, taxis, Buses, to trucks as shown in Table (2.2). According to Palestinian Central Bureau of Statistics the total number of licensed Vehicles in the Gaza strip in 2010 equals to 60,901veh. (PCBS, 2010)

Table (2.2): Type and Number of Licensed Vehicles in the Gaza Strip and the West Bank (Palestinian Central Bureau of Statistics, 2010)

	West bank Vehicles		Gaza strip Vehicles	
	Percentage	Number	Percentage	Number
Private Cars	70.64	85,874	50.62	30,830
Taxis	7.09	8,616	4.66	2,841
Motorcycles	0.25	303	23.12	14,083
Private Buses	0.41	499	0.63	385
Public Buses	0.70	851	0.38	230
Trailers	0.57	693	0.24	149
Tractors	0.68	830	1.21	736
Road Tractors	0.26	315	0.00	2
Trucks	19.01	23,114	18.34	11,172
Other Vehicles	0.39	470	0.78	473
sum		121,565		60,901

The growth rate of vehicles in the Gaza Strip is high whereas the growth rate of buses approaches to zero. (Palestine Ministry of Transport, 2012)

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The numbers show the massive possession of vehicles to match the high population density of the Gaza Strip with a limited road network. This implies seeking a feasible solution that can be effective and helps in minimizing vehicles numbers while increasing the accessibility of passengers and goods.

2.4 Public Transportation in the Gaza Strip

The Gaza Strip consists of five main governorates as shown in Figure (2.1). These are from North to South: Northern Governorate, Gaza Governorate, The Middle Governorate, Khan Yunus Governorate, and Rafah Governorate.

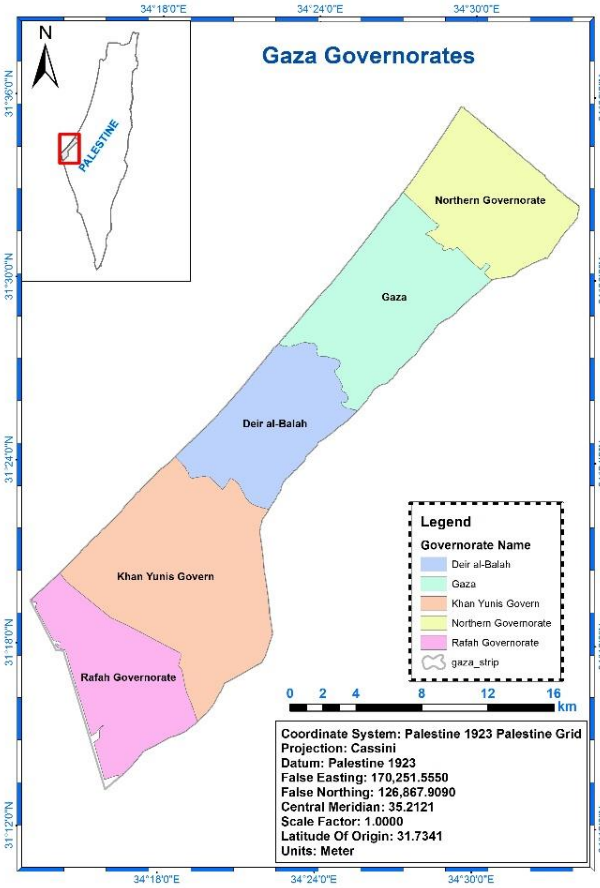

Figure (2.1): the Gaza Strip Governorates.

Public transportation System in the Gaza Strip is divided into two main types; buses and taxis. Buses are considered as a basic constituent in the public transportation system in the Gaza Strip.

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Bus, as a transportation mode, is less expensive than taxi, less noisy and less air pollutant due to its advantage of replacing ten taxis at least, knowing that a bus maximum load is 50 passenger, while a taxi is fully loaded by only five. This advantage can be useful in minimizing traffic congestion. Another advantage is that buses should have specific stations and special lanes of movement, which means that jams caused by taxis loading and uploading can be reduced. Despite all of these advantages, buses are not widely used in Gaza. (Alokshiya, 2013)

Until June, 2012, the number of buses in the Gaza Strip was 212. The buses form about 0.3% of the total number of vehicles in the Gaza Strip. The percent of buses is very low compared to the taxi in Gaza, which form about 19% of Gazans' means of transport (Ministry of Transport, Gaza, 2012).

Encouraging public transport system can strongly reduce the use of taxis, and hence can contribute in decreasing the level of congestion leading to better levels of service on streets.

Buses are mostly used in transferring university students in the Gaza Strip. Since most universities are located in Gaza city, buses travel from other cities to Gaza city daily. It can be said that a bus system with constant schedules and routes does not exist in the Gaza Strip. What exists is: 212 buses come from all over the Gaza Strip to Gaza city at 8:00 o'clock and leave at 15:00, transferring university students. (Alokshiya, 2013)

2.4.1 Public Transportation Modes in the Gaza Strip

Along with the increase of the population and the development of the industries, the Gaza Strip governorates are extending gradually. The interactions between people in the governorates are more frequent than the past days. Therefore, the public transportation is an important means to connect people to each other. The essential purpose to develop the public transportation is to assist citizens to make a trip easily and ensure the normal operation of the essential social organizations and their activities. Public transport consists of all shared ride transport service systems in which the

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passengers do not travel in their own vehicles such as bus services and shared taxi services. There are two public transportation modes in the Gaza Strip Governorates namely, buses and shared-taxis. The fleet is owned and operated by the private sector; individuals or firms. No major developments in public transportation have been observed during the past few years. There were no funds assigned by the Palestinian National Authority (PNA) for the improvement of the public transport amenities. As public transport is owned and operated by the private sector, the PNA depends on the private sector initiatives to develop the sector. Due to the lack of the PNA power on the ground due to the continuous Israeli military aggressions in the Gaza strip Governorates, there has been fragile control of the PNA on public transport. The following reasons explain the decision of PNA to delay the development of public transport (Elsobeihi, 2012):

1- Public transportation agencies are privately owned.

2- PNA focused on physical infrastructure rather than on operation projects.

3- Some of public transportation development projects need public awareness.

Table (2.3) shows the Total Weekly Bus Riders between Pairs of the Gaza Strip Governorates:

Table (2.3): Total Weekly Bus Riders between Pairs of Governorates (Elsobeihi, 2012)

To / From	N.Gaza	Gaza	M. Area	Khan Y.	Rafah
N. Gaza	x	7800	-	-	-
Gaza	7800	×	4140	4380	8640
M. Area	-	4740	×	1800	1200
Khan Y.	-	4620	2100	×	5700
Rafah	-	10020	1200	5700	×

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2.4.2 Integration of Public and Private Transport in the Gaza Strip

Beside the public transport services between Governorates (bus and shared taxi), the existing of private cars in the Gaza Strip cannot be ignored and it is impossible to create a zero private car city. In fact, the coexistence of public transport and private car is possible. For instance, people can take a bus to go and come back from work to a void congestion whereas they could use their own cars for vacation purposes such as shopping. Through this way, the number of private cars in the future can be reduced regularly starting from reducing the use of private cars at present. The rising amount of car utilization within urban centers will create the problem of congestion and hence will become a threat to economic growth, noise, poor air quality and even global warming. (Elsobeihi, 2012)

2.5 Transportation Development Programs in Palestine

According to Abu-Eisheh and Al-Sahili, (2006), before arriving at a defined strategy and developmental program for the transportation sector in the Palestinian territories, it is intended to briefly review the previous efforts towards the formulation of development plans and programs in the transportation sector.

In 1993, the World Bank had published a series of volumes on developing the Palestinian territories. Volume 5 dealt with the infrastructure, including the transportation sector. It identified the recommended projects categories and summarized financial needs in the sector on the short- and long-terms to equal 848 million USD, including physical investment (roads and the airport) and technical assistance. (The World Bank, 1993)

Regional plans for the Palestinian territories prepared by Ministry of Planning and International Cooperation (MOPIC) in 1998 identified the conceptual framework for the development of each of the sectors, including the transportation sector, within a comprehensive developmental outline for the West Bank and the Gaza Strip regions. (Palestinian Ministry of Planning and International Cooperation, 1998).

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The objectives of the plans include improvement of the transportation systems and accessibility at the inter- and intra-regional levels, concentrating on the development of new road links and upgrading and enhancing the capacities of existing roads on one hand, and the efficient use of transportation system on the other.

Since the establishment of the PNA, it had been regularly preparing 3-5 year plans, called the Palestinian Development Plans, considering all developmental issues and sectors. Information on the 1999-2003 plan indicated the inclusion of an estimated budget of 192.6 million USD for road and border crossings projects and building the capacity of institutions in the sector. (Palestinian Authority, 1999)

Finally, a study was prepared by the World Bank on the transportation sector in the West Bank and Gaza in 2000. The study formulated a strategy aiming to respond to the various development challenges facing the sector. It highlighted the need to establish a sound institutional framework; maintain the existing poor road network; develop border crossings; and develop road, air, and sea transportation systems. The study identified the priorities and estimated the investment needs in the transportation sector at about 1.26 billion USD for the short-, medium- and long-term. Moreover, it identified a five-year public expenditure needs program, which had components with estimated costs reaching 664 million USD. Due to the start of the Intifada shortly after that, none of the projects included in the program were implemented. (The World Bank, 2000).

Based on the above, the developed plans prepared years ago have not materialized, where developments on the ground after their preparation prevented them from being implemented. The need, therefore, exists to revisit the issue of identifying the framework for development of the transportation sector for both alleviating the impacts of damages to this sector during the current political crises, and upgrading the sector to be able to perform its role towards the statehood stage. (Abu-Eisheh and Al-Sahili, 2006)

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2.6 Palestinian Transportation Sector and Road Network Analysis

A diagnostic study on the current status of the various transportation sub-sectors has been prepared. An assessment of such diagnostic study results in defining key transportation sectoral and sub-sector issues. Based on such, the sectoral developmental framework can be well defined. A number of general sectoral key issues, as well as some sub-sector issues, are presented here. These include the following: (Al-Sahili,and Abu-Eisheh, 2006)

- There have been several restrictions imposed on the movement of passengers and goods within the Palestinian territories and with the outside world through establishing permanent road blocks and enforcing closures of areas. These have been combined with Israeli demands for special permits to travel, and restrictions forbidding the Palestinians from using specific roads and transportation facilities. The impacts of these measures, which were intensified since the start of the Intifada, include limiting mobility and accessibility, increasing travel time and cost, and restricting the transportation of products and goods.
- There is a considerable damage to the various components of the transportation sector as a result of Israeli military actions, which has to be repaired or replaced. Damage resulted in segments of the national, regional, and urban roads; public and private transportation vehicles; facilities and equipment within the Gaza International Airport; and facilities and installations of the under-construction Gaza seaport.
- There is still no linkage or free passage between the West Bank and the Gaza Strip. This is a key national issue, where connecting the two physically separated parts of the Palestinian territories via a transportation corridor would lead to their integration, lead to a self-dependant transportation system, facilitate flow of people and goods, and enhance economic development of the Palestinian territories. The two major Palestinian gates to the outside world and markets, the airport and the seaport that are both located in the Gaza Strip, are not accessible to the Palestinians living in the West Bank.
- The inadequate road facilities, which restrict accessibility of a considerable portion of the population and limited accessibility to reliable public transportation services for considerable portions of population centers
- Coordination between the components of the transportation sector and inter-modal transportation is lagging. Furthermore, no proper road infrastructure is present within the Gaza Strip that connects the road network with the airport, the seaport, border crossings, and the planned free trade zones.

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- The poor structure and organization of public transportation. The privately operated bus companies lack proper management and coverage, and operate sometimes with losses. However, there is excess supply of the competing shared-taxis, which are commonly used as intra- and inter-urban public transportation means. The flow of goods through border crossings or through Israel is controlled by the Israeli authorities, causing additional travel and shipping costs and losses or damage of products due to lengthy and complicated inspection processes.
- There are political constraints, which retard the development of a sound and efficient transportation system. These include the territorial classification of Palestinian areas into different classes with various degrees of freedom to manage the transportation facilities for each class; the weak control of the PNA on the ground; the realities due to the construction of the separation wall around parts of the West Bank; implications of the economic relationships with and the reliance on Israel; and dealing with the Israeli bypass and settlement roads.
- Development activities in the transportation system have not been following a national transportation master plan. The inexistence of such plan has led to projects, which, in a number of cases, are not coordinated, or not in harmony with the prioritized national needs within the transportation sector.
- The institutional structure of the Palestinian ministries and other agencies involved in the transportation sector suffers from lack of clearly defined responsibilities and functions, lack of coordination, inefficient management structures, lack of regulatory framework, and limited experienced and well trained human resources. The lack of sufficient well-trained human resources who can efficiently participate in the developmental efforts, and the limited capacity of the contractors, consultants, as well as the public sector, could restrict their potential to deal with a relatively massive transportation development and construction program.
- Funding is a limiting factor for both the development of the transportation sector and the maintenance of the road network. Most funds came from international donors and were spent to finance rehabilitation and upgrading of roads, and very little was devoted for road development and construction of new roads. The allocated funds by the PNA for the transportation sector and for roads are very limited and are mostly directed towards maintenance of roads through the Ministry of Public Works and Housing. The transportation related taxes and fees are not directed towards financing transportation projects. (Al-Sahili,and Abu-Eisheh, 2006)

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2.7 Palestinian Transportation Development Strategies

Under the Ottoman rule on Palestine, transport networks developed in the 19th century from primitive roads and lanes to paved roads. The first of these was the Jaffa-Jerusalem road, which was constructed in 1867, and the Nablus-Ramallah-Jerusalem road in early 1900s. Later, roads connecting Palestinian cities, towns and villages were constructed. In 1978, the West Bank was separated from the Gaza Strip. Both areas had already been severed from the transport network in historic Palestine occupied in 1948. Additionally, Israel has constructed settler bypass roads. Roads throughout the Palestinian territory have not been built on economically-feasible grounds, nor did they take account of the shortest distances between residential areas. Therefore, road networks are weak and inefficient. After the Palestinian National Authority (PNA) was established, the transport sector witnessed major developments: existent road networks were improved and new networks and mechanisms were in place, including the Gaza International Airport and Gaza Port. However, Israeli arbitrary measures have obstructed further development of the sector. During the second Intifada, for example, the Israeli forces causes immeasurable losses to the Palestinian economy. (Palestinian National Plan, PNA, 2011)

To meet needs of the transport sector, the Government will provide necessary facilities and infrastructure to secure access to public transport services as well as develop transport-related policies and strategies to guide the sector development process. The Government itself may not necessarily provide, manage and operate transportation installations, infrastructure or equipment. However, the Government should provide the means, through which such facilities and installations are made available. To create and operate transportation facilities and infrastructure is not an end, but a means towards more general and comprehensive purposes. These are a mixture of political, economic, security and social goals. Implementation and maintenance of transportation facilities and infrastructure will results in economic “goods”, which contribute to benefiting the Palestinian society as a whole. (Palestinian National Plan, PNA, 2011)

The main interventions needed in the public transportation sub-sector include the preparation and implementation of strategies to maximize the efficiency and coverage

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of provided services, and supporting the operators of public transportation. The proposed development program for this system includes (Abu-Eisheh and Al-Sahili, 2006):

- Establishing development strategies and the necessary policies to enhance public transportation through changes in the composition and structure of the passenger transportation industry, operating practices, and legislation in order to arrive at efficient, reliable, and affordable public transportation system.
- Initiating detailed studies by the MoT and municipalities on coverage, routes, and the traffic carried in order to arrive at sound public transport plans and services.
- Provision of financial and technical support to the operators of public transportation, as this is one of the priority areas in the sub-sector, due to economic hardships which already facing the sub-sector, in order to maintain the existence, improve, and expand the provided services. Furthermore, technical support is needed to help the public transportation operators perform soundly and up to standards.

Also a part of the Arab and international networks, Palestine houses a safe, developed transportation network that connects all governorates. It contributes to enhancing the quality of life, provides a solid basis for sustainable human development, and constitutes part of the infrastructure of the State of Palestine, which is founded on the rule of law, political pluralism, social justice, and respect of human rights. Accordingly, the mission of the Ministry of Transport (MoT) is to develop a distinctive transport sector, which provides necessary services to regulate a high-quality transport industry in order to contribute to developing and sustaining the Palestinian economy. MoT’s mission will be materialised by developing and improving the transport sector service delivery, protecting the environment, enhancing public safety, enacting and upgrading respective legislation, and promoting private sector investment, cooperation and coordination with all relevant local and international actors, thereby realising national goals and promoting the competitive capability of Palestine’s economy. (Palestinian National Plan, PNA, 2011)

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2.8 Previous Relevant Studies

The Road network in the Gaza Strip is considered as the main foundation of infrastructure. It is the only way for people, light and heavy goods carriers. Roads network should be developed, improved and continuously maintained to provide safe and secure driving environment for the rabid increase of driving population. (Lubbad, 2013).

Few studies tried to investigate the possible solution of such a crisis research. (El-Turkmani et al, 2003) suggested that a railway track in the Gaza Strip would be a possible solution. (Lubbad, 2013) Sat the road networks of the Gaza Strip as a case study, Divided the road networks into groups, Collected the roads representative Data, Surveyed the road information such as: Road widths, number of lanes and counting location for the representative roads were collected, Surveyed information on vehicles such as: number of vehicles, number of axles and weight of axle were collected. That will be very useful as a database for this research. A preliminary study was undertaken for a possible track for a metro project in the Gaza Strip by (Jendia and Hussein, 2011).

According to European Rail Research Advisory Council (2002), the metro market has a high growth potential ahead. It also has a great impact on the local economy. (ERRAC, 2002). Although the primary goal of any transit system investment is improved mobility, the economic and fiscal impact on a region is of equal importance in deciding whether to make a transit investment. The construction, operation and maintenance of a transit system create jobs, spending and tax revenues. New transportation infrastructure typically leads to new development and redevelopment activity, introducing shifts in development patterns and governmental service costs. Generally, travel time, air quality, business transportation costs and quality of life are positively affected. Regional competitiveness improves, thus affecting the location decisions of individuals and businesses (The Adams Group and Development Research Partners, 2004)

In the Gaza Strip, where the growth rate of population is about 3.2%, an activation of public transport is considered a must, knowing that the rate of

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infrastructure developing activities is very low due to the bad and unstable economic and political situations. (Alokshiya, 2013)

Public Transportation is part of the Palestinian transportation network and plays an important role in the society by transporting large number of people to jobs, schools, and community activities. Public transportation assists in reducing congestion and in protecting the environment on local roads through shifting people to use high occupancy vehicles. (Elsobeihi, 2012)

According to Al-Yazori (2013), the Gaza Strip suffers from continuous increase in the population as well as the number of taxies. The majority of the Gaza Strip citizens use taxi in their movement. Relying completely on taxi and neglecting the availability of public transport could lead to more traffic congestion and negative impacts on the environment in the future. Al-Yazori, in his thesis for proposing a "Metro" route as a public transportation mode in Gaza City, examines the approval of the community of a metro network as a public transportation through a questionnaire. Random sample was selected and 96 questionnaire papers were distributed among the potential users of a metro facility in Gaza. The result was a full satisfaction by the community to select and use a "Metro" route as a public transportation mode in Gaza City. Finally, Al-Yazori recommended giving more attention to solve the current traffic problem, which may become worse tough the time. Al-Yazori also recommends to extend the metro network to include other areas in the Gaza Strip by connecting the metro network of the City with northern and southern governorates to solve traffic congestions in the future.

2.9 Railroad Transport in Palestine

The Hejaz railroad (Palestine’s section) was an Islamic Waqf property. Comprising a narrow gauge of 105 cm, the Hejaz railroad measured 1,400 km and ran from Damascus in Syria all the way to the Medina in Saudi Arabia. It branched off to connect countries of the Levant with one another. Started in 1900, the railroad was inaugurated in 1908. With the outbreak of World War I in 1916, the Hejaz railroad ceased operation after it was damaged during the fall of the Ottoman State. Constructed at the behest of the Ottoman Sultan Abdul Hamid II, the main purpose of the Hejaz Railroad was to

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establish a connection between Constantinople, the capital of the Ottoman State and the seat of the Islamic Caliphate, and Hejaz in Arabia, the site of the holiest shrines of Islam and the holy city of Mecca, which is the yearly pilgrimage destination of the Hajj. Another important reason was to facilitate the transportation of military forces in case of need. The track stretched from Turkey, to Syria, Palestine, Jordan, towards Saudi Arabia. As part of its effort to rehabilitate the Palestine-Hejaz track as well as add new lines, PNA developed economic feasibility studies and infrastructure assessment in order to implement a project to connect the Gaza Strip to neighbouring countries as well as to construct a light rail between Gaza and the West Bank. PNA also developed a master plan for construction of a railroad in the West Bank, to link historic cities to eastern slopes and Jordan Valley. The line will then cross bridges to the East Bank and connect to the railroad between Jordan and Saudi Arabia. However, the Israeli occupation obstructs implementation of these strategic projects. (Palestinian National Plan, PNA, 2011)

Transport situation in Palestine cities is rapidly deteriorating because of the increasing travel demand and inadequate transportation system. The Gaza Strip cities of all sizes are facing the crisis of urban transport. Despite investments in road infrastructure and plans for land-use and transport development, all face the problem of congestion traffic accidents and air pollution and the problems continue to grow. Large cities are facing an unprecedented growth of personal vehicles and in medium and small cities different forms of intermediate public transport provided by informal sector are struggling to meet the mobility demands of city resident.

This study tries to address a wide range of issues associated with the development of a metro system reaching to a recommendation whether the Metro system seems a feasible trends to enhance the development of transport in the Gaza Strip and proving the best practice of establishing and running these national facility.

Accordingly, Metro Networks could be a good trend for all of these challenges. The following chapter discusses the metro systems, requirements, characteristics, and benefits.

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Chapter (3)

Metro Systems

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3.1 Introduction

This chapter analyses methodologies and arguments used for planning metro networks world-wide. It also presents typical metro systems in terms of capacity, travel time, accessibility to the system, design requirements, and evaluation indices reflecting commuter's perspective. It explains short, medium, and long term parameters that should be while planning and designing for a metro network. The chapter came up with specific criteria that will be the objectives of planning the metro network in the Gaza Strip.

3.2 Metro Systems Characteristics

Metro has to be understood along the Union Internationale des Transports Publics (UITP) or International Association of Public Transport definition, "a tracked, electrically driven local means of transport, which has an integral, continuous track bed of its own (large underground or elevated sections)." This results in a high degree of freedom for the choice of vehicle width and length, and thus a large carrying capacity (passengers per hour per direction – pass/h/dir.). Intervals between stations would be typically more than 1 km, and because the alignment does not have to follow existing streets, curve radii and section gradient can be more generously dimensioned and permits for an overall higher commercial speed. Metro systems can be implemented only in large cities where demand justifies the capital cost. (European Rail Research Advisory Council (ERRAC), 2002)

3.3 Typical Metro Systems

Metro systems have been introduced in many international cities (Madrid, Spain; London, Paris, New York, Washington, Singapore, Hong Kong). These systems have limited seating and several doors on each side of the carriage. This design allows a high capacity with a larger number of standing passengers and faster times for passengers to move in and out of the carriages, reducing station dwell times. These metro systems operate in higher density cities in inner metropolitan areas and rely on interchanges with suburban rail systems to serve commuters from further afield. Metro systems are typically introduced to cater for high volume, short distance passenger trips (Australian Department of Infrastructure, Planning, and Natural Resources, 2004).

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A metro system generally has the following characteristics:

- capacity to transport up to 20,000 people per hour;
- typical average operating speeds between 35 and 65 kilometers per hour depending on geometry and other design parameters
- exclusive rights of way and protected at-grade crossings with grade-separation preferred;
- a corridor width of 12 meters for track sections and 18 meters at stations;
- stations spaced at between 1 to 2 kilometers apart, the adjacent residential density or the location of employment and commercial and use; and
- a minimum radius of 50 meters with a maximum gradient of 6 to 8 percent.

The author has taken into consideration most of the aforementioned criteria when selecting the best site for metro routes and facilities in the Gaza Strip.

3.4 Metro System Performance Evaluation Criteria

More criteria should be taken into consideration while planning and designing metro facilities. Advani and Tiwari, (2005) explain such criteria in the following:

a) Influence zone

Public transport service has to meet the needs of commuters. This includes accessible stations, minimum affordable time loss at interchanges, safer and reliable services. Since 500 m. is an ideal walking distance, population residing along the metro within walking distance has the highest accessibility to metro.

Limit of access to metro is based on the assumption of most comfortable walking distance as 0.5 km. When this distance increases passengers have to use feeder system, which requires a transfer. A transfer has major impact on passenger journey. Generally simple long trip is preferred over short journeys involving transfers because each transfer implies added impedance in terms of time, cost, inconvenience and uncertainty. Transfer requires a good coordinated scheduling of feeder and main service, combined ticketing and waiting time. A journey made without any transfer and a journey with one or more transfers always plays an important role in modal choice. To compare bus and metro as a transit service, both are considered without any transfers and in that case influence zone is the area within the distance of 0.5 km (walking distance) is taken.

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b) Feeder service and an integrated ticket

If a very good, coordinated, well-organized feeder system is provided to the Metro, accessibility of metro will increase. It is important to plan for an integrated ticket. If the integration works out, the same ticket will be valid in metro trains as well as buses. However, this will translate to higher rider-ship only if commuters are willing to accept the added transfer time and transfer costs.

c) Luggage

Many passengers coming and going through railway station and bus terminal have a luggage with them as it is connected to long distance travel. Metro is not available to them.

d) Parking

Parking place outside the Metro station has been provided but non-metro user can also use it. To encourage people to use Metro there should be a separate parking place for the monthly pass holders.

e) Flexibility

In any case if demand of route pattern changes it is very difficult to change the Metro route accordingly. But in case of bus, it is very easy to change the route in a short time and at low cost.

f) Convenience to reach stop/station

Generally people living within walking distance of metro stations or bus stops can reach the system conveniently. This requires high-density residential areas near the metro stations.

g) Speed

Metro has stops at average distance of 1.0 km and average distance between bus stops is 500 m. Because of more stops, buses run at lower speed. If distance between bus stops is increased and a separate lane is provided to run the buses, speed of buses also can go up. If metro has to stop at every 500 m, average speed of metro will go down. . (Advani and Tiwari, 2005).

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Table (3.1) analyzes the metro performance. Metro officials have often used these statements for justifying and highlighting the benefits of metro system. Therefore it is important to analyze these statements. The analysis questions the basis of benefit assessment methodology for metro.

Table (3.1): Metro Performance Evaluation

(Advani and Tiwari, 2005)

1.	**Metro will carry the same amount of traffic as nine lanes of buses.**		
	1 bus carries 80 passengers, 9 buses carries 9*80 = 720passengers	1 metro has 8 bogey, each bogey carries approximately 100 passengers = 800	This is static capacity comparison. This does not provide any useful information for comparing the corridor capacity, which is most crucial for public transport system.
2.	**It reduces journey time by 50 to 75%.** It is not clear that time is reduced by 50 to 75% is the journey time of buses or journey time of passengers shifted from buses to metro.		
a)	Journey time of buses	As buses have to stop at every 500 m after a certain limit it is not possible to increase its speed.	
b)	Journey time of passengers shifted from buses to Metro	It needs a total trip profile comparison. If metro stops are given every 500 m, average speed of metro will remain between 15-20 km/h.	
Bus passengers will use feeder bus to reach Metro and if they don't that means they are living close to Metro station. Therefore very few passengers will shift from bus to Metro. Two wheeler users can shift to Metro, if two wheeler owners are living near metro corridor. However, if they are living away (at distance more than 500 m) then question is why they were not using bus earlier. What will attract them to use metro?			
3.	**Average Speed of buses will increase from 10.5 km/h to 14 km/h**		
	Journey speed of bus is dependent on frequency and distance between bus stops and junctions. Speed improvement can come from rationalization of bus stops and junctions.	If the bus has to stop many times, average speed will go down. Speed may not get affected due to the number of passengers on the bus stop. If only a single person is boarding/alighting speed of bus has to decelerate. New system can be implemented to increase the speed by introducing separate lane for buses and by stopping buses at alternate bus stops only. 1 2 3 4 5 This will increase the distance between two bus stops and therefore will increase the speed. Route 620A: 1…3…5 Route 620B: 2…4…6	
4.	**2400 less buses on the roads…!!**		
	Bose (1998) shows that Vehicle projection and composition (%) for Delhi for 2011 is, 2-wh 3-wh car/jeep taxi bus total 56.21 3.46 38.47 0.51 1.35 2786016 Forecasted no. of buses in 2011 is 37611. 2400 buses of that mean only 6.38%. This indicates that even 2400 less buses on the roads makes only marginal difference.		
5.	**Less bus will be on the roads so less congested roads will be.**		

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3.5 Proposed Long Term Strategies for Corridor Planning

The strategies and actions needed to ensure that the corridor can meet the long term performance. These strategies include developing capital projects that will address significant capacity deficiencies and/or bottlenecks, other less-costly improvements that address specific safety and/or operational issues and policy-type directives that proactively promote development of the corridor vision through local ordinances and access guidelines. These strategies are shown in Figure (3.1) below.

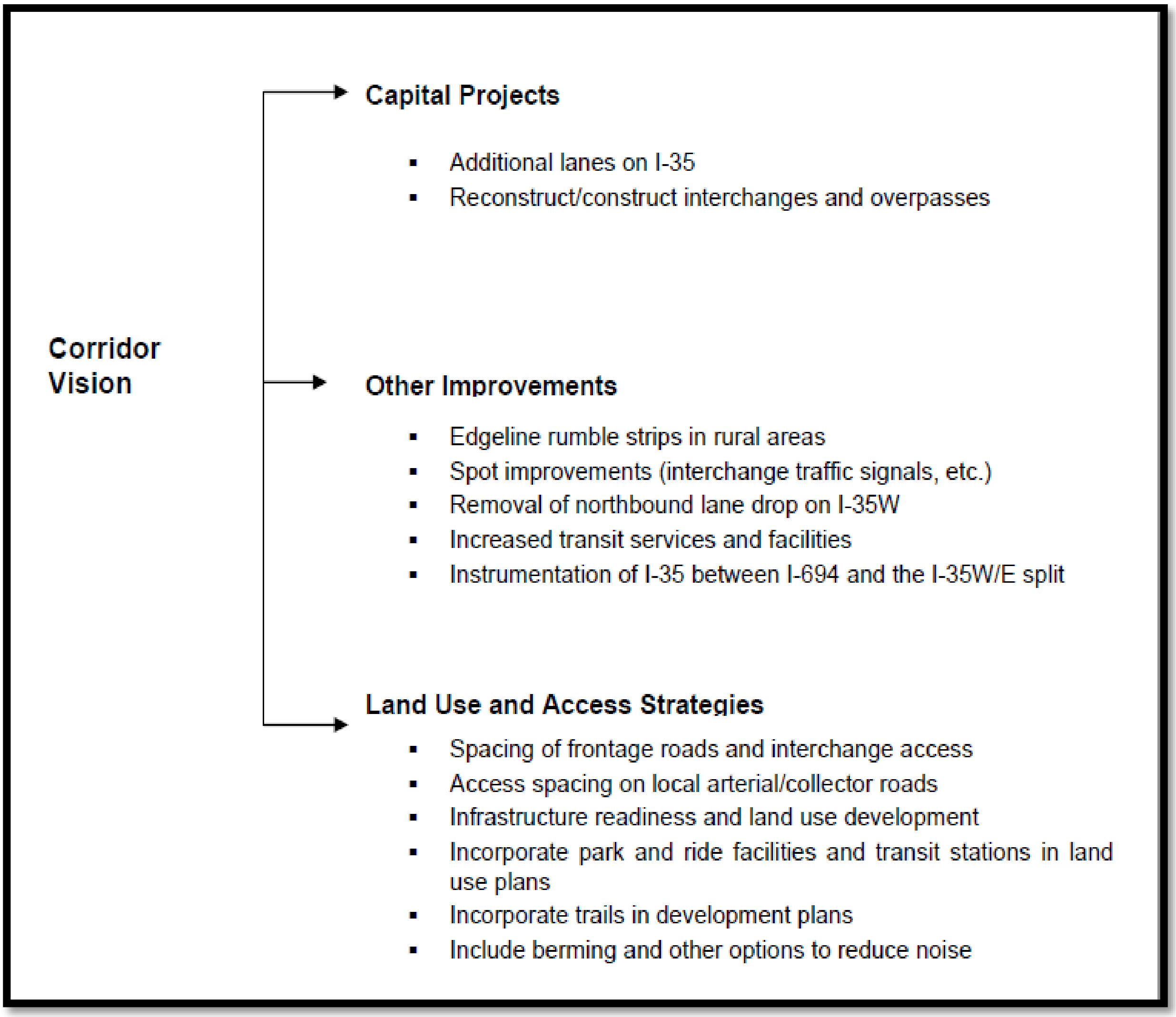

Figure (3.1): Strategies for Corridor Long Term Performance

Source: (Minnesota Department of Transportation, 2011)

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3.6 Europe-wide Overview of Metro Systems

Within Europe, there are 45 metro systems: 35 (78%) can be found within the current European Union (EU), 5 (11%) within the new member states joining the EU and 5 (11%) within the countries beyond the. This can be shown in Figures (3.2) and (3.3). (UITP and ERRAC, 2009)

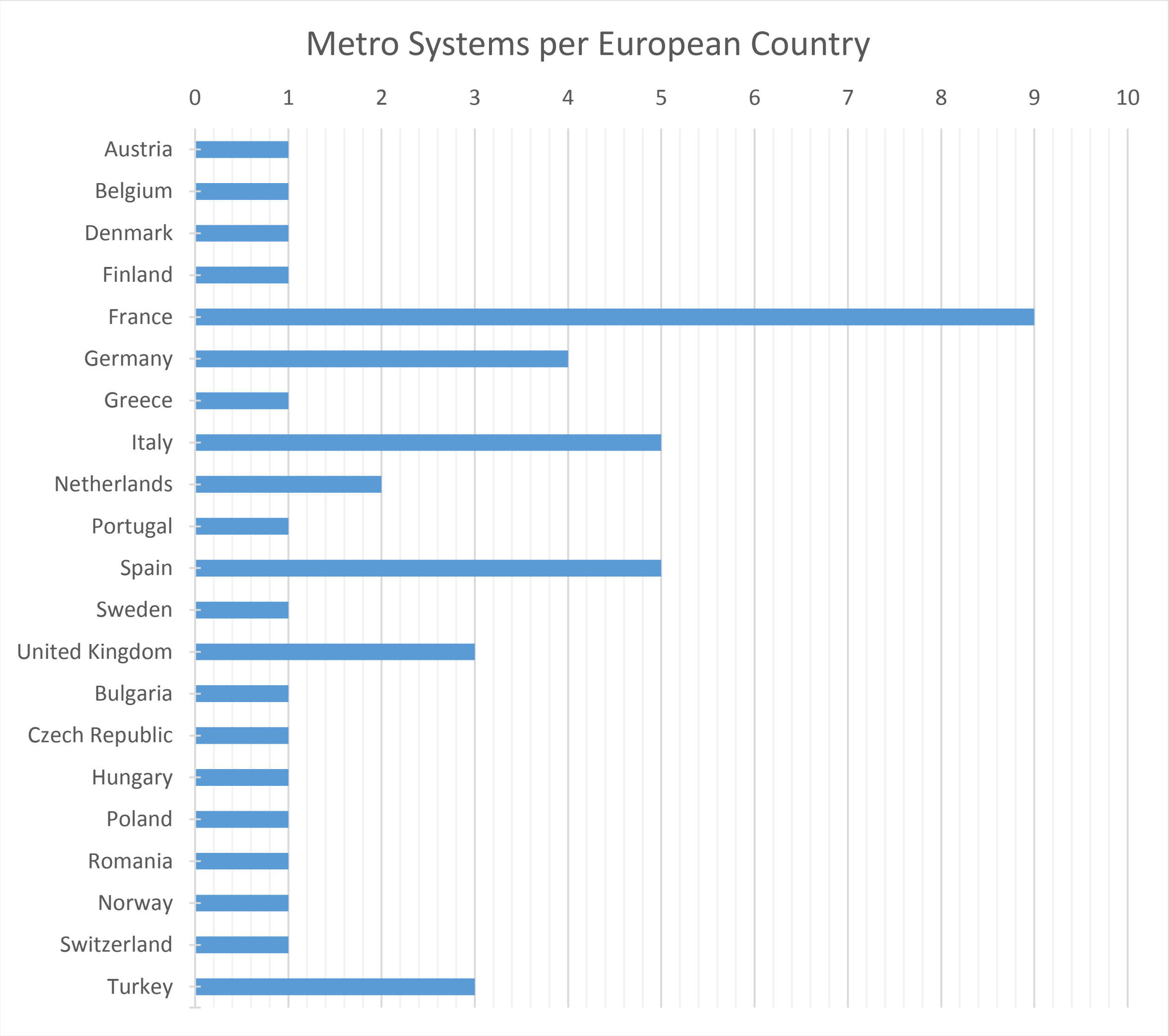

Figure (3.2): Metro Systems per European Country
(UITP and ERRAC, 2009)

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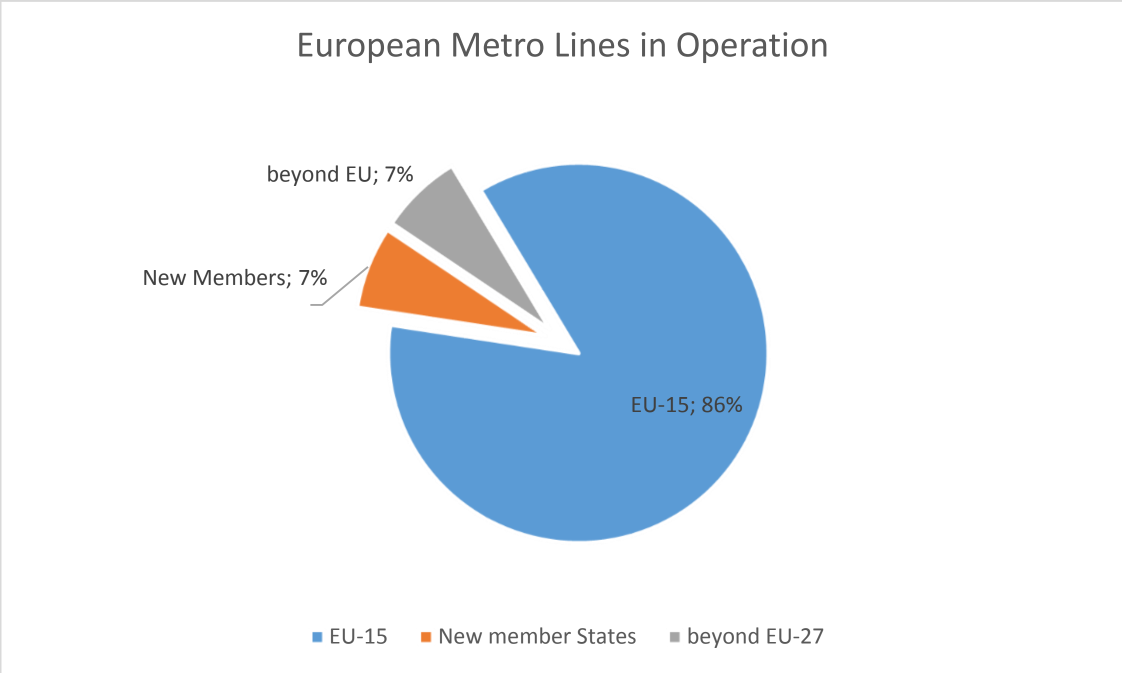

Figure (3.3): Metro Lines per European Country
(UITP and ERRAC, 2009)

3.7 Metro System Prospective

Metro systems require, therefore, heavier investment than light rail, and can be implemented only in large cities where demand justifies the capital cost.

A rolling Stock can be defined as a collective term for the track, signals, stations, other buildings, electric wires, etc., necessary to operate a railway.

According to European Rail Research Advisory Council (ERRAC) (2002), The metro market has a high growth potential ahead, especially for rolling stock. In terms of infrastructure expressed in track*km, and still rather substantial with a 21% increase (135 km in construction and 503 km in planning). If we assume average construction cost of 150 million EUR/km (without rolling stock), the monetary evaluation of the market is in the range of EUR95 billion over the next 20 years (20 billion for lines in construction and 75 billion for planned lines). These figures do not include expenditures on infrastructure refurbishment and line automation. Automation of conventional lines is a major research area. On the infrastructure side, it can be estimated that research into

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civil engineering activities is rather moderate and could range between 1 and 2 %, i.e. between EUR950 and EUR1900 million.

As far as rolling stock is concerned, the forecast both for the replacement and the new markets is assessed at around 14,000 units (cars) for the period 2000-2020. If we take an average cost hypotheses of EUR1.5 million/car (average between motorized car and trailer), we find a turnover of about EUR 21 billion. R&D expenditures dedicated to rolling stock can be estimated at 1.5% of this value (EUR315 million) and should be increased to 3% (as encouraged by the European Commission). It is thought that this increase in R&D to EUR630 million could generate return on investment between EUR1.05 and EUR2.1 billion through a decrease in cost between 5 and 10%. (ERRAC, 2002)

3.8 Alternative Medium Capacity Mode

Corridor Public Transport Use Assessment Report specified the medium capacity modes are considered as either a light rail transit system or a bus based transit system. They are highly flexible modes and can be integrated with surrounding environments to provide for medium volume short passenger trips. Medium capacity modes bridge the gap between heavy rail and local bus services. (Australian Department of Infrastructure, Planning, and Natural Resources, 2004).
A medium capacity mode generally has the following characteristics:

- capacity for up to some 20,000 passengers per hour;
- typical operating speeds between 30 to 60 kilometres per hour;
- priority or shared environments;
- corridor width of 12 metres for track sections and 14 to 22 metres at stations;
- stations spaced at between 800 metres and 2 kilometres apart, depending on land uses;
- light rail systems have an absolute minimum radius of 25 metres and 300 metres at platforms with an absolute maximum gradient of 6 to 8 percent;
- bus based systems have an absolute minimum radius of 10 metres with a maximum gradient of 8 to 15 percent; and
- low floor vehicles allowing for high quality accessible stations.

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3.9 Optimized Metro Network Planning Parameters

Thus, planning process for a metro network includes three parameters: short term parameters, long term parameters, and the service efficiency level. These parameters are shown in the Figure (3.4).

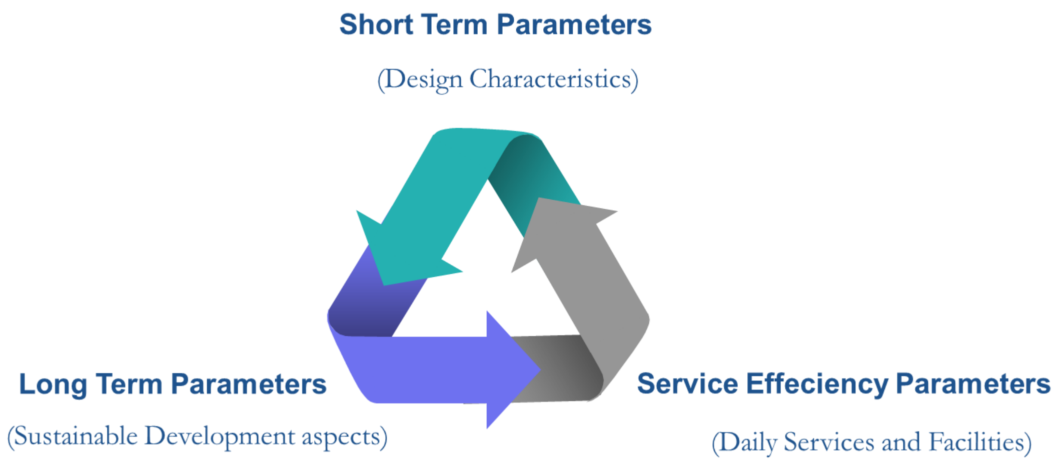

Figure (3.4): Metro Network Planning Parameters

- Short Term Parameters: these parameters should include design characteristics such as: typical operating speeds, corridor width, stations locations and facilitates, adjacency, and gradient.
- Long Term Parameters: where metro network should satisfies the sustainable development aspects such as economic, social, and environmental components of the design.
- Service Efficiency Parameters: a metro network planning and designing process should serve the influence zone, feeder service, integration with existing public transport, parking, and flexibility.

These parameters should be met as an objective for the planning the designing process of a metro network.

Taking into consideration all the criteria that have been explained and mentioned in this chapter and applicable or relevant for the Gaza Strip context, the following chapter explains the most useful tools and approaches for multi criteria analysis for selecting the corridor and metro facilities.

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Chapter (4)

Route and Site Selection of Metro Networks

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4.1 Introduction

After studying metro network requirements, planning processes, and approaches; this chapter describes adopted approaches for an optimal selection process for metro facilities according to what has been studied and summarized from previous chapters. This includes tools, multi criteria analysis, ideal cases, and principles in order to reach the most optimized route and stations for a metro facility.

4.2 Background

Building a new urban transportation facility is a major, long-term investment for owners and investors. Route/site selection of such a capital project (e.g. a corridor rapid transit project like a metro-rail system) is considered a crucial action made by owners/investors that significantly affects their profit and loss. Decisions related to the locations of the facilities (e.g. metro-rail routes, stations, depots, etc.) influence economies of the metropolitan area and strongly impact on the lifestyle of the whole residential community.

Any public transportation infrastructure development project should begin with the recognition of an existing or projected need to meet the present and the growing demand in the future. This problem triggers the series of actions starting with searching out and screening of geographic areas and specific locations. Routes/sites that satisfy the screening criteria are subjected to detailed evaluation. (Farkas, 2009)

According to Eldrandaly, Eldin, and Sui (2003), the screening criteria include multiple measures, such as engineering, economic, institutional, social, and environmental factors. The goal in a route/site selection project is to find the best location with desired conditions that satisfy predetermined selection criteria. Route/site selection typically involves two main phases: (i) site screening (i.e., identification of a small number of candidate sites from a broad geographic area and a range of selection factors) and (ii) site evaluation (i.e., in-depth examination of each candidate site to find the most suitable one). The selection process attempts to optimize a number of objectives in determining the suitability of a particular route/site for a defined transit facility. Such optimization often involves a multitude of factors, sometime

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contradicting. Some of the important factors that add to the difficulty of the proper choice include the existence of numerous possible options within a sought territory, multiple objectives, intangible objectives, diversity of interest groups, lack of quantitative measures of the factors' impact, uncertainties regarding impact timing and magnitude, uncertainties regarding government influence on the selection process through legislations, uncertainties regarding possible delays of permitting and construction (Keeney,1980).

According to El-Yazouri (2013), There are several basic principles and definitions should identify them to know the nature of the spatial analysis of data using GIS based on multi criteria decision analysis (MCDA). Criteria: are set of guidelines or requirements used as basis for a decision (a choice between alternatives).

There are two types of criteria: (Estoque, 2011)

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration (i.e. distance to road (near = most suitable; far = least suitable).

A constraint serves to limit the alternatives under consideration; element or feature that represents limitations or restrictions; area that is not preferred in any way or considered unsuitable (i.e. protected area, water body, etc).

4.3 GIS as a tool for Multi-Criteria Decision Making methods

Geographic Information Systems (GIS), Multi-Criteria Decision Making methods (MCDM), and Expert Systems (ES) have extensively been used in solving site selection problems for the last two decades. However, each of these techniques has its own limitations in addressing spatial data, which is indispensable when one is dealing with spatial decision problems such as a route or a site selection problem. For example, the traditional MCDM techniques have been non-spatial. However, in a real life situation it can hardly be assumed that the entire study area is spatially homogenous, because the evaluation criteria used to vary across space. A modified approach has kept spreading in practice, in which the three tools are combined as is seen in Figure (4.1) in a manner so that the shortcoming of one tool is complemented by the strength of another. An ES is used to assist the decision makers in determine values for the screening criteria of the

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site screening phase, building the decision model and assigning weights to the attributes used as evaluation criteria for the site evaluation phase. A GIS system is utilized to perform the spatial analysis required in the screening phase of candidate sites. A MCDM procedure is used for the evaluations, usually the Analytic Hierarchy Process (AHP) method, to identify the most suitable site in the second phase (Farkas, 2009).

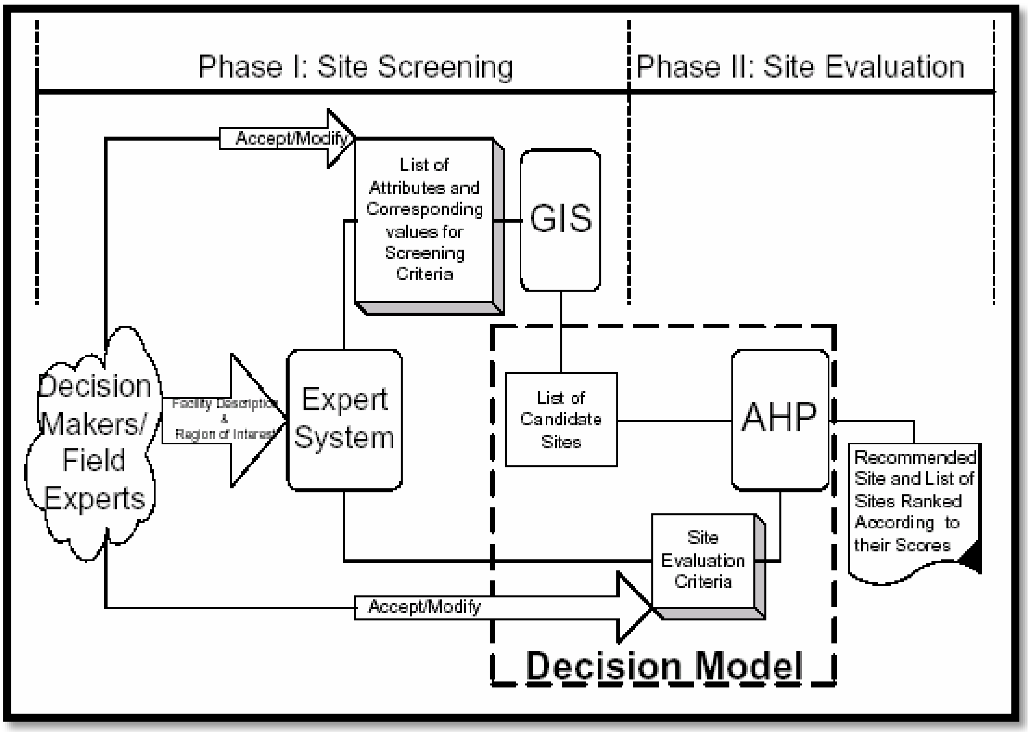

Figure (4.1): Framework for Site Screening and Evaluation
(Eldrandaly, Eldin, and Sui (2003), p.76)

4.4 GIS and Spatial Multi- Criteria Evaluation

Recent advances in geo-information technology through various remote sensing techniques has offered appropriate technology for data collection from the earth's surface, information extraction, data management, and visualization, however, it lacks well-developed, analytic capabilities to support decision-making processes. Spatial Multiple Criteria Evaluation (SMCE) is based on multiple attribute decision analysis techniques and combines multi-criteria evaluation methods and spatio-temporal analysis performed in a GIS environment. (Sharifi, Boerboom, and Shamsudin, 2006).

According to Farkas (2009), The performance assessment of an option in one or more criteria at a point in time can be described by a defined set of maps. Therefore,

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the spatial decision problem can be visualized as a two or three dimensional table of maps, or map of tables which has to be transformed into one final ranking of alternatives.

In the SMCE, the decision alternatives are the pixels (basic units for which information is explicitly recorded) or polygons in the maps. (Sharifi, Boerboom, and Shamsudin, 2004, p. 2).

Thus, Spatial Multi- Criteria Decision Analysis (SMCA) is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences and the manipulation of data and preferences according to specified decision rules. For ranking of the alternatives, the evaluation table of maps has to be transformed into one final ranking of alternatives. The ranking of the alternatives could be different, since the decision makers, i.e. the groups of stakeholders, may have conflicting interests as they represent dissimilar perspectives (Farkas, 2009).

According to Keeney (1992), two major approaches can be distinguished in MCDM: (i) the alternative-focused and (ii) the value-focused approach. The alternative- focused approach starts with development of alternative options, specification of values and criteria, then, it follows the evaluation and recommendation of an option. The value-focused approach considers the values as the fundamental component in decision analysis. Therefore, first, it concentrates on the specification of values (value structure), then, it develops the values feasible options and evaluates them with respect to the predefined value and criteria structure. This implies that the decision alternatives should be generated in a way that values specified for a decision situation are best met. Hence, the order of thinking is focused on what is desired, rather than the evaluation.

In the context of route/site selection of urban transportation facilities the value-focused approach has many advantages over the other (Sharifi and Retsios, 2004). To implement this, for an urban transportation project like a metro-rail system is, a top-down decision analysis process is proposed to define the goal, the objectives and their related indicators for the facilities. This hierarchical decision tree model is presented in Figure (4.2). In the decision making phase, a consulting team, technical committee

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members, designers, investors, local authority officials and public representatives are involved as the basis for development and evaluation of the project. The various elements of this criteria structure are briefly described as follows (Farkas, 2009):

Goal and Objectives: The goal of this framework is to identify an effective public mass transportation system for a metropolitan area integrated with an efficient land use so that it meets the present and long-term socio-economic and environmental requirements of the residents of the marked territory. This goal can be achieved if the following objectives are met:

Economic Objective: Economic objective seeks to maximize feasible economic return on investment from the system. A number of criterion is used to measure how well an option performs on each indicator, e.g., benefit/cost ratio, first year return, internal rate of return, net present value, construction cost and operation cost, as well as minimizing land/real estate acquisition (expropriation of property), intensification of existing land use and maximizing the potential of the location.

Engineering Objective: This objective looks at three main concerns that are the efficiency of the system, the construction issues and the effective use of the network for work and non-work travels. The criteria used to measure the extent to which such achievements are met by the transit route or facility options are the following:

- Efficiency is measured by examining the minimum number of transfer, (whereby an alternative with excessive transfer will score low for this criteria) A transit option which contributes to a reduction in travel time compared to time spent on the roads and provides a close-to-optimal convenience for pedestrian access and links to other local and commuter transportation modes, and, also an effective connection of housing jobs, retail centers, recreation areas is beneficial and will score high.
- From the construction perspective, alternatives that have rail routes passing through high demand areas like high-density built-up areas, commercial, industrial and institutional areas, will score high for this criterion. This aspect, however, particularly when it is accompanied by poor geological conditions at a route/site option, conflicts with a low construction cost requirement. To build metro-line stations, the commonly used construction modes are: open-cast construction (just below grade, building pit is beveled or secured by walls, requires large construction areas, more flexibility in design); bored-piled and cover-slab construction with or without inner shell (bored-piled wall, generates column free space, reduces surface interruption);

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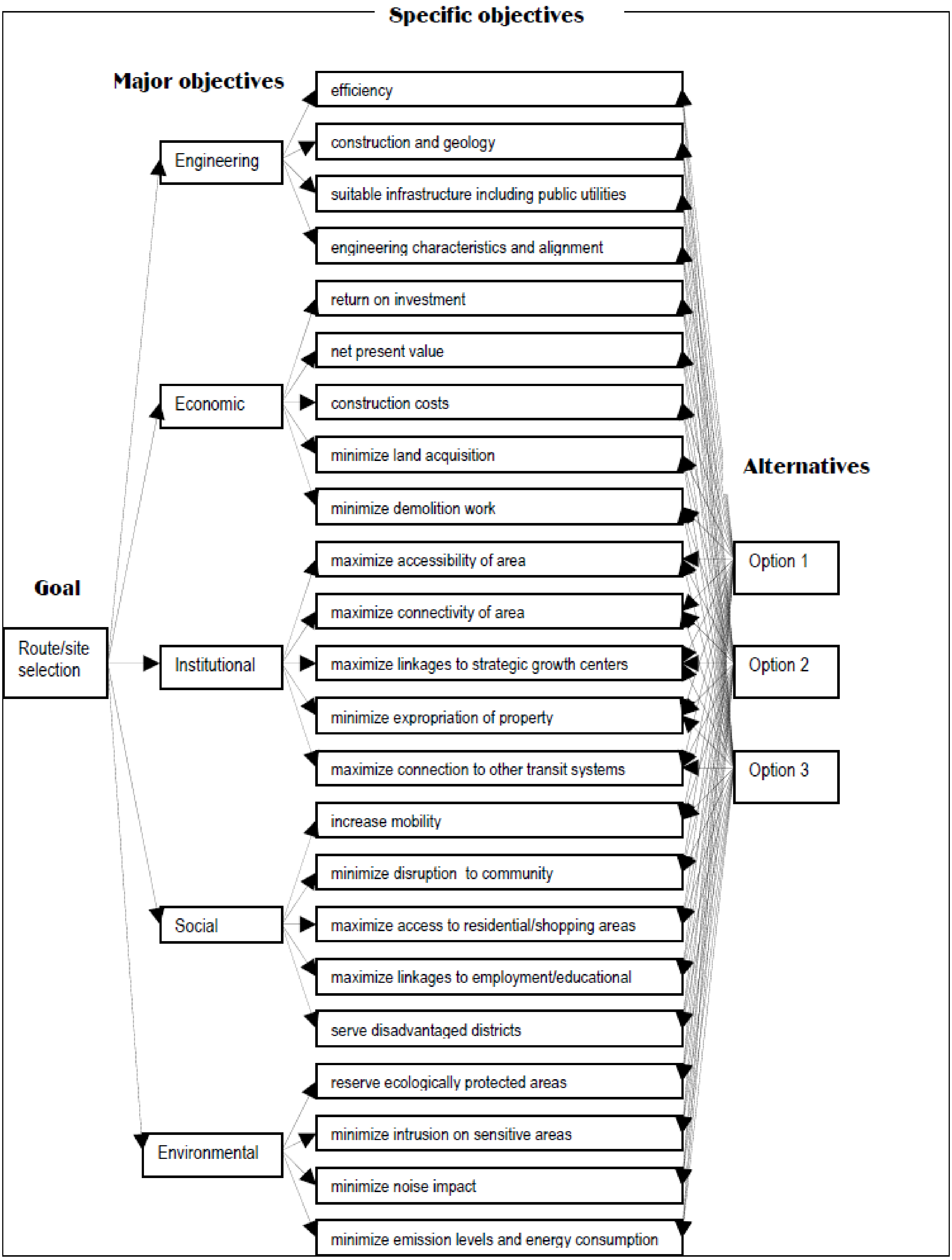

Figure (4.2): Hierarchy of Goals, Objectives, Criteria and Indicators
Source: Farkas (2009)

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- Engineering characteristics and alignment are evaluated with respect to the measures/attributes constituting the geological environment (including soil mechanics, intrusive rock structure, stratification, etc.); hydro-geological conditions (including underground water-level, chances of inrush, perviousness, locations of permeable or impermeable layers, chemical and physical characteristics of underground water and their effects on the built-in architectural structures) and geotechnics (rock boundaries, response surfaces, geographic configuration). Special focus should be given to safety. Therefore, the recognition and control of risk factors are of utmost importance (water intrusion, gas explosion, earth quake).
- Infrastructure involves the careful examination/analysis of over-ground building-up, the suitability of the existing public utility network capability and the required overground organization to be made before the construction works are started.

Institutional Objective: This objective measures the match between the transit system and spatial policies of the government/urban municipality, e.g. to maximize interconnectivity to existing public transport systems; to maximize linkages to strategic growth centers, to provide good linkages among urban centers and suburban railway networks, airports, long-distance bus stations, park and ride lots as well as to minimize land acquisition.

Social Objective: Establishment of a transit system should increase social mobility by way of easy access to existing and future settlements. This can be measured by forecasting the passenger/km reduction for residential to employment areas, and residential to educational institutions. Based on plans and ideas of future settlements, employment and educational institutions, efficiency of the land use objective should be achieved by maximizing access between residential areas and shopping, service and recreational centers. Such systems would serve highly populated areas and particularly disadvantaged areas (low cost settlements); would increase access to tourism attraction areas; and minimize disruption to neighborhood communities.

Environmental Objective: The designed transit project should minimize intrusion and damage to the environment. Protected areas must be excluded from the set of the potential options. The expected accomplishments are: a reduction in energy consumption, minimal emission levels, minimal intrusion into environmentally sensitive and reserved areas, minimal noise impact to sensitive land use (such as hospitals, residential buildings and schools) during site construction.

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Criteria and Indicators: To further support the design and evaluation of a metro- rail network, the major objectives are further broken down into specific objectives with their corresponding indicators (sub-criteria). These indicators are then used to measure the performance of each alternative route/site option on each objective.

A proper governmental/metropolitan council's transportation policy should comply with the criteria structure shown by Figure 4. In contrast to the conventional approaches of predetermining route/site alternatives and then assessing their impacts subsequently, this integrated GIS/MCDM approach utilizes an opposite strategy. Determine first the proper, but at least promising locations of such facilities (the sites of the metro stations), along which the appropriate route options can be defined (Farkas, 2009).

These objective are briefly shown in Figure (4.3) which are: Engineering, Economic, Institutional, Social, and Environmental objectives.

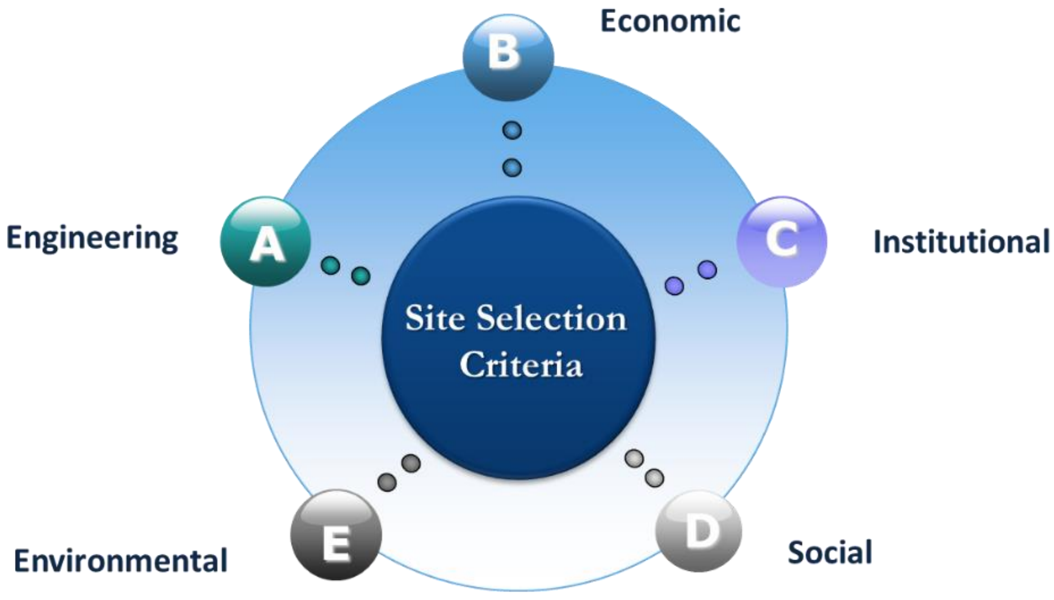

Figure (4.3): Metro Facilities Site Selection Criteria

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4.4.1 Metro Network Planning through GIS and Spatial Multi-Criteria Evaluation

This section presents an application of how a combined GIS-SMCE (as a Path 2 analysis) system can assist the design of alternative solutions for urban transit zone locations in a given metropolitan area. As is usual in many countries, spatially referenced data (with geometric positions and attribute data) are rarely available in a direct way

Spatial data includes field collected data and GIS datasets (which consist of data derived by remote sensing from satellite imagery and/or field measurements) Attribute data are partly based on actual measurements, but, for the most part, are elicited from judgments, and, thus, they are fictive. To display geographic data (spatial and attribute data) on screen or in a printout, digitized vector maps (point, segment and polygon maps) and raster maps are used in a conveniently chosen visual representation form. Each map should contain the same coordinate system and georeference. In a raster map, spatial data are organized in pixels (grid cells). Pixels in a raster map all have the same dimensions. A particular pixel is uniquely determined by its geographic coordinates expressed in Latitudes (parallels) and Longitudes (meridians). With the help of a map projection, geographic coordinates are then converted into a metric coordinate system, measuring the X and Y directions in meters. This way a very high degree of accuracy is reached (Farkas, 2009).

The geographic area of the planned metro-rail project (network system) is given by the polygon map. Block attributes are the geometric area in square meters; the prevailing land use type, i.e. residential (city blocks used primarily for housing), commercial (city blocks containing malls, supermarkets, shops, banks, hotels, etc.), institutional (such as schools, universities, hospitals, museums, governmental offices), industrial (buildings dedicated to industrial activities, storages), recreational (including protected areas, parks, sport fields), existing transport facilities (railway stations, bus stations, taxi services, public parking lots), airport, water (including lakes and rivers) and vacant (blocks that are not used for any urban activity); the codes of city districts; and population (number of persons living or using a city block).

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4.5 Summary

A considerable approach of selecting metro facilities using spatial analyses and evaluation techniques has been described in this chapter. This approach has been adopted and utilized in order to select the most optimize metro components in the Gaza Strip as explained in the following chapter in order to achieve the five objectives of selecting metro facilities that have been concluded from this chapter. These objectives are engineering, economic, institutional, social, and environmental parameters of the criteria in order to reach the best possible locations for the metro network.

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Chapter (5)

Planning and Designing
A Metro Network for the Gaza Strip

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5.1 Introduction

This chapter introduces the methodology adopted to solve the main problem, which is planning a metro system in the Gaza Strip. The planning process mainly involves identifying the optimal locations for the main components of the system, which are (1) Stations and (2) Routes. The locations of such components can be classified as the best ones, if they satisfy certain criteria such as engineering, environmental, and economical requirements. In other words, the location that reduces costs, has less impact on the environment, and can be used without any construction or engineering constraints is the favourable one.

It should be noted that the first-class components would be considered here. The secondary and local components will be left for other research works. Consequently, the researcher would suggest the potential metro line that links the north of the Gaza Strip with its south. This configuration is not randomly selected, but based on the analysis of future travel demand. For example, the eastern part is characterized by the agricultural and industrial regions which could be a source for attraction of many workers and employees currently and in the future. The western part is well known for tourist attraction. In addition, the operation of sea port of Gaza would attract more and more people.

Based on that, the main problem will be reduced to selecting the best locations for the two lines and the relevant stations. The selection would be based on engineering, environmental, and economical criteria. Since the problem we have has a spatial context, GIS Software and Techniques would be employed extensively in this research. ArcGIS Desktop 10.1 is selected for pre-processing and analysing the data spatially and non-spatially.

5.2 General Workflow

The general workflow adopted is outlined in. At the first step, it is crucial to state the problem precisely. The problem can be formulated as determining the best locations for the proposed metro lines and their stations. This step also involves breaking the main problem down into sub-problems so that it would be easier for handling it. At the second step, the data needed for solving the problem is identified

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and collected from different sources. The data is identified based on the criteria defining the optimal sites.

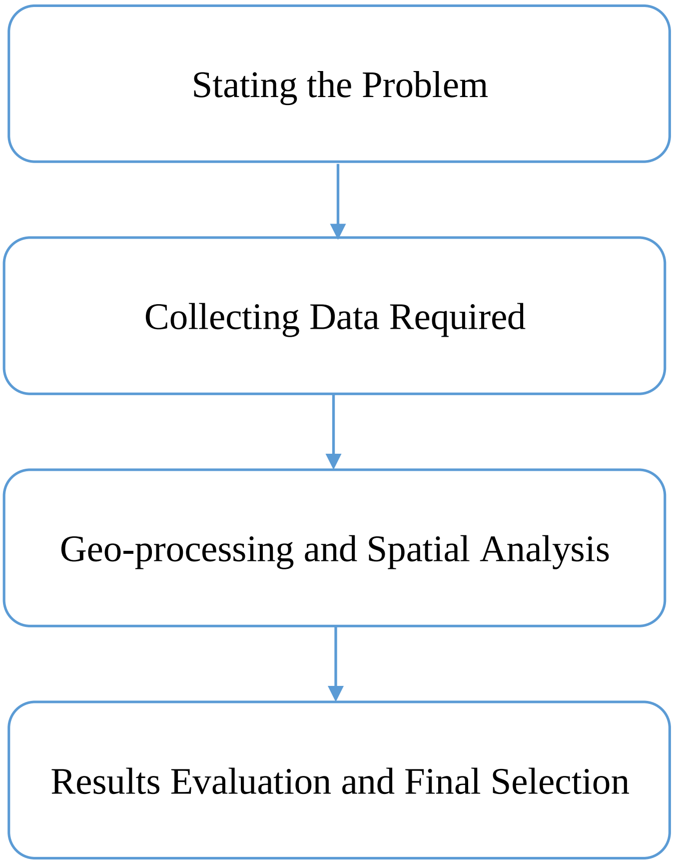

Figure (5.1): General Workflow of Designing the Metro Network in the Gaza Strip

The third step constitutes the core of this work because here the data is geo-processed and spatially analysed for making decisions regarding the best locations for metro lines. This step involves a series of geo-processes expressed as cartographic model. The Model Builder tool in ArcGIS is used for this purpose.

The fourth step includes the evaluation process of the results. If the results are not satisfactory, then the proposed methodology should be revised.

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5.2.1 Step1: Stating the Problem

The main problem is finding the best location for metro system components. That means we need to identify the optimal sites for stations and routes. That can be achieved by considering the criteria that satisfy the engineering, environmental, and economical requirements. Figure (5.2) shows the main problem and its sub-problems and criteria.

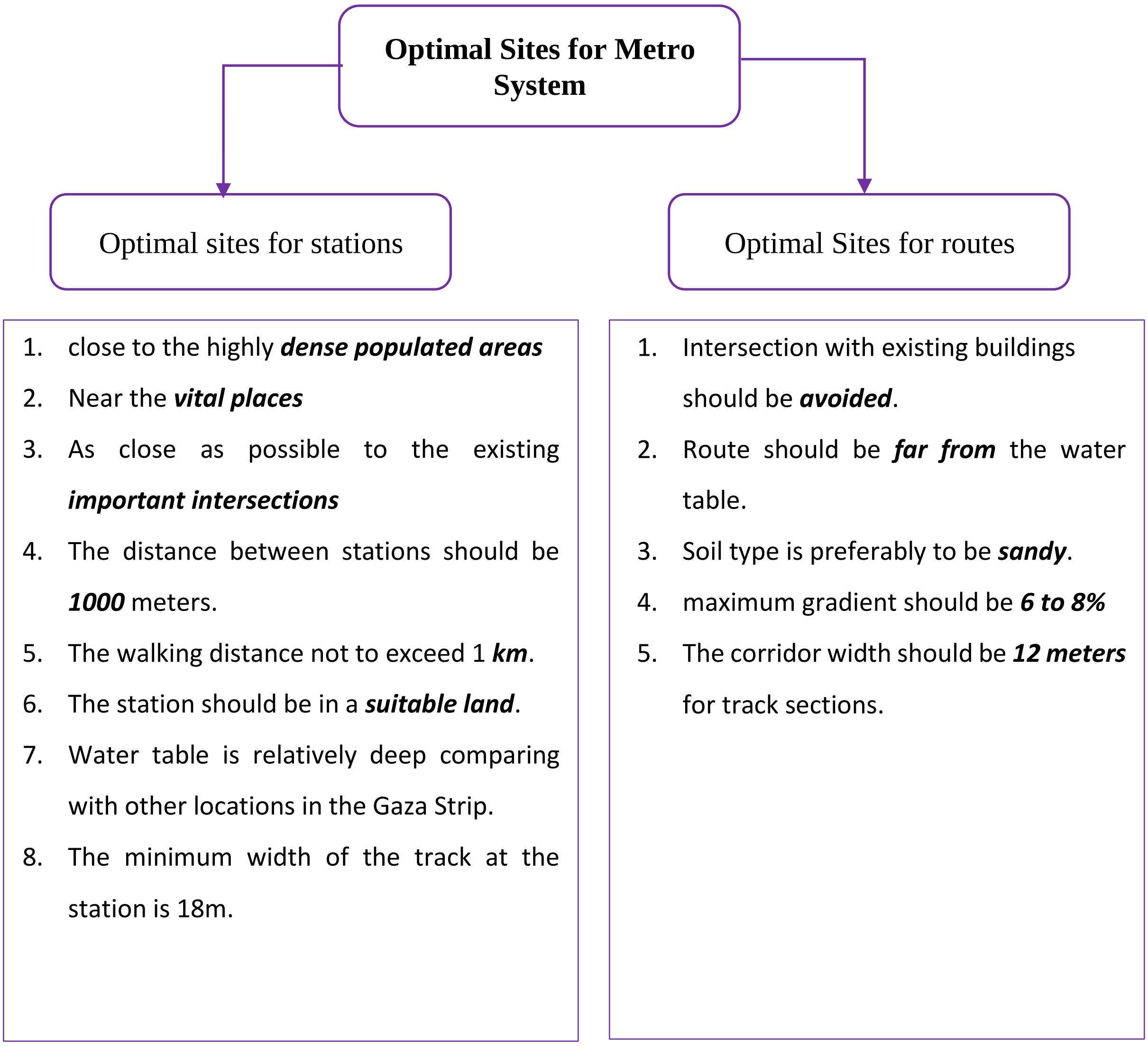

Figure (5.2): Optimal Sites for Metro System Facilities

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The optimal site for a station should satisfy the following criteria:

1. It should be in Close proximity to the highly dense populated areas
2. Near the vital places, such as universities, schools, shopping centres, etc. those places plays important role in trip generation and attractiveness.
3. It should be in Close proximity to the existing important intersections. The most important intersection is that one with the following characteristics:
    a. It has a high number of available parking
    b. It has a large space.
    c. It has high traffic volume.
4. The distance between stations should be 1 km apart
5. The walking distance travelled by pedestrians to any proposed station should not exceed 0.5 km.
6. The station should be in a suitable land.
7. For construction and environmental considerations, the site should be selected where the water table level is deep.
8. The corridor width at the station should be at least 18m.

The aforementioned criteria is specified for intermediate stations, for end stations extra criteria is need such as:

1. Large area for parking and maintenance works.
2. Far away from the borders for security purposes.

The optimal site for a route is the one that keeps the cost at its least value. Therefore, it should satisfy the following criteria:

- Its intersection with existing buildings should be avoided as much as possible.
- The route should be far from the water table.
- The soil type is preferably to be sandy
- The slope should be as minimal as possible. The maximum gradient should be 6 to 8%
- The corridor width should be 12 meters for track sections.

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The aforementioned criteria are set based on literature review and some subject matter experts where several brain storming sessions and focal groups were held to choose suitable weights and scales for each criteria. Infrastructure experts, GIS professionals, and Ministry of Transport officials have also participated in the sessions that reached the weights, criteria, and scales used in this methodology.

It can be said that the main problem can now be decomposed into sub-problems. In other words, each criteria is considered as a problem on its own. Therefore, to solve the main problem, the sub-problems (criteria) should be solved individually, and then aggregated to reach the final objective.

5.2.2 Step2: Data Collection and pre-processing

The data is one of the main components of any problem solving process. Therefore, the required data should be first identified and collected from relevant sources. The data could be easily identified from the criteria mentioned in the previous section. When the data has a spatial context, they will be referred to as *layers*. The data needed is listed in Table (5.1).

Table (5.1): Data Required for Spatial Analysis

Criteria	Data required	Data model
1. Close to the highly dense areas	• Population density	• Table
2. Near the vital places	• Vital places (e.g. universities, Public facilities...).	• Vector layer: points
3. Close to the existing important intersections	• Important intersections and Parking places	• Vector layer: points • Vector layer: points
4. Walking distance not to exceed 0.5 km	• Existing road network	• Vector layer: polylines
5. station should be in a suitable land	• Land use	• Raster layer

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6. water table level should be deep	• Water table level	• Raster layer
7. The intersection of routes with existing buildings should be avoided.	• Existing buildings	• Vector layer: polygons
8. soil type is preferably to be sandy	• Soil types	• Raster
9. slope should be as minimal as possible	• Digital Elevation Model	• Raster

The required data were collected from local sources such as municipalities, relevant ministries, and GIS professionals. The collection process was one of the difficult tasks in this work. That was because of the lack of consistent and accurate data. Even if it was available, it would be difficult to get it due to the legal constraints.

Once the data was collected, the data was inspected and pre-processed to bring it into a suitable format for the next step, which is the analysis. The pre-processing includes converting all the data into suitable GIS formats. For example, some data has been collected as CAD files (e.g. Buildings) and Excel files (e.g. water table elevations). CAD and Excel files were converted into Environmental Systems Research Institute (ESRI) Geodatabase Feature Classes. Furthermore, all layers should have the same coordinate system, which is the Palestine 1923 Palestine Grid.

The following sections describes the collected data in more details.

5.2.2.1 The Gaza Strip Population

The Gaza Strip is one of the highest population density in the world. The population of the Gaza Strip has reached 1,760,037 in 2014. That means it has a population density of 4890 capita/km^2. The Gaza Strip consists of 5 Governorates and 25 municipalities. Table (5.2) shows the population for each governorate for years 1997, 2007, 2014 and 2039. Furthermore, population for each municipality has been collected and mapped by ArcGIS Desktop 10.1.

Figure (5.2) shows the population density change across the Gaza Strip.

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Table (5.2): Population in each of Gaza Governorates

Governorate	1997	2007	2014	2039 (Estimated)
North Gaza	178,605	265,594	348,808	806,584
Gaza	357,768	489,642	606,749	1,401,590
Deir Al-Balah	144,015	202,493	255,705	590,678
Khan Yunis	195,475	267,294	331,017	764,649
Rafah	119,659	170,697	217,758	503,020
Total	995,522	1,395,720	1,760,037	4,066,521

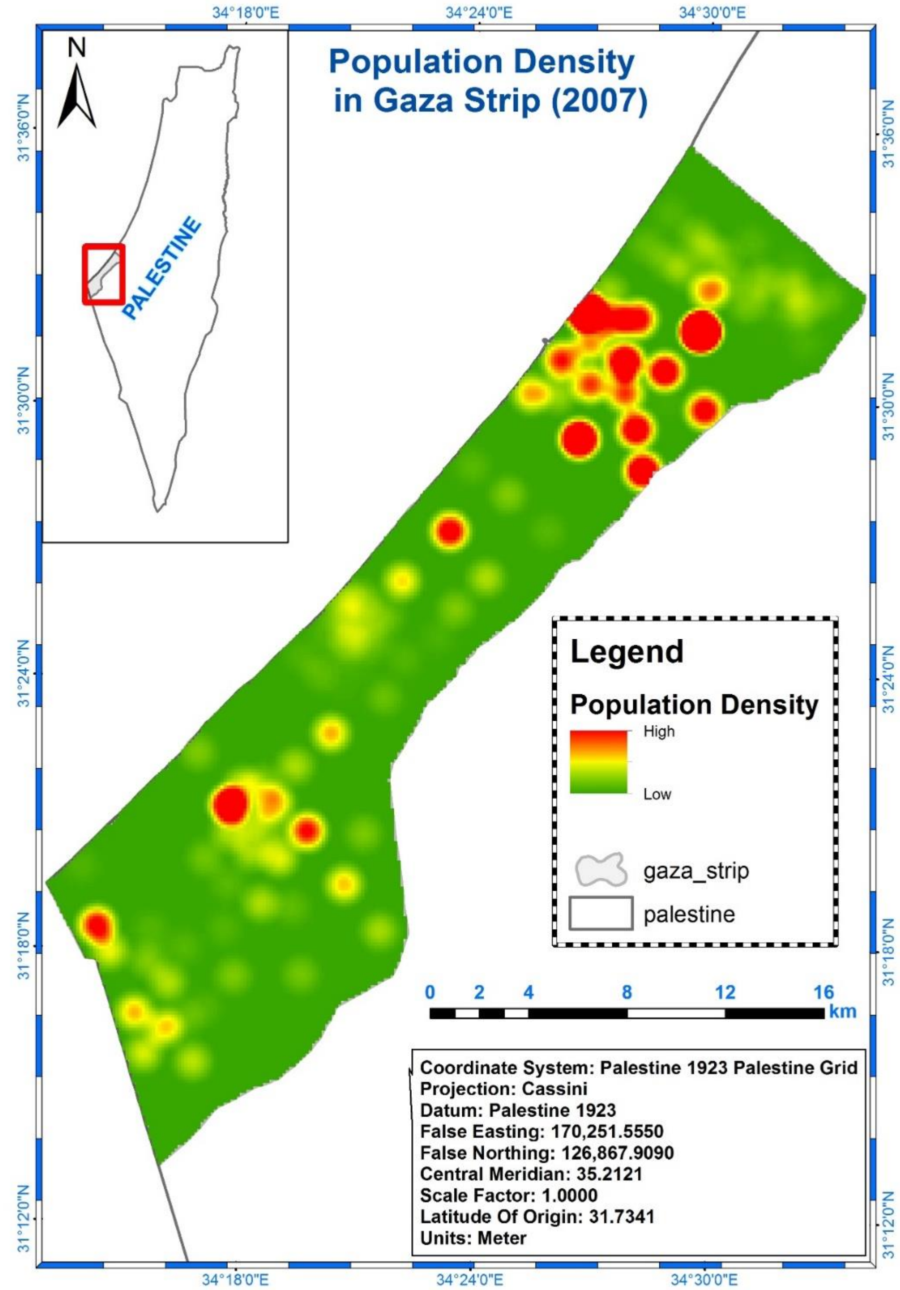

Figure (5.3): Population Density in the Gaza Strip

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5.2.2.2 Vital Places

Vital Places are the places that attract more people such as schools, universities, markets, and so on. The Gaza Strip has many vital places. They are distributed across the Gaza strip, but they are concentrated in some regions more than others are. The spatial distribution of vital places is essential for determining the optimal sites of the metro system. The map shown in Figure (5.4) exhibits the spatial distribution throughout the Gaza Strip.

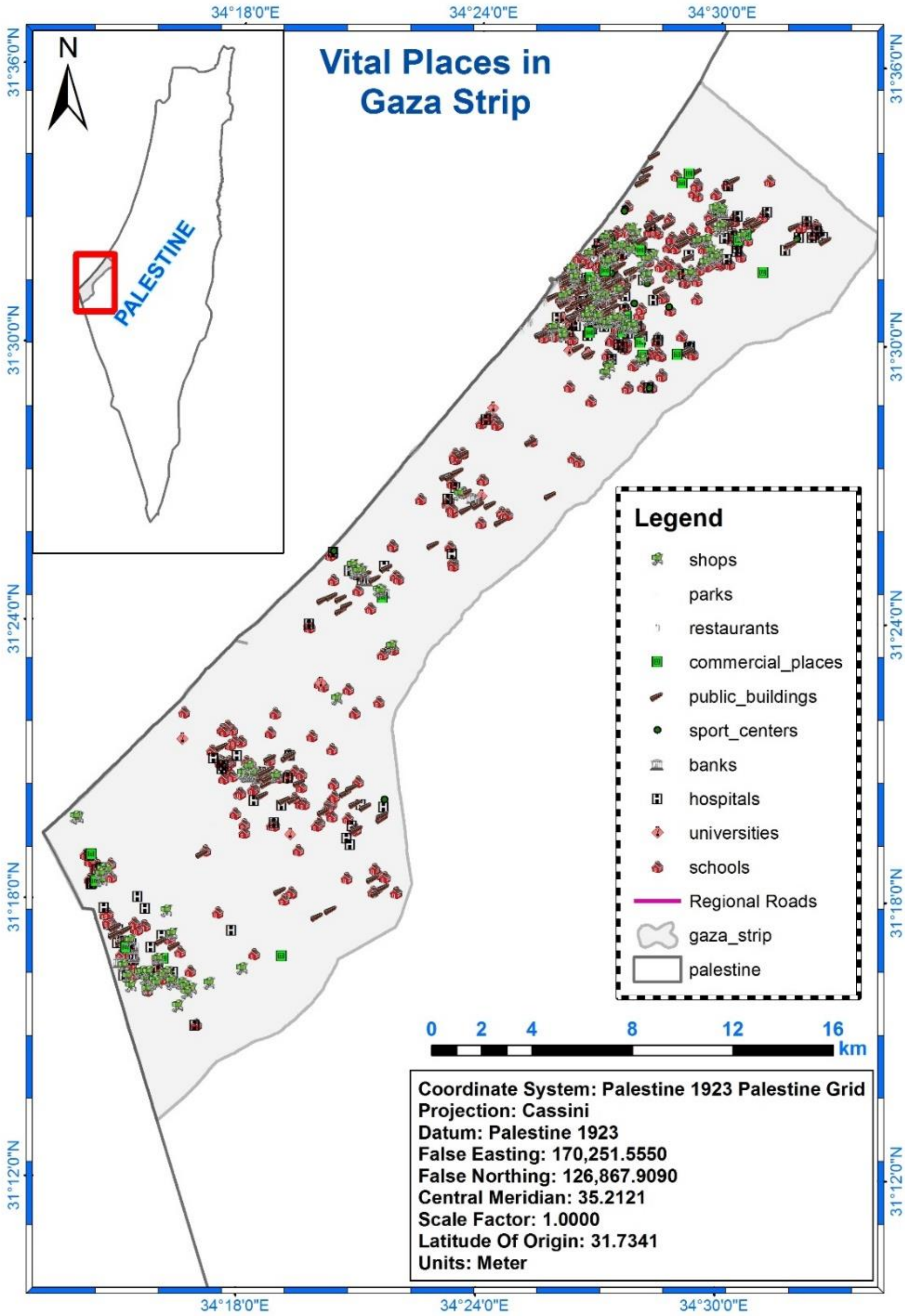

Figure (5.4): Vital Places in the Gaza Strip

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5.2.2.3 Existing Road Network

Figure (5.5) shows the existing road network in the Gaza Strip. The roads can be classified into classes: (1) Regional Roads, (2) Main Roads, and (3) Local Roads. One of the main criteria in planning and selecting best sites for metro network is to maximize the interconnectivity to the existing road network. Therefore, getting this type of data is essential.

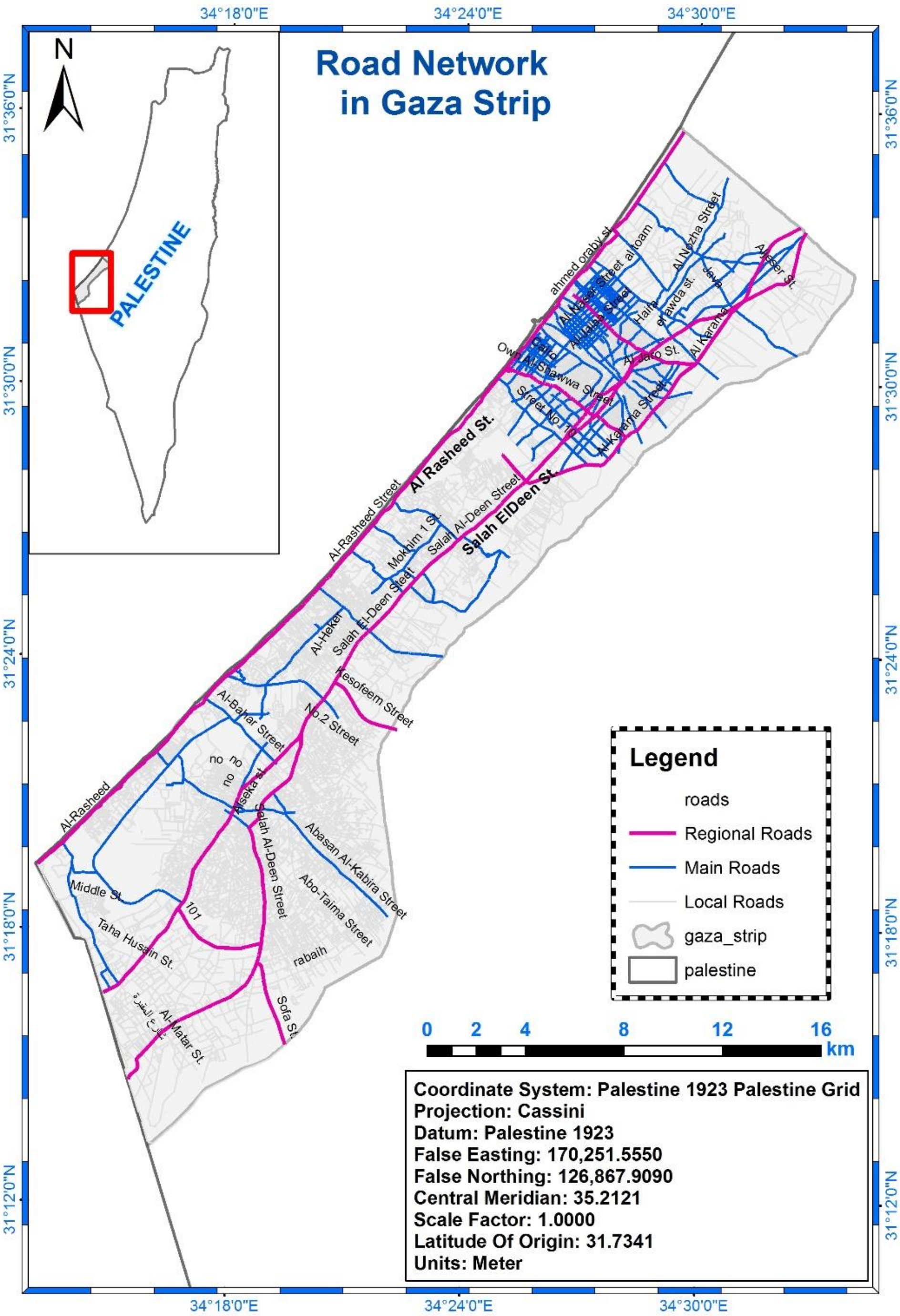

Figure (5.5): Road Network in the Gaza Strip

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5.2.2.4 Important Intersections

Identifying the important intersections is important for getting a knowledge about the current traffic demand and its hot spots in the Gaza Strip. Figure (5.6) shows some of the main intersections in Gaza City. The author has tried to collect the data about intersections from many sources. Some regions lack the data. Therefore, the important intersections are identified according to their location. The important intersection should be located in a vital region and on main and regional road network which was shown previously.

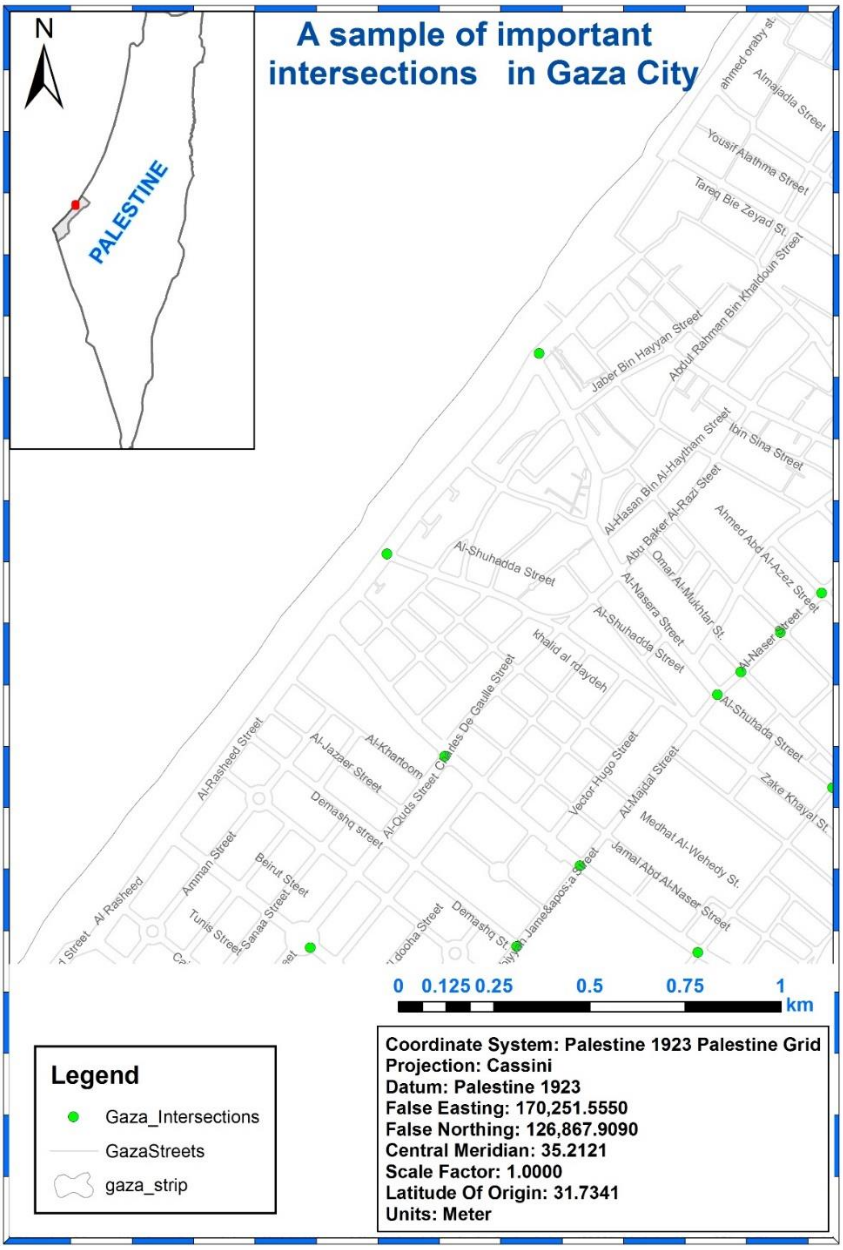

Figure (5.6): Important Intersections in Gaza

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5.2.2.5 Land-use in the Gaza Strip

Land-use maps depicts the current and future use of the land. They are important for site selection of the Metro lines in the Gaza Strip. The metro lines should located on suitable land. Figure (5.7) shows the land-use for the Gaza Strip.

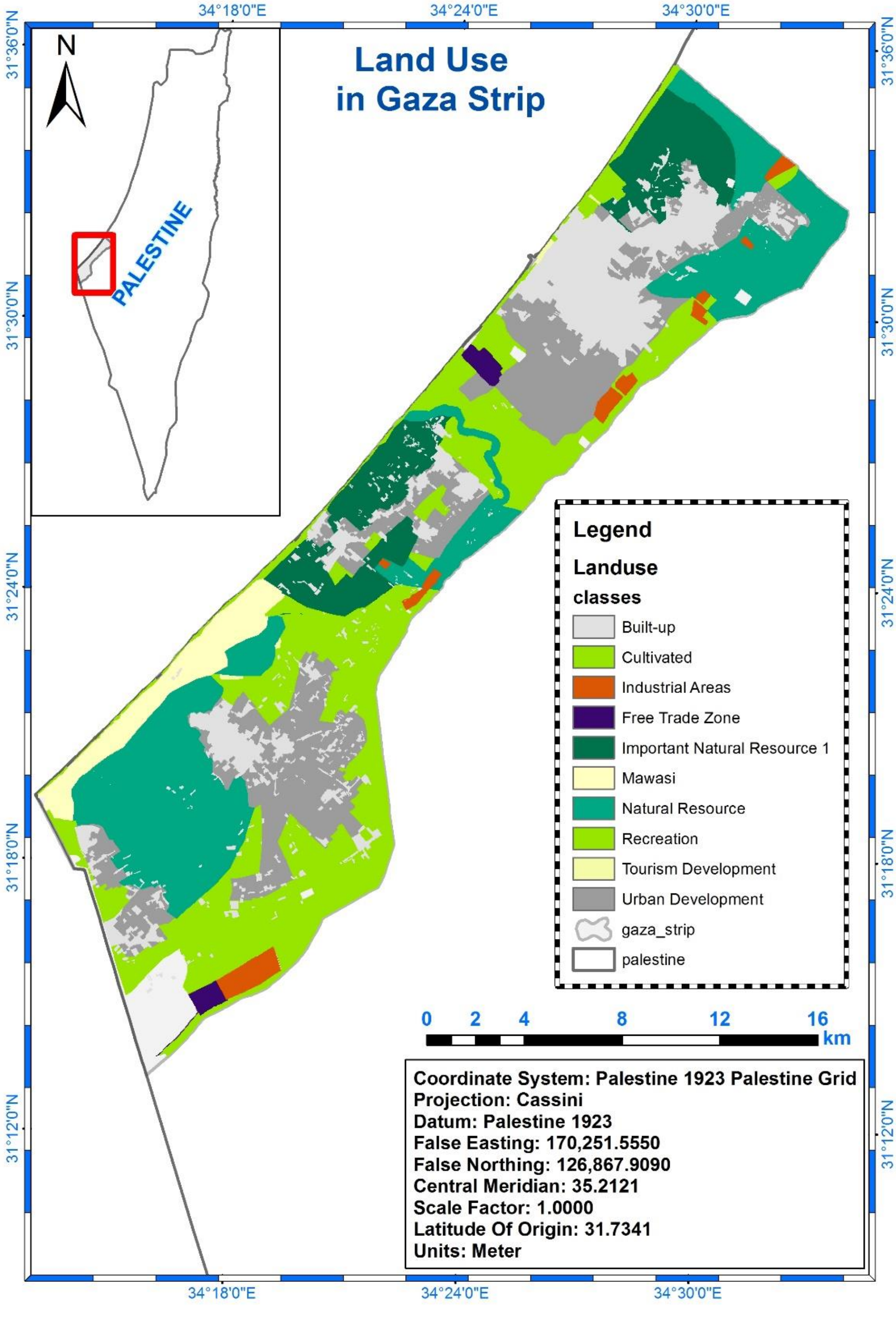

Figure (5.7): Land-use for the Gaza Strip

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5.2.2.6 Water Table Level

Water Table is an important factor that should be accounted for when planning underground and even surface structures such metro lines. This factor is imposed to reduce the impacts on the environment. Figure (5.8) shows the vertical distance between the existing topography and groundwater level. It can be concluded that the eastern regions have the highest depth. Consequently, the eastern part of the Gaza Strip is favourable for constructing metro lines.

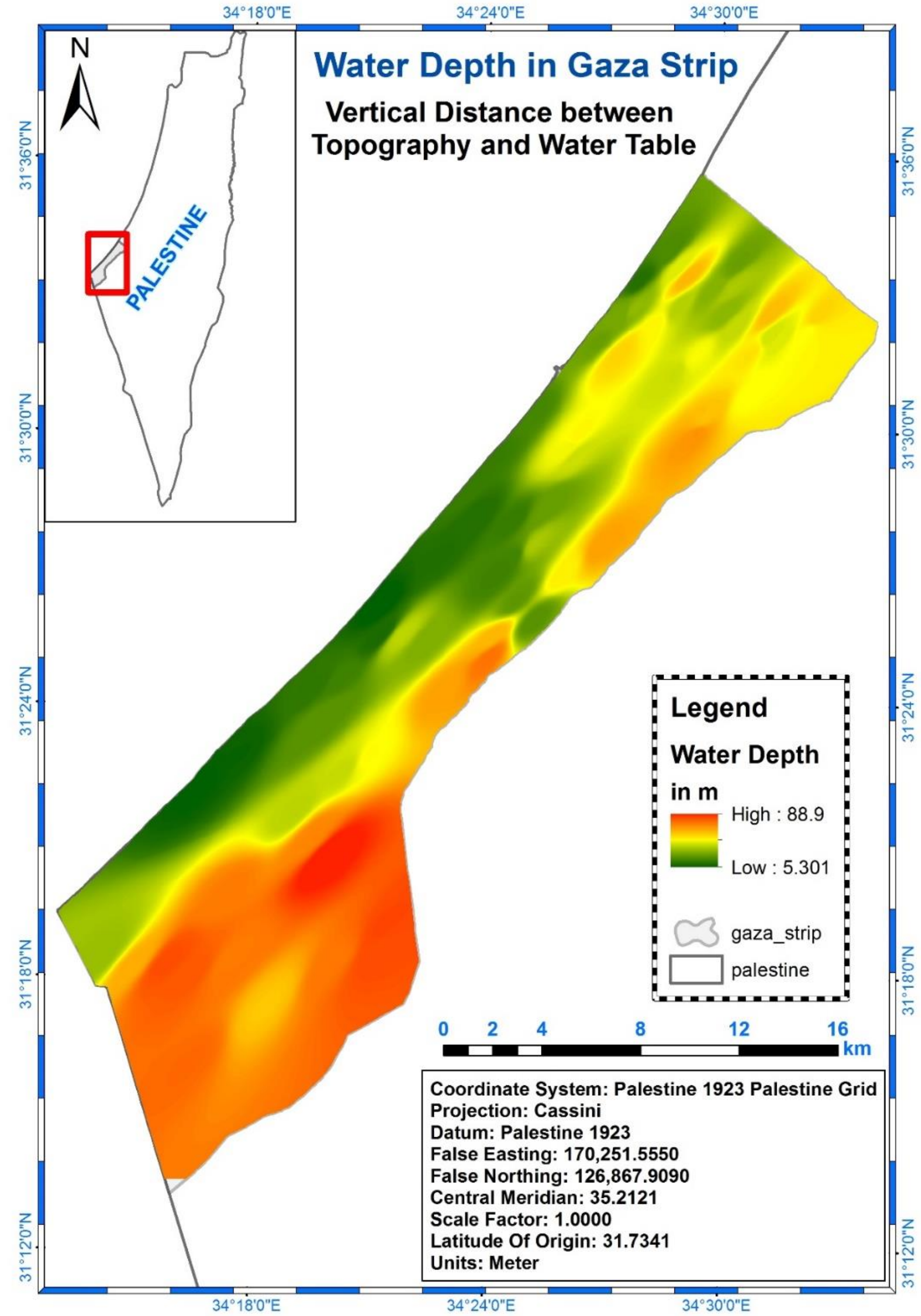

Figure (5.8): Water Table Depth in the Gaza Strip

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5.2.2.7 Existing Buildings

Existing buildings in the Gaza Strip is expected to be one of the main obstacles for constructing metro lines in the Gaza Strip. Therefore, the existing buildings should be avoided when planning metro system in the Gaza Strip. Gaza and north Governorates have the highest buildings density and Khan Younis as well. We expect the proposed lines will pass in the eastern part of Gaza and North Governorates due to the low density of buildings. On contrary, the metro may pass through the middle of Dier Albalah Governorate due to its very low buildings density. Figure (5.9) shows the buildings distribution across the Gaza Strip.

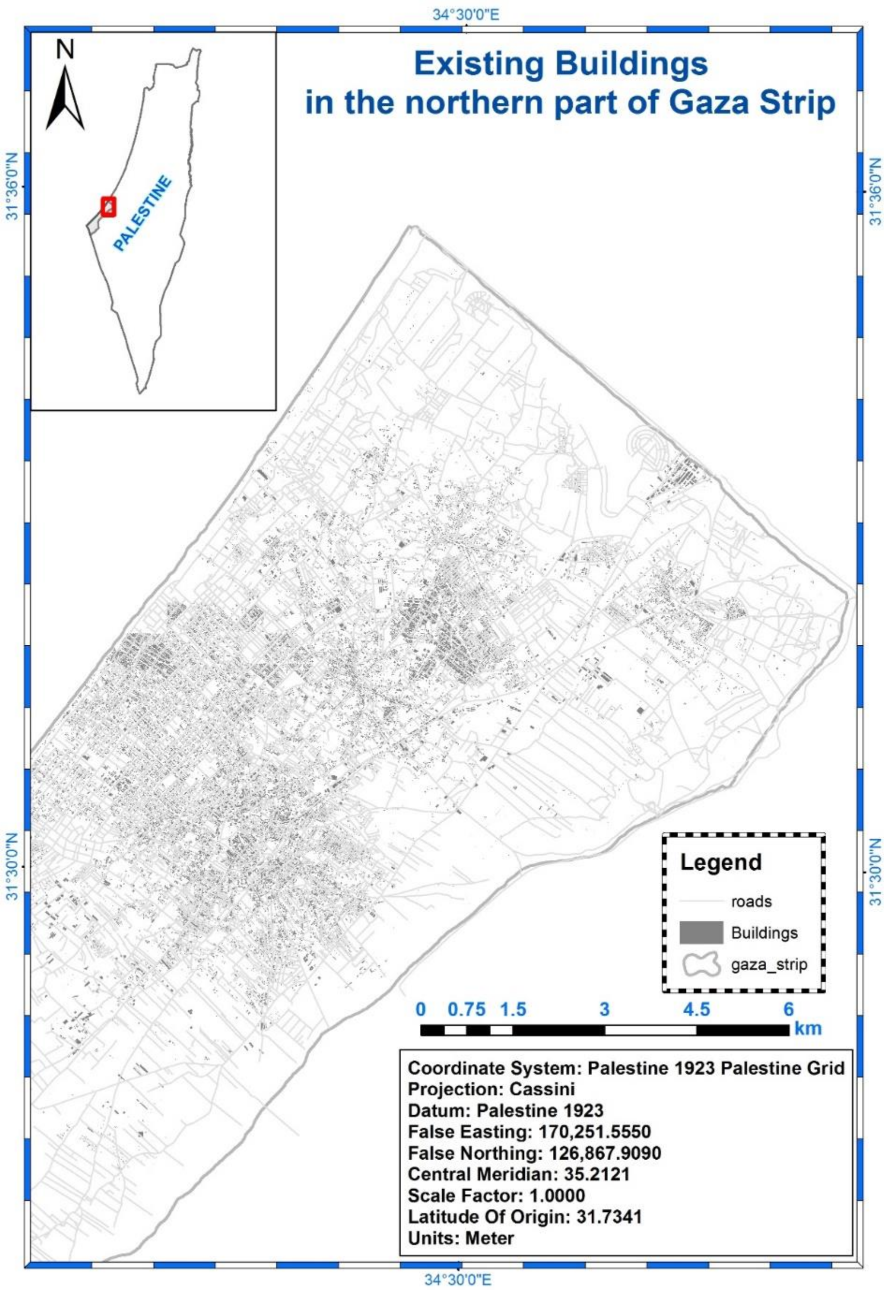

Figure (5.9): Existing Buildings Distribution in the Gaza Strip

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5.2.2.8 Soil Types

Soil types is a factor which, if accounted for, reduces the construction costs and other design issues. Sandy soil is a good choice for constructing the metro lines. Therefore, the regions with sand soil are preferable. Figure (5.10) shows the soil types distribution across the Gaza Strip. Note that some regions in the north will not be good alternatives since they have a clay soil type.

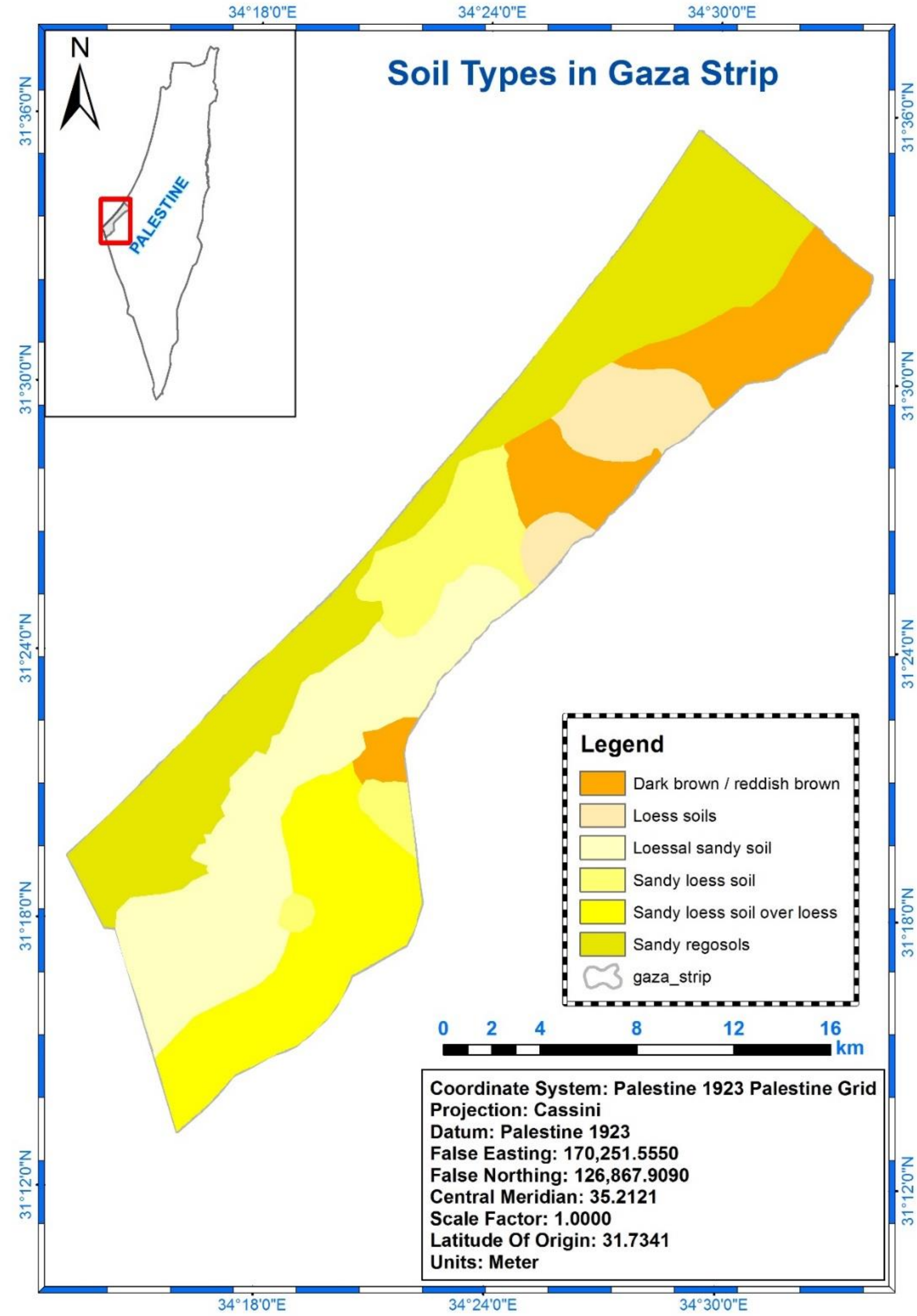

Figure (5.10): Soil Types Distribution in the Gaza Strip

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5.2.2.9 Digital Elevation Model

The most versatile and useful representation of terrain in GIS is the digital elevation model, or DEM. This is a raster representation, in which each grid cell records the elevation of the Earth's surface, and reflects a view of terrain as a field of elevation values. The elevation recorded is often the elevation of the cell's central point, but sometimes it is the mean elevation of the cell (Longley P., et al., 2005). Figure (5.11) depicts the elevation map for the Gaza Strip. This type of data is needed for deriving slope data, which is an important factor in selecting the least cost route for metro lines. The area with the least slopes are preferred.

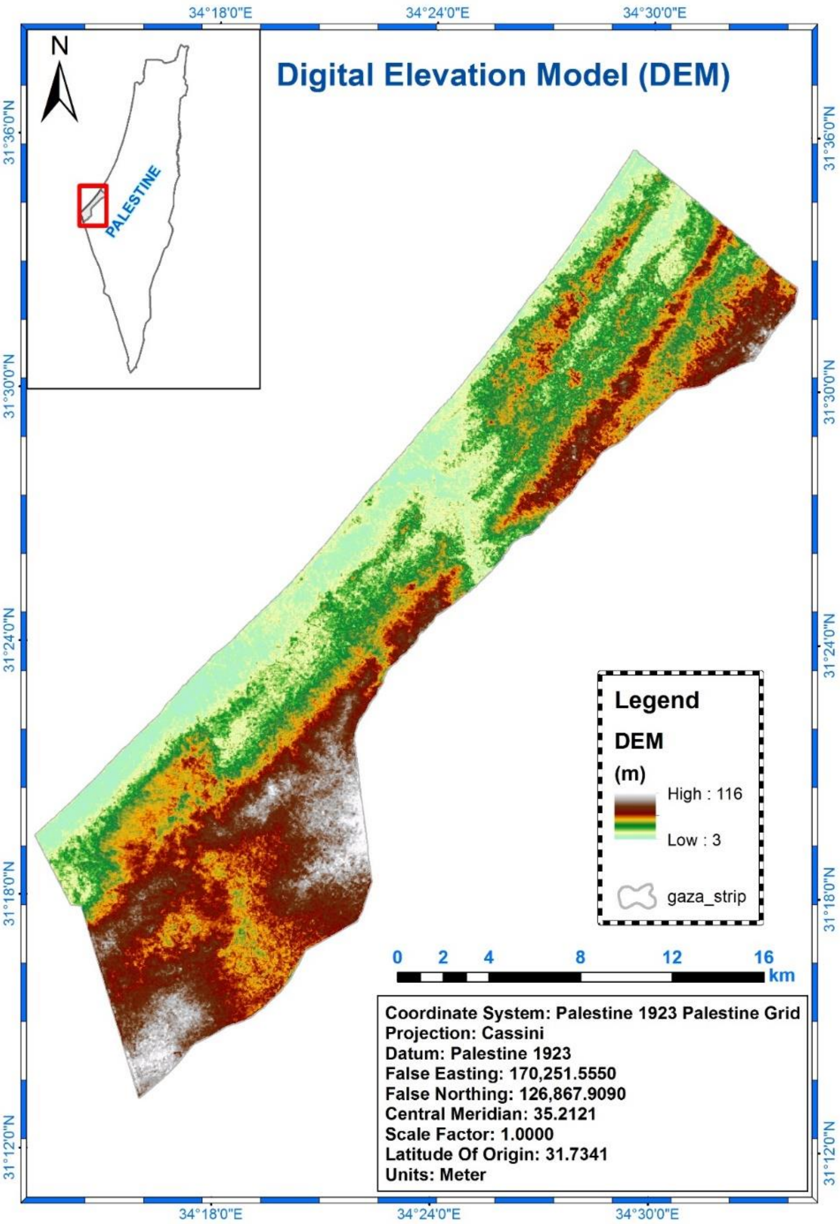

Figure (5.11): Digital Elevation Model for the Gaza Strip

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5.2.3 Step3: Spatial Analysis

After data collection and pre-processing, the data is to be analyzed spatially and non-spatially to come to the final solution of the problem. This step represents the core of the research. The data was analyzed using the spatial analysis techniques provided by ArcGIS Desktop 10.1. The analysis that is concerned with selecting best sites for facilities is known as *suitability analysis*. Such analysis has been used extensively for selecting the optimal regions for metro stations. The procedure followed for identifying the optimal sites can be summarized in the following three steps as shown in Figure (5.12):

1. Select the optimal sites for end stations (master origin and master destination).
2. Select the least cost path between the master origin and master destination.
3. Distribute the intermediate stations along that path according to the criteria specified previously.

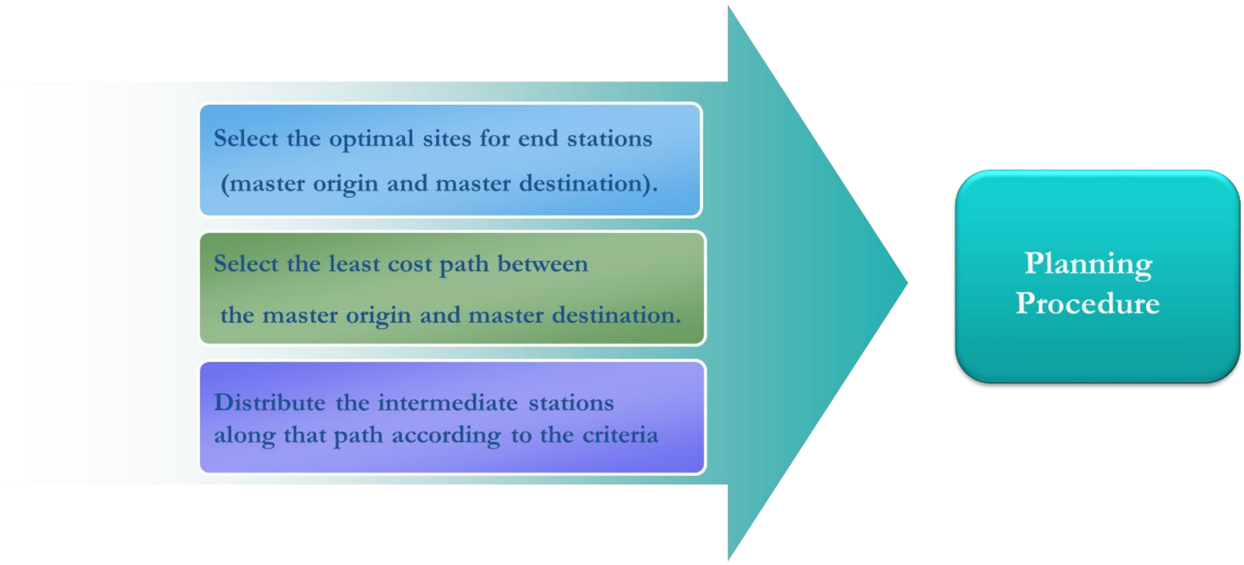

Figure (5.12): Spatial Data Analysis Procedure

The idea that would be used here is to rank the regions of the Gaza Strip according to the criteria mentioned previously in this chapter. The scale 1-10 will be used for such purpose. If a location is ranked 10, it would be the most suitable location for metro station. That also means 100% of the criteria has been satisfied.

On the other hand, if a location is ranked 1, then it is the least suitable location for a metro station. That can also be interpreted as 10% or less of the criteria has

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been satisfied. In addition, number 0 in the scale means that this component is restricted and forbidden.

The main challenge here how to rank each location in the Gaza Strip. The space is continuous. Therefore, it would be more reasonable if the Gaza Strip is divided into Grid of small cells with predefined size. In that way, the ranking process is reduced to ranking those cells. Consequently, the raster data model would be employed extensively in the suitability analysis. That is because raster data model divides the study area into grid of cells. Furthermore, ArcGIS provides powerful tools for processing and analyzing spatial data using raster data model.

The final output of the suitability analysis is a raster map showing the suitability ranking of each location in the Gaza strip for metro stations. This map is called *Suitability map*.

The ultimate rank of each location is computed using the weighted average of the ranks of each criteria specified previously as depicted in the following equation.

$$Ru = W1*Rc1 + W2*Rc2 + \ldots. + Wn*Rcn$$

Where:

Ru: Ultimate rank of a location

W1: Weight of criteria 1.

Rc1: Rank of a location for criteria 1, (e.g. population density)

W2: Weight of criteria 2.

Rc2: Rank of a location for criteria 2, (e.g. vital places)

As an example, if a location is characterized with high population density and low number of vital places, it might receive 9 for the first criteria and 4 for the second one. The ultimate rank would be (9+4)/2=6.5, if they has the same influence.

The suitability map comes after a series of geo-process on the input data. This series of geo-processes constitutes what is so called *cartographic model*. Therefore, the *Model Builder* tool in ArcGIS is used to build such model. The main advantage of the Model Builder is saving your work so that you can repeat the same processes for another study area or for updating your model. That would save time and effort.

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The following sections will present the workflow of getting the suitability map for metro stations. Each location will be ranked for each criteria, and then the rankings from all criteria are averaged.

5.2.3.1 Site Selection of End Stations

The optimal sites for end stations should satisfy the following criteria:

1. The station should be on a suitable land.
2. The station should be far away from borders including the coastal lines.
3. The station should be located in Rafah or Northern Governorates since these are the border governorates while the Gaza Strip is a narrow, 40-km long slice of land between the Mediterranean to the west and the Negev desert to the east.
4. The area should be large enough so that the station works as a parking area for trains and for maintenance.

After the data is collected and preprocessed, a sequence of geo-process are performed to answer the basic question, which is where the optimal sites for end stations should be located. The following will describe these processes and the underlying theoretical concepts.

5.2.3.1.1 Criteria 1: the stations should be on a suitable land

The suitable land means that land which satisfies the following criteria:

- The land owned by government is preferable.
- The land use such as natural reserve, built up, water, agricultural, and existing industrial should be avoided as much as possible.

The lands here should be put on a scale of 1 to 10 according to classification limits in the GIS model. That is possible through the ***Weighted Overlay tool*** which provides means of scaling, weighting, and summing up the raster layers that represents the criteria.

Table (5.3) shows the land use and their scale values for example.

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Table (5.3): Land-use Scaling for the Spatial Analysis Model

Value	Protection	Scale
1	Nature Reserve	Restricted (0)
2	Important Natural Resource 1	1
3	Recreation	4
4	Natural Resource 2	7
5	Existing Industrial Area	1
6	Cultivated	1
7	Built-up	1
8	Tourism Development	1
9	Waste Water Treatment Site	1
10	Free Trade Zone	5
11	Proposed Industrial Area	5
12	Solid Waste Disposal Site	1
13	Natural Resource 2 TW	7
14	Mawasi	1
15	Airport	1
16	Harbour	1
17	Fisheries Site	1
18	Urban Development	6
19	Cultivated by treated water	1

The scale values are selected such that the impacts on environment, development and economy is minimized. For example, the natural reserve, cultivated, existing industrial areas, and so on are scaled down.

The values in Figure (5.13) are inserted through the interface of the weighted overlay tool as shown.

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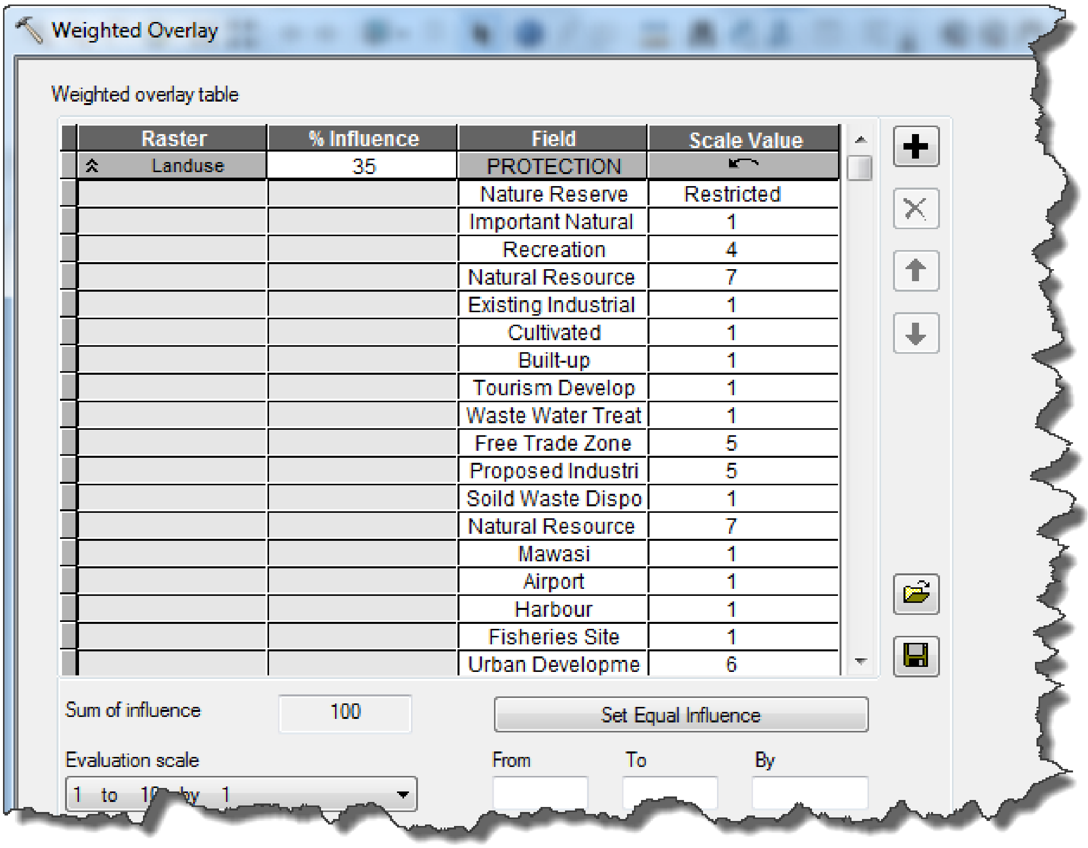

Figure (5.13): Weighted Overlay Interface

Table (5.4) shows the land ownership types and their scale values.

Table (5.4): Land-Ownership Scaling

Value	Ownership Type	Scale
1	Private	3
2	Governmental	9
3	Wakf	0
4	Beer Sabeh (term used by technicals)	6

This criteria should be weighted so that its influence in making the final decision is reflected. The land use and ownership is one of the most important criteria influencing the site selection of the end stations. Therefore, a weight or influence of 35% will be chosen for land use and 50% for land ownership type.

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5.2.3.1.2 Criteria 2: To be outside a buffer region of 1500 m from borders

This constraint is important in order to provide safe places for metro stations. The border areas could be very dangerous due to the Israeli-Palestinian conflict. The feasible regions are identified by excluding a buffer region of 1500 m from the borders. Then the alternatives in the feasible region are ranked according to their closeness or farness from the infeasible region (buffer of 1500 m). To quantify how far or near is a cell from the borders; the Euclidean Distance is computed for each cell. The larger is the distance, the further is the cell. Since the output distance values would be continuous, it would be better to reclassify the values into new discrete and limited classes (for example, say 10). After reclassification, the output new classes are put on a scale from 1 to 10, as we have done in the previous section.

To ease the scaling process, the number of the new classes is selected to be 10 in the reclassification process. The higher distances are reclassified to 10 and the lower distances are reclassified to 1. That means the higher distance (far away from borders) are preferable and the lower ones (close to borders) are not. In the scaling process, the values will be mapped automatically so that the distances in class 1 is scaled to 1 and so on.

The weight of this criteria is selected to be 15%, because it is less important than the land-use and ownership type.

5.2.3.1.3 Criteria 3: The station should be located in Rafah or Northern Governorates

This criteria is governed by the geography of the Gaza Strip which places the Rafah at the southern end and the Northern Governorate at the northern end. Therefore, the end stations should be located in these governorates. Here we don't need to weight this criteria, because it is a constraint and not a factor.

5.2.3.1.4 Criteria4: The area should be enough large

The area should be large so that the trains can be parked and for maintenance issues also. This criteria is involved only in the final decision. So, it will not weighted as others.

The aforementioned processes are represented as a cartographic model of the weighted overlay as shown in Figure (5.14)

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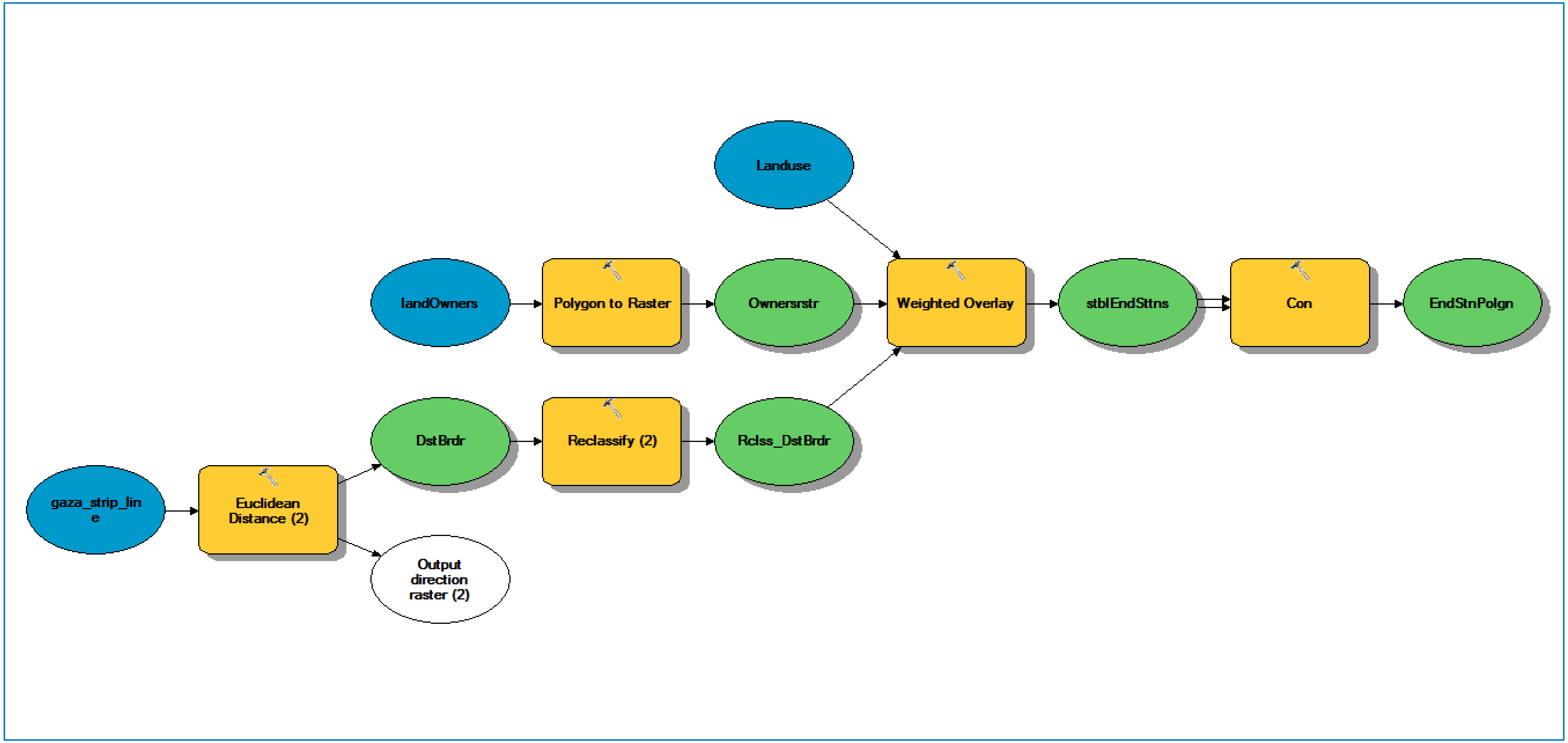

Figure (5.14): Cartographic Model of End Stations Selection

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5.2.3.2 Site Selection of the Least Cost Route

After the selection of optimal sites for end stations, the major routes of the metro system can be constructed by searching for the least cost paths. The path can be described as the least cost if it minimizes the overall cost. The cost could be in terms of environmental, economic, construction costs. After long searching in the literature and interviewing some experts, the least cost path should satisfy the following criteria:

1. Intersection with existing buildings should be ***avoided***.
2. Route should be ***far from*** the water table.
3. Soil type is preferably to be ***sandy***.
4. maximum gradient should be ***6 to 8%***
5. The corridor width should be ***12 meters*** for track sections.
6. Close to vital regions (universities, parks, main stations, …)
7. Close to dense populated areas

In order to solve the problem of finding the least cost path for metro lines, some of geo-processing tools, which are provided by ArcGIS, are used extensively to make the final decision. The workflow is described below and as shown in Figure (5.15).

The steps can be summarized as follows:

1. The above criteria are combined and weighted using the *Simple Linear Combination* method as explained previously in this chapter. The output was a raster layer called *Cost Raster Surface* with values from 1 to 10. The value 1 represents the areas with the lowest cost for constructing metro line, the value 10 represents the areas with the highest cost.
2. The Cost Distance tool is employed to compute the least cumulative cost distance for each pixel from the origin to destination.
3. The output of the Cost Distance is inputted to Cost Path tool which computes the least cost path from the origin to destination.

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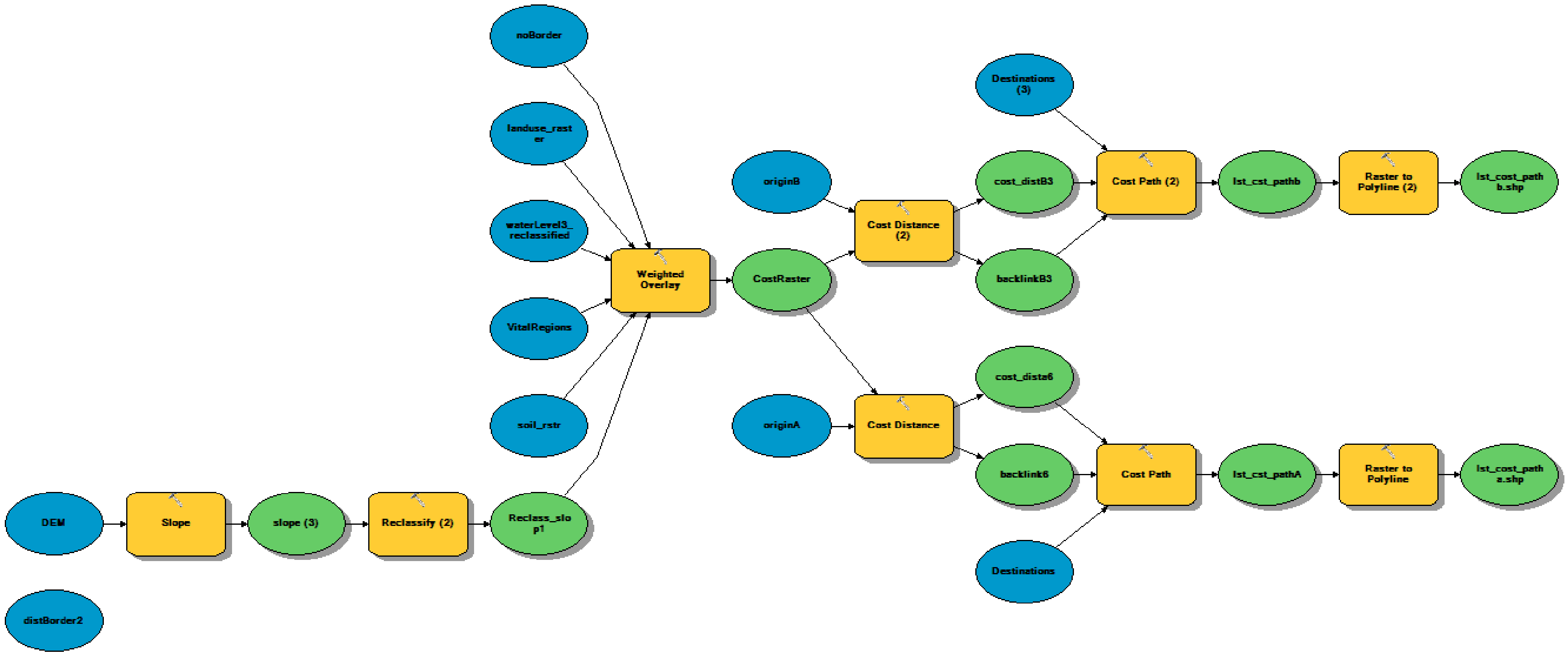

Figure (5.15): Cartographic Model of Least Cost Route Selection

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5.2.3.3 Site Selection of Intermediate Metro Stations

5.2.3.3.1 Criteria 1: Population Density

The final output of this step is a raster composed of cells. Each cell represents a region of size $30x30m^2$ that could be a core of a station. Each cell has a value representing how much it is suitable for a metro station. The regions with highest population density receives a rank of 10, and those with lowest density receives a rank of one. The population data is obtained for each municipality in the Gaza Strip. The processes that are performed to get the raster suitability map is summarized as follows:

1. The population density was estimated for each region in the Gaza Strip. ArcGIS Spatial Analyst provides tools for such purpose. *The Kernel Density tool* is used in this work.
2. The output of the Kernel Density tool is a raster composed of cells. Each cell has a value representing population density.
3. The density raster is reclassified to new values that ranges from one to ten (1-10). The *Reclassify tool* is employed for that purpose. The cells with highest density values get the new value 10, and those with lowest density values get the new value 1.

The output raster of this step will be overlaid with raster layers from other criteria, and averaged to get final suitability map.

5.2.3.3.2 Criteria 2: Near Vital Places

The final output of this step is a raster composed of cells. Each cell represents a region of size $30x30m^2$. Each cell has a value representing how much it is suitable for a metro station. The regions that are the closest to vital places receives a rank of 10, and those that are furthest receives a rank of one.

The processes that are performed to get the raster suitability map of this criterion are as follow:

1. For each region in the Gaza Strip, the distance to the nearest vital place is computed. The *Euclidean Distance tool* is used. The output of this tool is a raster composed of cells. Each cell has a value representing the distance to nearest vital place.

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2. The distances obtained in the previous step are reclassified. The cells with the highest values get a new value of 1 and those of lowest values get a new value of 10.

The output raster of this step will be overlaid with raster layers from other criteria, and averaged to get final suitability map.

5.2.3.3.3 Criteria3: Close to the Existing Important Intersections

The main challenge here is how to identify the important intersections in the study area. It is a challenge due to the lack of available data about important intersections in the whole Gaza Strip. Therefore, a procedure for reclassifying the intersections according to their importance is adopted. Before we introduce the procedure, we need to know the specifications of important intersection. The intersection can be classified as important if:

- It is located on regional and primary roads, and
- It is located in a vital, active and dense area.

The procedure adopted for identifying the important intersections is summarized as follows:

1. All intersections are ranked according to their position on roads. The regional roads get highest score and the local roads get the lowest.
2. All intersections are also ranked according to their proximity to the vital places.
3. The ranks are combined using the weighted linear combination assuming equal influence for both ranks.
4. The intersection which gets the highest rank

The same procedure is repeated for the criteria in order to reach the intermediate stations of the Metro Network in the Gaza Strip.

In the following Chapter, the results of the multi-criteria spatial analysis and the metro components selection process based on the abovementioned criteria are shown,

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Chapter (6)

Final Results and Recommendations

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6.1 Introduction

This chapter provides the work results and the most important conclusions, and recommendations. These conclusions and recommendations are useful for decision makers, universities, policy makers, researchers, and other stakeholders of the transportation systems

6.2 Results and Outputs

Throughout the methodology approached in previous chapters, the following results came up with specific conclusions regarding the end stations, the least cost metro route, and finally the intermediate stations that are located at the most optimized best locations according to the criteria followed while selecting these metro components.

Table (6.1) shows that 3 end stations have been chosen to be the origin and destination stations. It also shows that the total proposed metro line length is 51,759 km. It covers all the Gaza Strip Governorates and serves the most vital places. Intermediate stations are 57 stations distributed along the proposed metro route. It also serves the most important intersections and vital places in the Gaza Strip Governorates.

Table (6.1): The Gaza Strip Metro Components Results

Route Length	51759 m
# intermediate stations	57
# end Stations	3

The results are shown in the following figures. It is illustrated whenever more specific information is needed. The proposed metro facilities seem to be a promising public transportation mode in the Gaza Strip. It will facilitate the movement of goods and passengers for different usages across the Gaza Strip Governorates. In addition, it will facilitate the potential regional connection of the Gaza Strip beside the physical connection of the Gaza Strip with the West Bank reaching to a national frame work of developing and improving the Palestinian public transportation infrastructure and facilities. More site investigation and institutional efforts are still needed to develop this work so that it could be more applicable towards achieving the overall aims.

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6.2.1 Best End Stations, Intermediate Stations, and Least Cost Route/Path Location for the Metro Network in the Gaza Strip

Figure (6.1) shows the best possible route and intermediate stations of the Metro network. It shows that the best origin metro station is located in Um-El Naser Area with coordinates (34° 32' E, 31 ° 43' N) while two destination stations have been chosen in the East of Khan Yunis Governorate with coordinates (34° 20' E, 31 ° 17' N) and in Rafah Governorate with coordinates (34° 15' E, 31 ° 19' N). This is clear where the main two borders of the Gaza Strip are Rafat Crossing Border and Beit Hanoon (Erez) Crossing could be served by these origin and end destinations. The other crossing borders of the Gaza Strip could also be served by the intermediate stations assuming that Goods movement will be served by the metro.

The least cost route runs throughout the Gaza Strip Governorates as shown in Figure (6.1) with a total length of 51,759 m. The route is integrated with the main vital places and roads of the Gaza Strip as approached in the methodology adopted where further and deep investigation of another structural design components should be carried out. The corridor minimizes the intervention on the existing facilities and infrastructure as much as possible through taking into consideration all the criteria mentioned the previous chapters. Accordingly, it could be considered the least cost route of the metro line in the Gaza Strip. Figure (6.1) also shows that the metro network is divided into two branches starting from Deir Albalah Governorate with coordinates (34° 21' E, 31 ° 22' N) for the splitting point reaching the final destinations in Khan Yunis and Rafat Governorates. Metro stations coordinates are show in table

The Intermediate Stations are located along the route where it is spaced at 500 m inside the governorates or where there are vital place that should be served by these stations. On the other hand, the intermediate stations are spaced at 1 Km between the Gaza Strip Governorates where there is a light duty on the metro stations. The total number of the intermediate stations is 57 stations where each station locates on a suitable place based on the criteria mentioned previously.

The components shown in Figure (6.1) seem to be acceptable taking into consideration the Gaza Strip context and nature.

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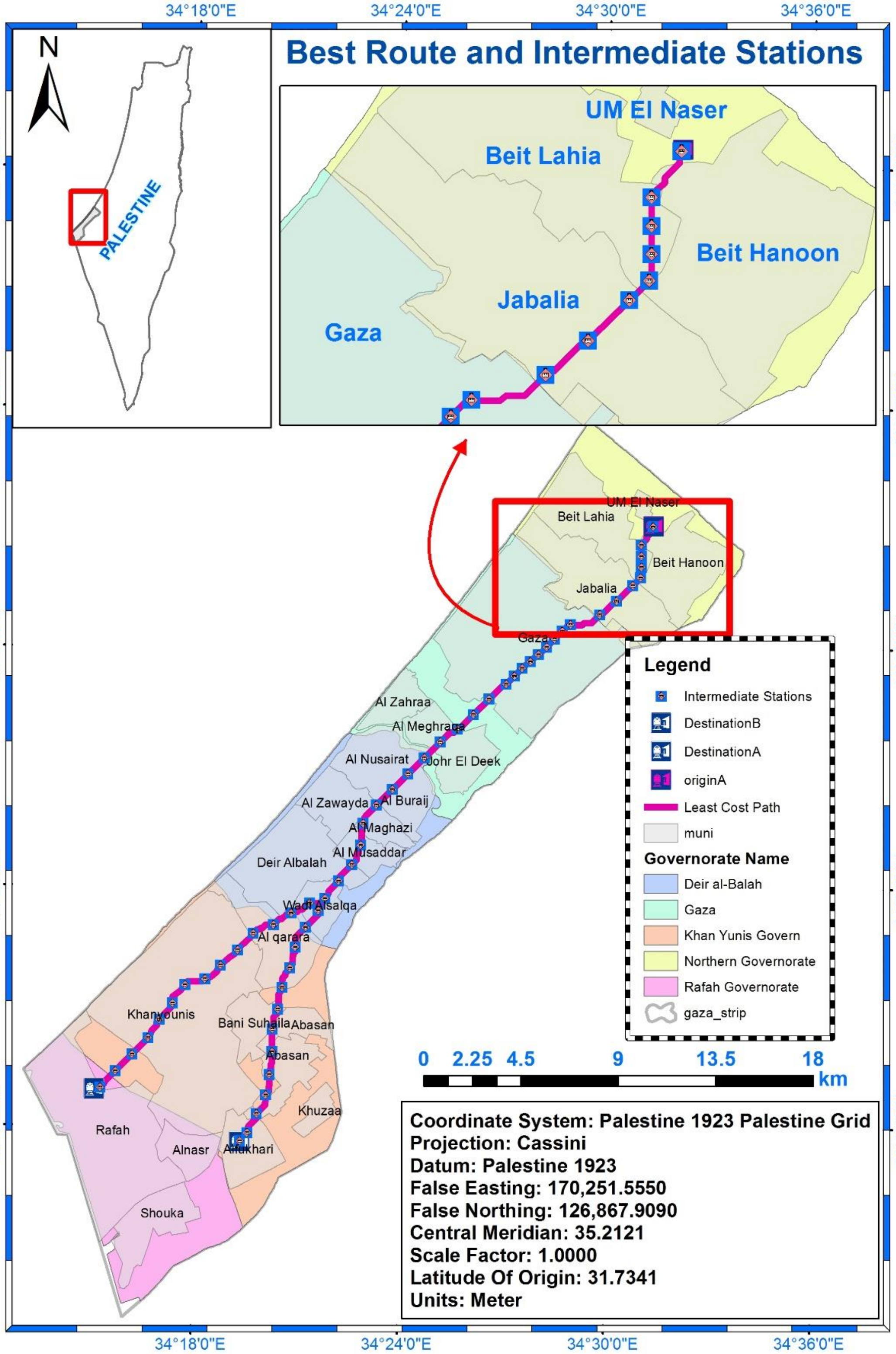

Figure (6.1): Best End Stations, Intermediate Stations, and Least Cost Route/Path Location for the Metro Network in the Gaza Strip

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Figure (6.2) shows the metro stations chainage calculated from the origin station. It explains the accumulative distance from the station x to the origin station starting from the origin station S1 reaching Split Station. It is calculated inversely after the split station in Deir Albalah reaching 0 to Rafah Destination station S56 and starting from 0 after the split station reaching Khan Yunis Destination station S57.

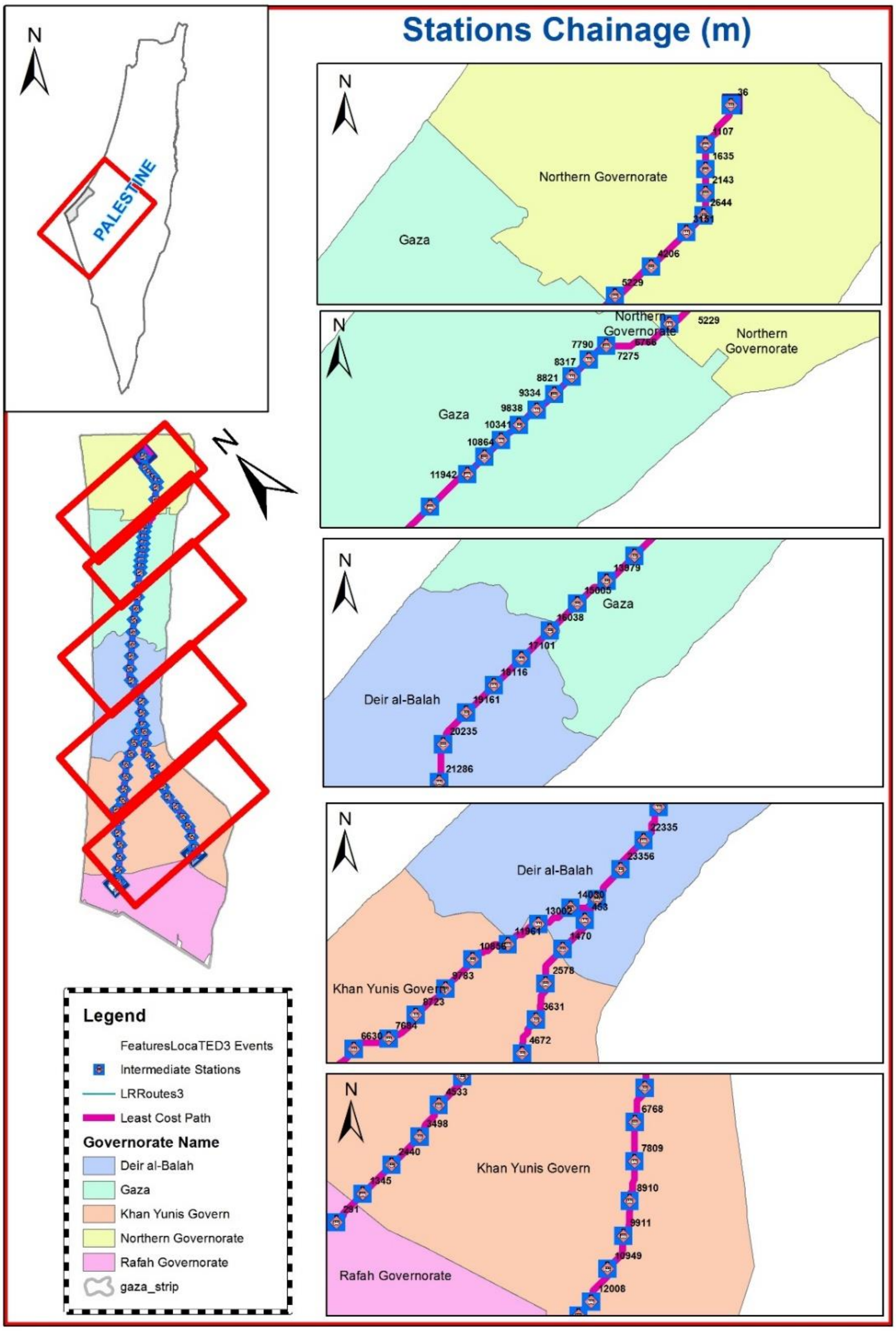

Figure (6.2): Metro Stations Chainage (m)

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Figures (6.3), (6.4), (6.5), and (6.6) show additional illustrations for the best End Stations and Least Cost Route/Path Location for the Metro Network in the Gaza Strip.

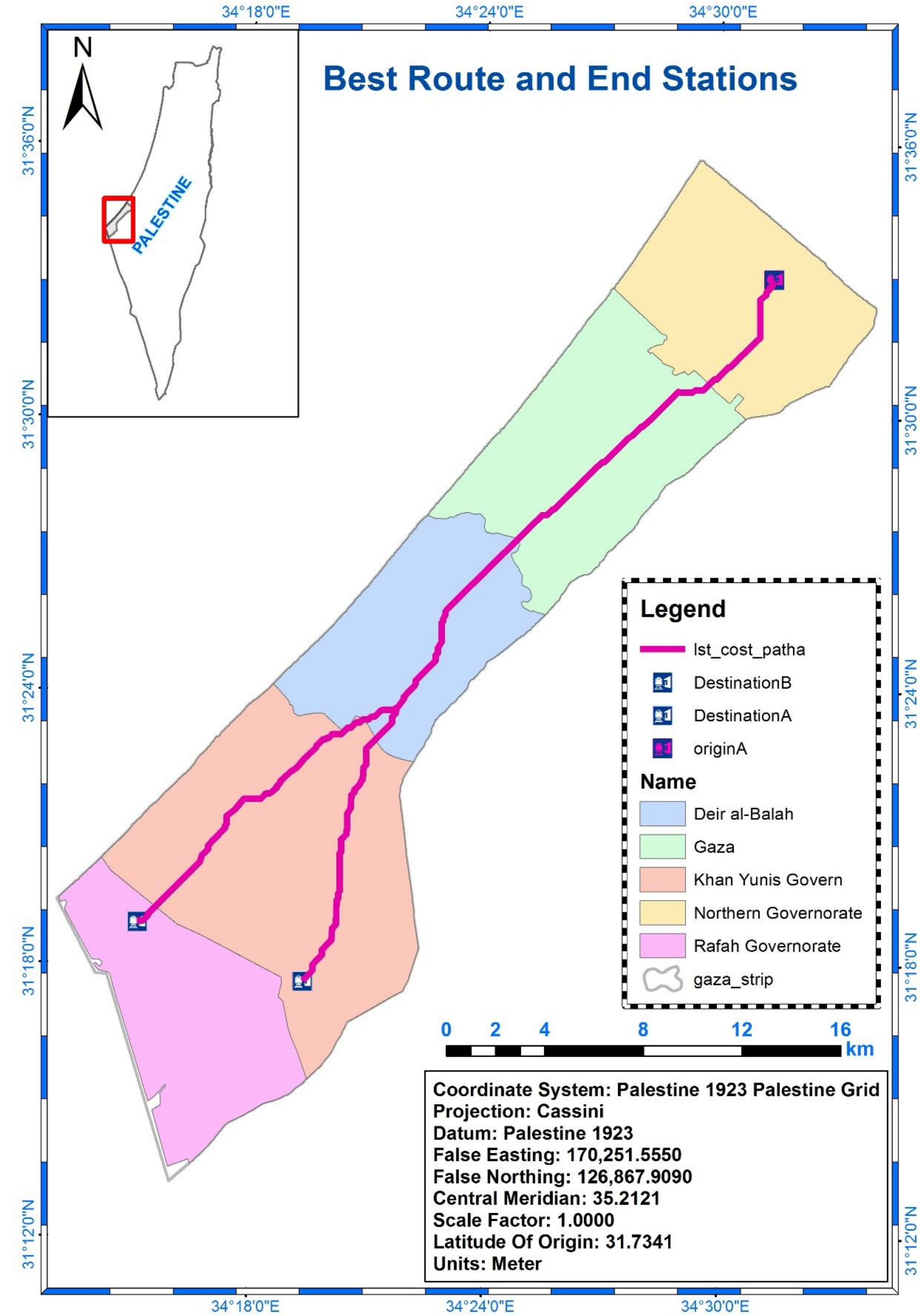

Figure (6.3): Best End Stations and Least Cost Route/Path Location for the Metro Network in the Gaza Strip

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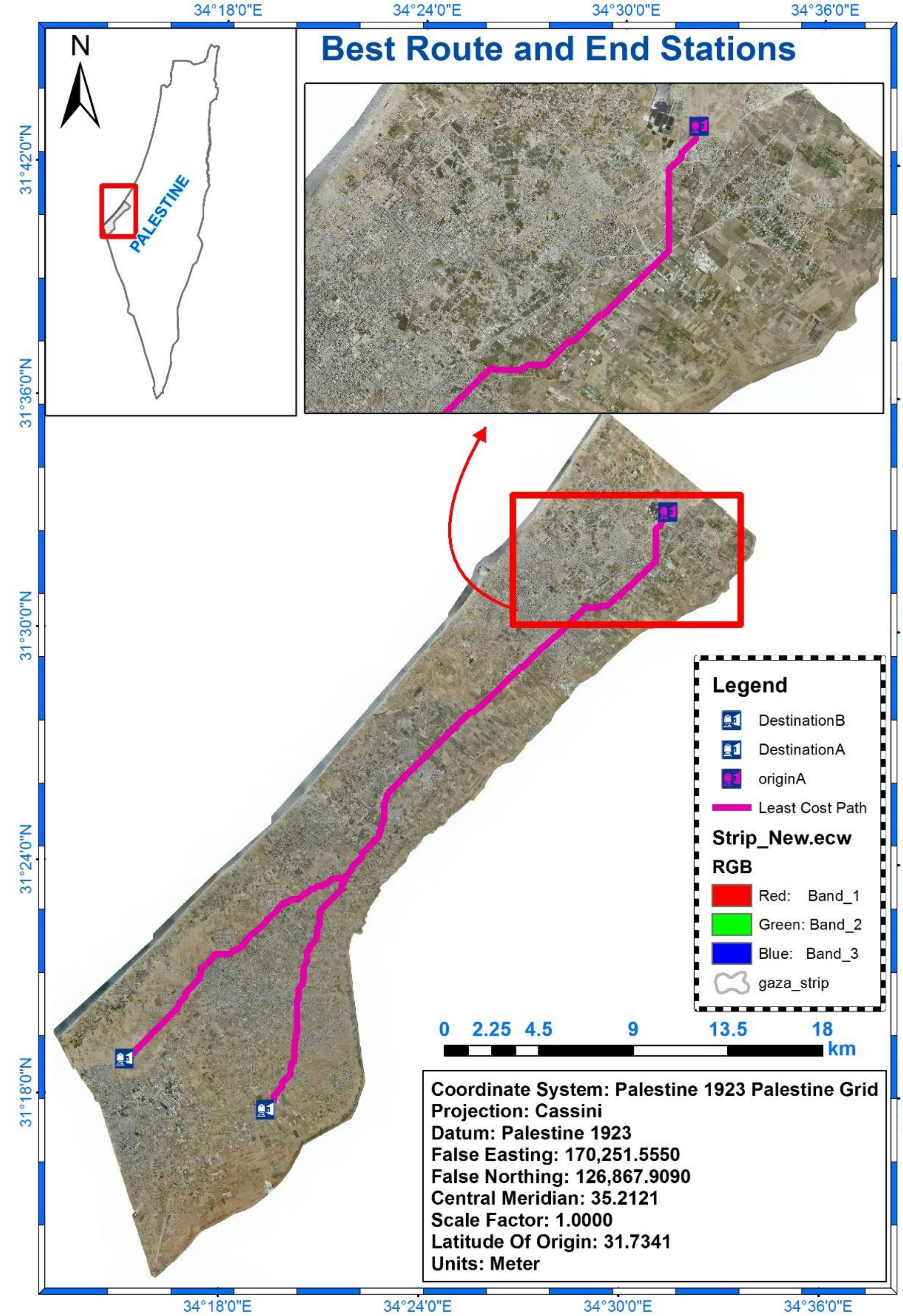

Figure (6.4): Best End Stations and Least Cost Route/Path Location for the Metro Network in the Gaza Strip (Illustration)

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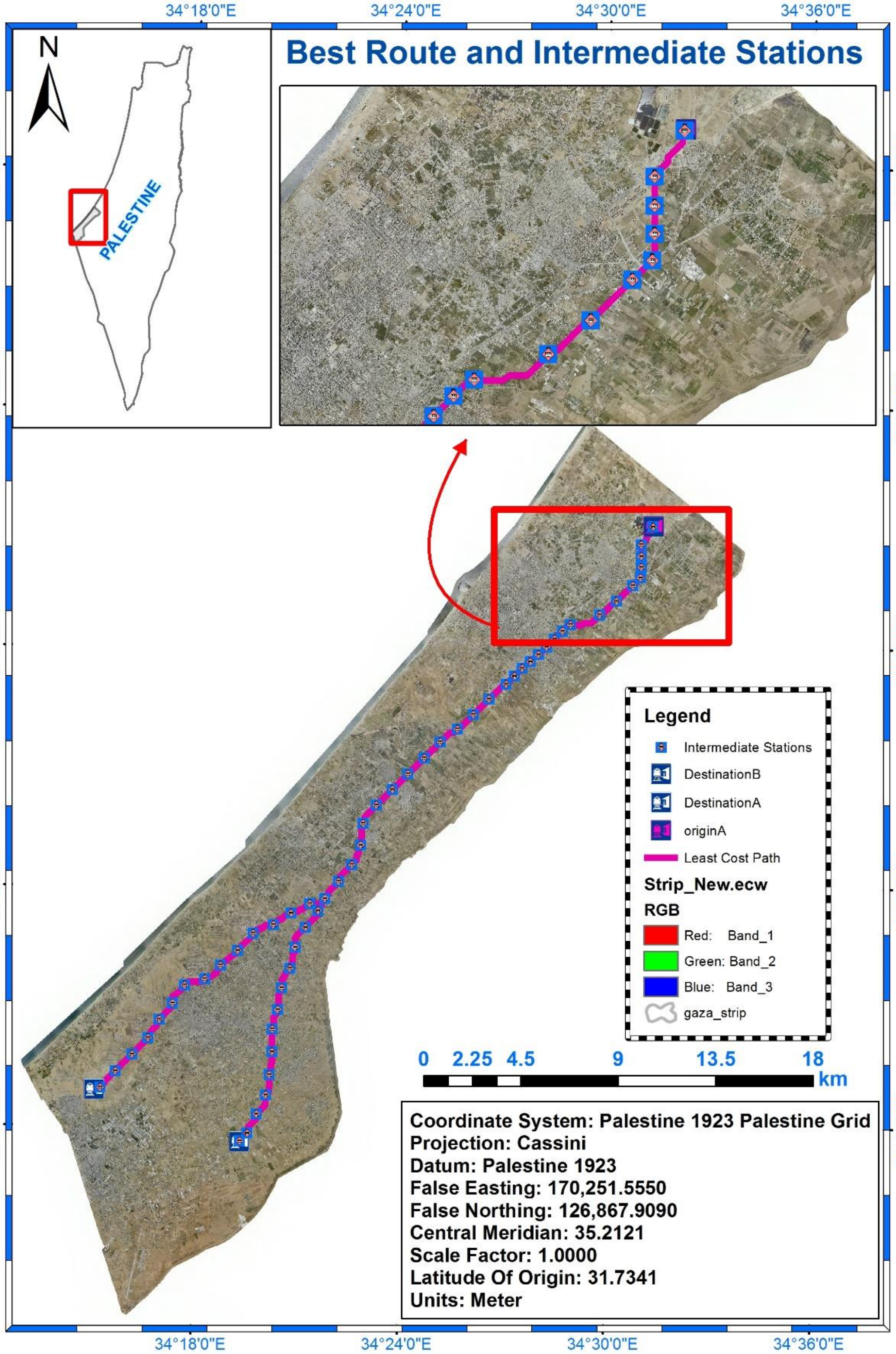

Figure (6.5): Best Intermediate Stations Location for the Metro Network in the Gaza Strip

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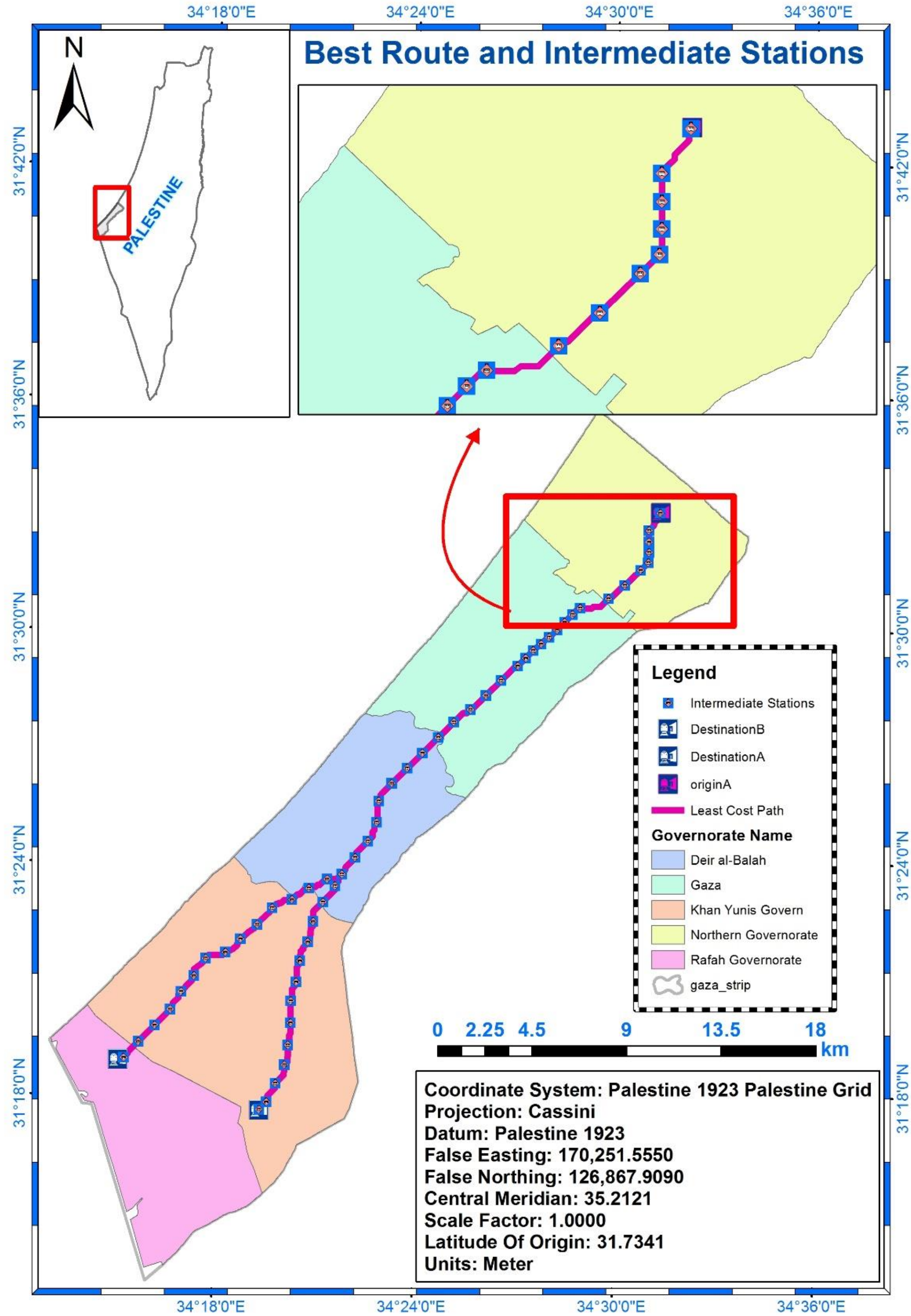

Figure (6.6): Best Intermediate Stations Location for the Metro Network in the Gaza Strip (Illustration)

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Finally, Table (6.2) shows some important stations coordinates:

Table (6.2) Some Important Metro Stations Coordinates

Some Metro Stations Coordinates

Station	Location	Coordinate
Master Origin	Um-El Naser - North Gaza	(34° 32' E, 31° 43' N)
Master Destination A	East of Khan Yunis Governorate	(34° 20' E, 31° 17' N)
Master Destination B	Rafah Governorate	(34° 15' E, 31° 19' N).
Split Station	Deir Albalah Governorate	(34° 21' E, 31° 22' N)

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6.3 Recommendations

- The author recommends adopting the proposed Metro Network for the Gaza Strip as a feasible solution for current and future challenges.
- The study recommends institutionalizing public transportation systems in order to provide better services for passengers in the Gaza Strip.
- Having a metro network could be a part of solving the Gaza Strip problems since it helps in connecting Gaza to the regional roads extensions.
- Environmental impacts should be investigated to minimize the ecological consequences of such a strategic infrastructure project.
- Economic factors should be studied to highlight economic impacts of the establishing and running the metro network in the Gaza Strip.
- A customer profile should be developed for the metro facility that helps in improving the service and the best practice for running the facilities taking into consideration: Flexibility, Convenience to reach stop/station, and Speed.
- Preparing a preliminary cost estimation of such a project. This could be achieved for the establishment of new metro lines reaching a preliminary estimate of such a national project.
- National strategies and actions are needed to ensure that the corridor can meet the long term performance envisioned by corridor partners. These strategies include developing capital projects that will address significant capacity deficiencies and/or bottlenecks, other less-costly improvements that address specific safety and/or operational issues and policy-type directives that proactively promote development of the corridor vision through local ordinances and access guidelines. In short a transportation long-range funding solutions that are realistic, innovation, and focused.
- The author recommends universities, research facilities, and development centers to build on these results in order to have an integrated full program for establishing and operating a metro network in the Gaza Strip.
- Further research studies should be carried out for deeper design levels to plan structural design, transportation system, horizontal and vertical alignments, corridor facilities, and institutional operation.

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