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Metro Route Site Selection in Gaza City Using GIS and Spatial Multi Criteria Evaluation

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Abstract: This study involves the evaluation of a case study in Gaza City to select the Metro site route. Fifty major intersections in Gaza City are chosen as candidate sites for Metro-rail stations, with 500m buffer of each intersection. The criteria that used to choose the best stations of Metro lines are population density, vital places, available parking, area of intersection, traffic important of intersection, and land use. The control boundary criteria that used to choose the routes are soil type and ground water wells level. By using spatial multi criteria decision analysis and GIS, three routes are resulted. Two Metro lines have been chosen based on soil type, and level of ground water wells boundaries. The length of Line One equals 4.283 km and passes through six stations while length of Line Two equals 6.907 km and passes through eight stations. The Metro mode can be extended to reach new places that will be important and densely populated in the future. It is recommended to extend the Metro network to include other areas in Gaza Strip by connecting the Metro network of the City with northern and southern governorates to solve traffic congestions in the future.

Keywords: Gaza City, Metro Network, GIS, Multi-criteria Analysis, Public Transport

I. INTRODUCTION

Public transport includes various transport services available to the general public including vanpools, buses, trains, ferries, and their variations. These services can play various roles in a modern transport system and provide various benefits, including direct benefits to users and indirect benefits that result if transit helps reduce automobile travel or create more compact [1]. The Metro is a type of public transport network. The METRO LRT Design Criteria Manual (2007) was developed as a set of general guidelines as well as providing specific criteria to be employed in the preparation and implementation of the planning, design and construction of new light rail corridors and the extension of existing ones [2]. The manual reflects the most current accepted practices and applicable codes in use by the industry. 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). In general, the screening criteria include multiple measures, such as engineering, economic, institutional, social, and environmental factors. Many researches use GIS and multi criteria spatial decision support systems for route site selection and to evaluate and design a new transportation modal. Reference [3] studies route/site selection of urban transportation facilities; an integrated GIS/ Spatial Multi-Criteria Evaluation (SMCE) approach to find locations that meet desired conditions set by the selection criteria through a comprehensive example of route/site selection of a planned Metro-Rail network. Reference [4] uses GIS model to design a new transportation modal. Socioeconomic and spatial data are used to identify components of the network; junctions and edges. Potential network elements and their associated attributes are subjected to Analytic Hierarchy Process (AHP) to rank alternatives. Metro system modal in Baghdad City is presented as a case study. Reference [5] studies the integration of GIS and multi criteria decision analysis. The research surveys the GIS based multi criteria decision analysis (GIS-MCDA) approaches using a literature review and classification of articles from 1990 to 2004. An electronic search indicated that over 300 articles appeared in refereed journals, provides taxonomy of those articles and identifies trends and developments in GIS-MCDA. Reference [6] overviews applications and future research directions regarding multi criteria spatial decision support systems. However, because of conceptual difficulties involved in formulating and solving spatial decision problems, researchers have developed multi criteria-spatial decision support systems (MC-SDSS). Reference [7] studies the impacts of transportation infrastructure on firm location and the effect of a new Metro line in the suburbs of Madrid. Statistical techniques and a spatial micro-level data base are used to evaluate the effects of Madrid's Metro line 12 expansion on business location patterns. Reference [8] studies the impacts of a Metro station to the land use and transport system having as a case study the (Thessaloniki Metro). Reference [9] investigates the establishment of a Metro mode system in Gaza City using an oriented questionnaire and finds that there is a satisfaction by the community to select "Metro" route as a public transport mode in the City.

II. THE STUDY AREA

Gaza City is located in the north of Gaza Strip at the southern side of the Palestinian coast on the Mediterranean. It is considered the largest Palestinian City in terms of population, and the second in terms of area compared to Jerusalem. The City's population reached 754,321 people in 2016, which is considered the largest gathering of Palestinians in Palestine [10]. The City area is about 56 km^2, which making it one of the most densely populated cities in the world. Knowing that Gaza Strip population exceeds 2 million people in 2016 that are distributed over an area of 365 km^2 [11]. Gaza City consists of 17 quarters, as shown in Fig. 1.

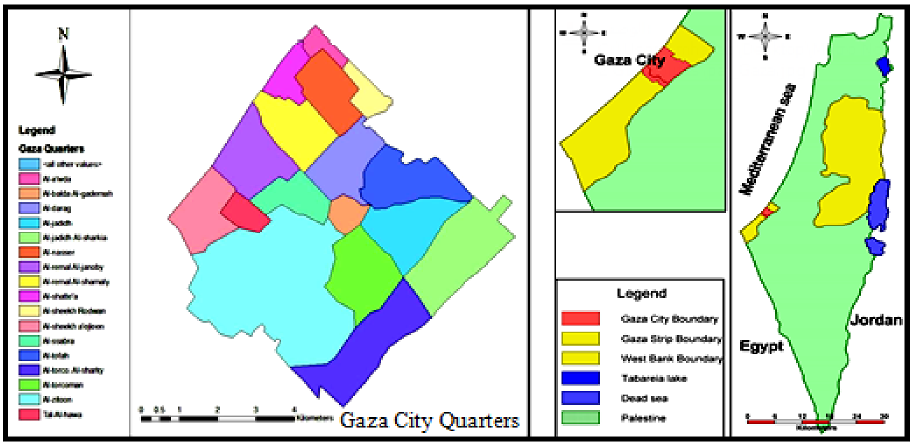

Figure 1: Gaza City location and its quarters

III. DATA COLLECTION

Data assembled in this study should include the following; Gaza population, vital places, road network, traffic data, land use, ground water levels in the City, soil type as well as planning standards related to this kind of research.

3.1 Gaza Population

Table 1 shows the population number in 2015 and the expected in 2037 for all quarters of Gaza City. Al-Shatte'a quarter is the largest quarter in terms of population, where the population is 118513 people in 2015. On the other hand, Al-Zitoon quarter is the largest quarter in terms of area, which reaches about 11329 donum

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Table 1: Population growth for Gaza City quarters [10]

Gaza Quarter Name	2015 Year			2037 Year	
	Population Inhabitant	Area Donum	Density Inh./Donum	Population Inhabitant	Density Inh./Donum
Al-A'wda	10864	764	15	23156	31
Al-Sheekh Rodwan	47405	1025	47	101045	99
Al-Nasser	43455	2044	22	92624	46
Al-Shatte'a	118513	975	122	252611	260
Al-Remal Alshamaly	28970	2379	13	61749	26
Al-Darag	65840	2430	28	140340	58
Al-Tofah	54648	2898	19	116482	41
Al-Jdaidh	47076	2754	18	100343	37
Al-Torcoman	63207	2899	22	134726	47
Al-Zitoon	86909	11329	8	185248	17
Al-Ssabra	36212	1516	24	77187	51
Al-Balda Algadema	36212	701	52	77187	111
Al-Remal Al-janoby	39833	2754	15	84906	31
Tal-Al-hawa	11588	794	15	24700	32
Al-Sheekh a'ejleen	26797	2219	13	57118	26

3.2 Vital Places in Gaza City

Gaza City, as a capital City of Gaza Strip, is a source of attraction for all people from various districts of Gaza Strip. It involves many vital places, which help to attract students, businessmen and patients as the main source of vital places. It also contains many of vital centers such as universities, hospitals, companies, public and private institutions, sport centers, ministries, and other vital facilities, as shown in Fig. 2.

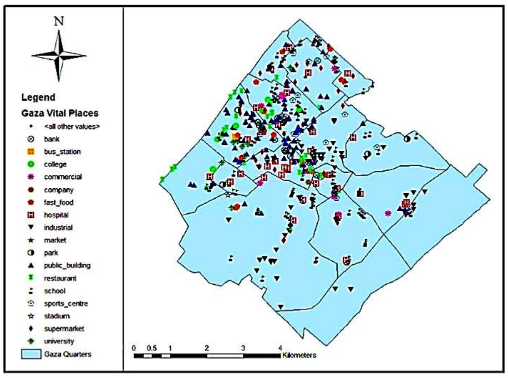

Figure 2: Gaza City vital places [10]

3.3 Gaza Road Network

Fig. 3 shows all road network in Gaza City, which are divided into primary, secondary, service, residential, track, and footway roads. All data of important roads in Gaza City including running and limit speeds, surface type, width, length and others are documented.

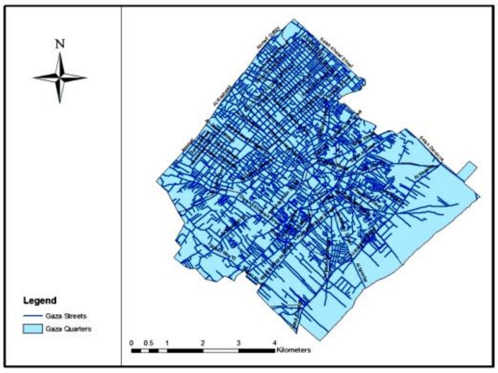

Figure 3: Gaza City roads [10]

3.4 Traffic Data

Two types of traffic data are obtained; the first one is the geographic location of available parking places near the important intersections in Gaza City and the second one is the importance level rank of each intersection according to traffic factors.

3.4.1 Parking Places in Gaza City

Data about parking locations in the City are gathered based on information from officials in Gaza Municipality and organized interviews with number of drivers that use these parking places, Fig. 4.

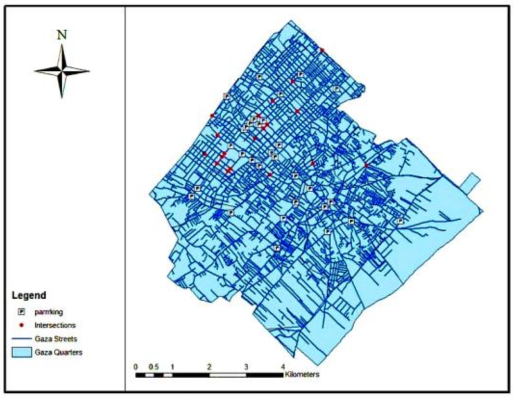

Figure 4: Available parking at important intersections in Gaza City

3.4.2 Traffic Importance Rank of Each Intersection

Fifty major intersections have been identified in Gaza City, based on traffic data count of vehicles at the City intersections. Traffic data count is obtained from the Ministry of Transport records and other counts conducted by researchers and professors at the Islamic University of Gaza. This information relating to the degree of importance of each intersection is ranked as: number 10 is the most importance (high traffic count) and number 1 is the least importance (low traffic count).

3.5 Gaza Land Use

Gaza City is composed of several areas, including agricultural, residential, vacant, and traffic lands, as shown in Fig. 5. The total area of agricultural lands is about 35.86 km ^{2}, residential lands is about 10 km^2, vacant land is about 7.32 km^2, and traffic land area is about 6.79 km^2.

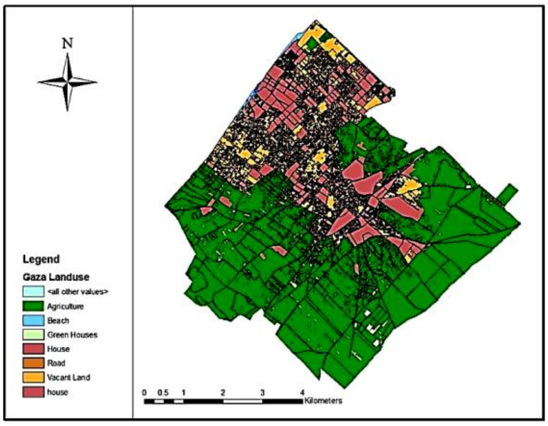

Figure 5: Gaza City land use [10]

3.6 Groundwater Wells Level in Gaza City

Data have been obtained regarding the level of all groundwater wells in Gaza Strip during the period from 2000 to 2010. Levels of groundwater wells (the distance between the natural surface of the earth and the water level of the aquifer) ranges from 16.63 m in the western area of the City on the coast line of the Mediterranean Sea to 73.55 m in the eastern area of Gaza City, Fig. 6.

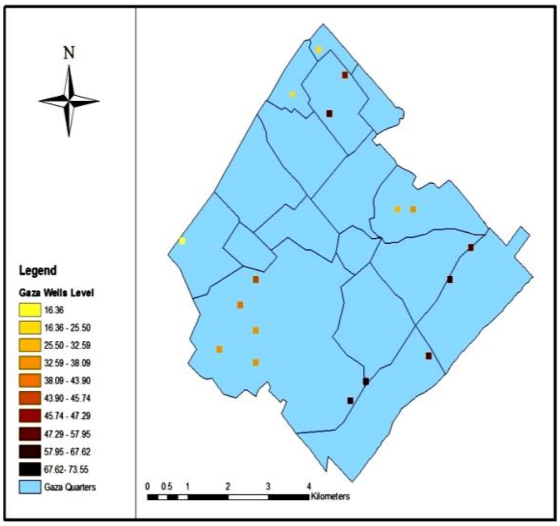

Figure 6: Groundwater wells level in Gaza City

3.7 Gaza Soil

There are three types of soil in Gaza City, such as sand, clay, and loam. Sandy soils are concentrated in the western area of the City along the Mediterranean coast, while all of loam and clay soils are concentrated in the eastern area of the City, as shown in Fig. 7. These data relates to the classification of soil based on the viability of each soil to dig through it to make Metro tunnel, where sandy soil is the highest susceptibility, that is the best soil, especially as one heads towards the east, and loamy soil is the lowest susceptibility, that is the worst soil.

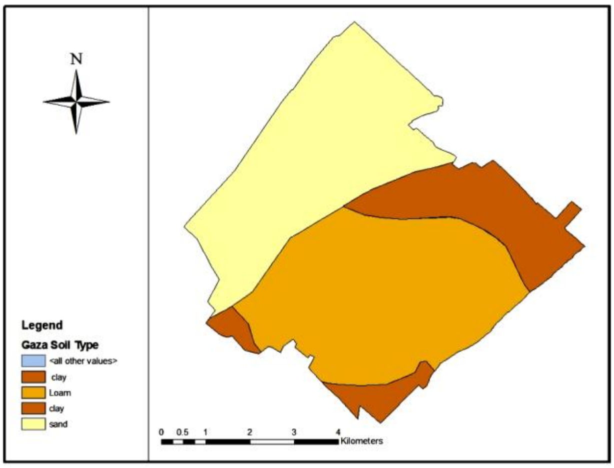

Figure 7: Soil type in Gaza City [10]

3.8 Planning Standards Related to Metro Project

The Ministry of Planning prepared a guide for systems and spatial planning standards in order to determine the size, density, location, and location requirements for different kind of land use. Data that have been obtained is related to the characteristics of the City quarter, which is a part of Metro project. Services in a quarter are five times the services in the neighboring with the provision of other extra services required at the whole level of the quarter [12]. The total area required for public services in the neighboring about 32.5 donum. The total area required for housing and services in the neighboring about 97.5 donum. The total area required for the transport 25% of the total area of the neighboring. Total area of the neighboring equals 130 donum (97.5/0.75). The necessary extra space in the quarter has allocated of services at the local level and the roads in which they serve. The total area required for the local center is equal to five times the area of neighboring added to the 36 donum and the necessary roads for it. Total area equals 698 donum (130*5) + 36/0.75. Quarter density = 4300/698 = 6.1 housing unit/donum. The geographic area of the planned Metro-rail project (network system) is given by the polygon map "Buffers" and is shown in Fig. 8. This map has a total of 50 Buffers. Considering that every buffer is a quarter containing all the necessary vital facilities. The total area of the buffer equals the total area of the quarter (698 donum). Thus, a 500 m buffer radius is considered to match this area. To each of these polygons, an identifier code is assigned from S1 to S50. Buffer attributes are the geometric area in square meters containing many data such as vital places, population, land use and traffic data. There are two determinants or control borders of data relating of Gaza City as a whole; one of them relates to soil type in the City, and the second corresponds to groundwater wells level.

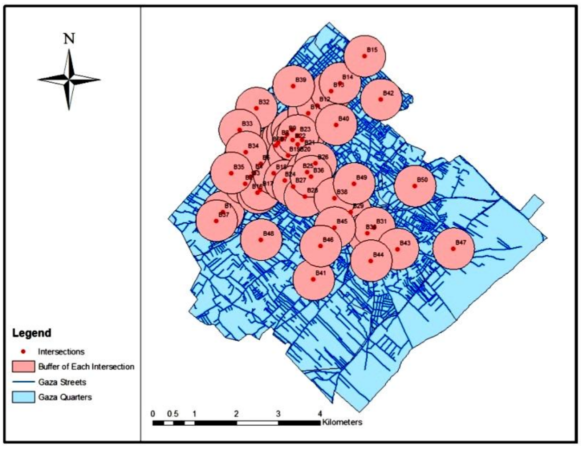

Figure 8: 500 m buffer of each intersection

IV. IDENTIFYING ASSESSMENT CRITERIA

As a simplified illustration of the site selection problem, that is to find the potential location of Metro-rail stations, considering the fifty important major intersections in Gaza City. This dependent polygon map has 50 buffers as it is depicted in Figure 8. Each buffer attributes include the following specific objectives (with their computed or estimated numerical data) for each polygon: C1 =Population density, C2 = Number of vital places , C3 = Available parking, C4 = Traffic importance of each intersection, C5 = Area of each intersection, and C6 = Land use. Each intersection buffer of each criteria is ranked using equal intervals classification method. In this classification method, each class consists of an equal data interval along the dispersion graph. To determine the class interval, the whole range of data (highest data value minus lowest data value) is divided by the number of classes that is decided to generate, as computed by equation 1.

$$Class\ Interval = \frac{(highest\ value - lowest\ value)}{number\ of\ classes} \quad , (1)$$

After that, the resulting class interval is added to the lowest value of data-set, which gives the first class interval. Adding this interval as many times as necessary in order to reveal the number of predefined classes (10 classes are considered). Rank 1 represents the lowest importance and rank 10 is used of the highest importance. As an example of ranking for C3, the number of parking of each intersection, each intersection buffer is classified based on number of available parking, where the high number represents the best buffer which has high rank, and low number represents the worst buffer which has low rank, as shown in Fig. 9. Fig. 10 shows the rank of each buffer according to its criteria using GIS tools.

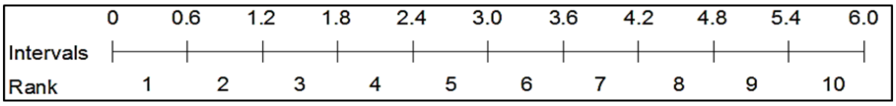

Figure 9: Rank of available Parking intervals

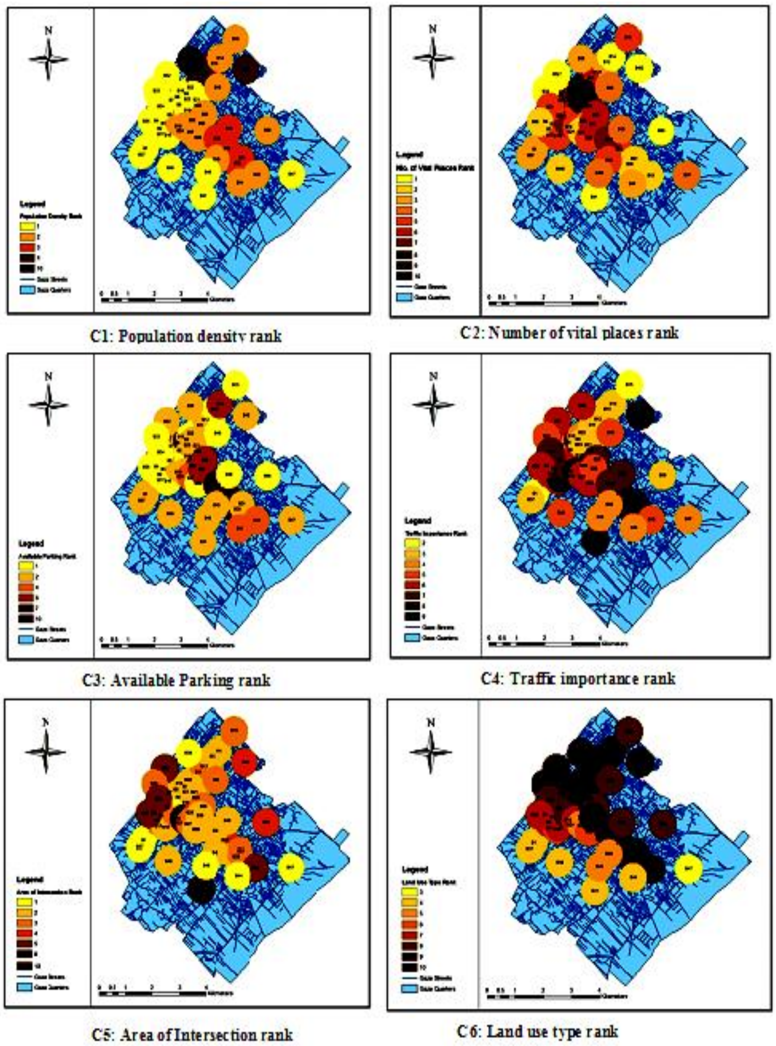

Figure 10: Map rank of each criteria

V. WEIGHTING EVALUATION CRITERIA

To choose the suitable locations of Metro-rail stations, only one specific objective from each set of the six sets of the major objectives is selected. Each of previous criteria has a weight which is confirmed by experts in road engineering and transport systems. The total of all criterion weights must sum to 100 as shown in Table 2. From spatial analyst in GIS software, the composite suitability score of all previous raster data can be calculated to obtain one suitability map which concludes all criteria data. This can be calculated by multiplying each criteria rank by its weight according to equation 2.

$$S = \sum_{i=1}^{n} C_i * W_i \quad , (2)$$

Where:
S: the composite suitability score,
C_i: criterion scores (cells), and
W_i: weights assigned to each criteria

Table 2: The total of all criterion weights

No.	Criteria	Weight (%)
C1	Population density	30
C2	Number of vital places	30
C3	Available parking at each intersection	15
C4	Traffic importance of each intersection	10
C5	Area of each intersection	10
C6	land use	5
Total		100

Each buffer of each intersection have a composite suitability score, where the buffer with low rank is the worst case (buffer with light color), and the buffer with high rank is the best case (buffer with dark color). Selection of the best stations of Metro lines can be based according to all composite suitability scores map of each intersection buffer as shown in Fig. 11.

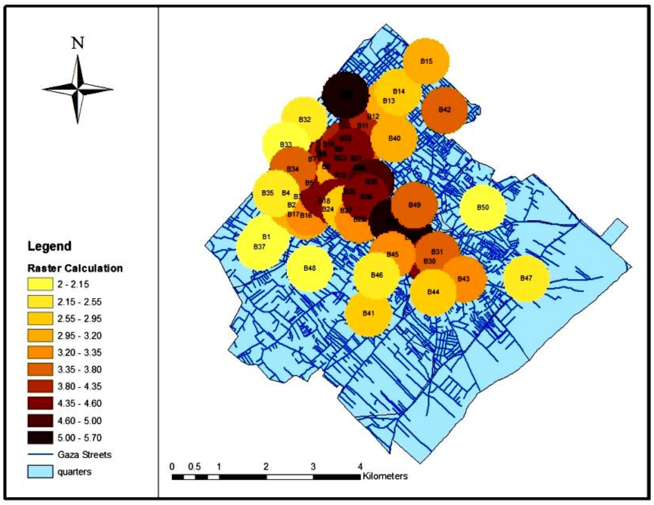

Figure 11: The composite suitability map score of all criteria

VI. SELECTION OF METRO SITE ROUTE

To draw the best Metro line routes, the best buffer that have high score should be chosen, as a Metro line station taking into account the distance between stations to match the international standards that have been reviewed in Section One. The longest tunnel distance between two stations is 2.5 km and the shortest distance is 297 m [13]. In addition, the level of groundwater wells in Gaza City and soil type that Metro routes may pass through should be considered. Reference [13] displays the minimum depth of Metro station requirement as 4.3 m which is achieved in its case for Gaza City. After connecting between the best buffers based on the criteria that have been mentioned, three Metro lines can be obtained as shown in Fig. 12.

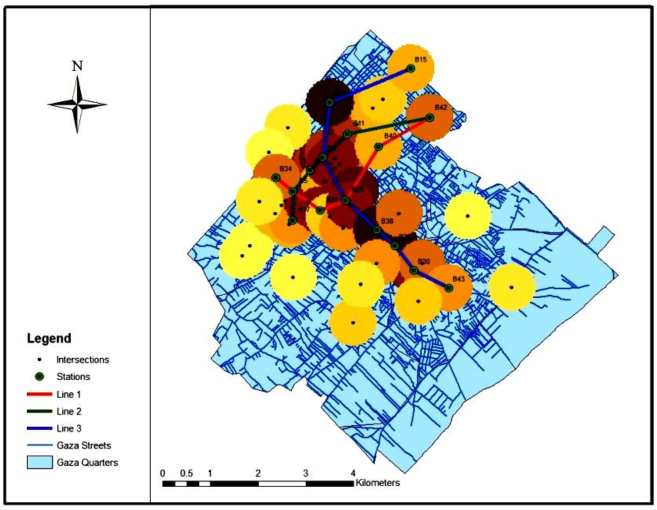

Figure 12: The three Metro lines

Because of the convergence of Line 2 (red color) and line 3 (green color), and because that both have the same origin and destination, one of them should be chosen. Line 2 is located to the east of Line 3, in the best sandy soil. In addition, the level of groundwater wells ranges from16.63 m in the western area of the City at the coast line of the Mediterranean Sea to 73.55 m in the eastern area. This means that the depth of water level of aquifer will increase if it heads towards the east. Metro line is established in the area above the water level of the aquifer and below the natural ground level. Thus, Line 2 is preferred than Line 3. Fig. 13 shows the two suggested routes of Metro which have been chosen. Table 3 summarizes all data of the two Metro lines such as, number of each station, distance between stations, total length of each Metro line.

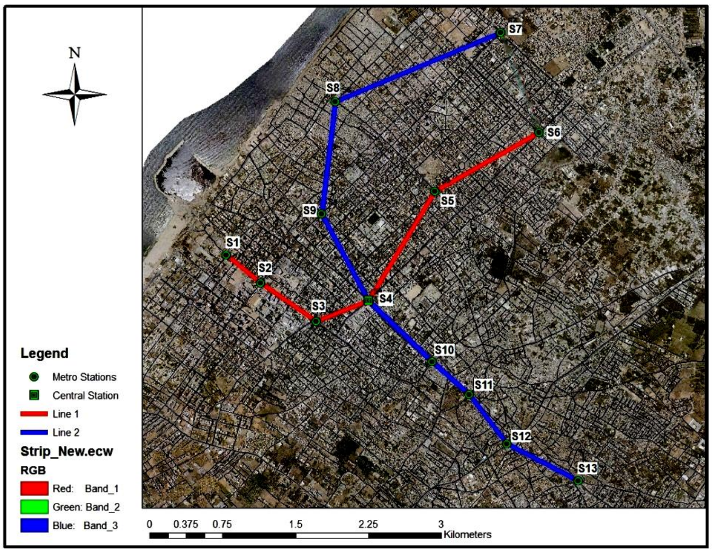

Figure 13: The suggested Metro lines

Table 3: Summery data of the two Metro lines

Metro Lines	Number of Stations by	Station Name	The Line Between Two Stations	Distance Between Two Stations (km)
Line 2 Red Color	6	S1	S1-S2	0.455
		S2	S2-S3	0.697
		S3	S3-S4	0.576
		S4	S4-S5	1.325
		S5	S5-S6	1.230
		S6	Total	4.283
Line 1 Blue Color	8	S7	S7-S8	0.820
		S8	S8-S9	0.641
		S9	S9-S4	0.510
		S4	S4-S10	0.908
		S10	S10-S11	1.020
		S11	S11-S12	1.167
		S12	S12-S13	1.841
		S13	Total	6.907
Total Metro Route Length				11.190

VII. FUTURE EXTENSION OF METRO NETWORK

The suggested Metro routes can be extended to reach new places which will be important and densely populated in the future. When creating Metro lines, attention is paid to consider the important buffers which are located at the border of North, South and East of Gaza City as the main stations that Metro network start for expansion to include other areas in the City as well as outside the City. Fig. 14 illustrates these stations; station S6, and S7 which connects Gaza City with Northern Governorate, where Line 1 or Line 2 can reach to the northern regions, station S1 which connects Gaza City with Southern Governorate, station S13 which links Gaza City with eastern regions, and station S12 which connects Gaza City with Northern and Southern Governorates through establishment of a third Metro Line.

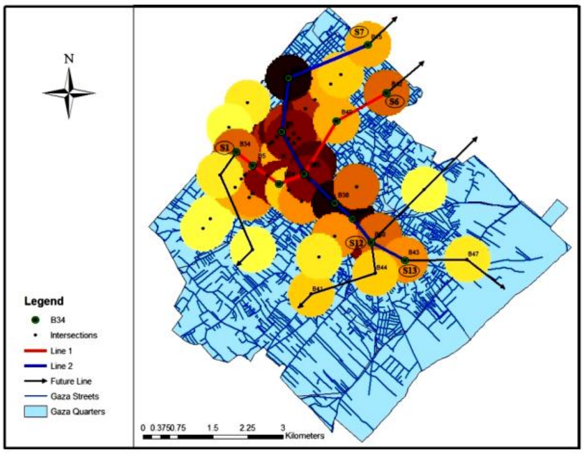

Figure 14: Future extension of the Metro network

VIII. CONCLUSION AND RECOMMENDATIONS

Fifty intersections in Gaza City have been chosen as candidate sites for Metro-rail stations, with 500m buffer of each intersection. The criteria that used to choose the best stations of Metro line was population density, vital places, available parking, area of intersection, traffic important of intersection, and land use. The criteria boundary that used to choose the best line was soil type and ground water wells level. By using multi criteria decision analysis and GIS, three routes are resulted. Two Metro lines have been chosen based on soil type, and level of ground water wells boundaries. The length of Line One equals 4.283 km and passes through six stations while length of line two equals 6.907 km and passes through eight stations. The Metro mode can be extended to reach new places that will be important and densely populated in the future. As a result of this study, the following recommendations are depicted:

1. Effective measures in the short term to improve the public transport services as part of a comprehensive long term transport plan should be taken by Ministry of transport.
2. Formation of a committee to develop an integrated strategy to start implementing the steps to create Metro project that includes members of General Authority for Investment, Ministry of Public Works and the Ministry of Transport.
3. Developing a feasibility study for the Metro project to find out the total cost of the establishment and operation.
4. Using of international companies specialist of Metro projects that is enjoyment of a long and broad experience in infrastructure projects, through the development of preliminary studies, which include the general plan, capital costs and technical perceptions of the project.
5. Implementation of economic feasibility studies on both technical and financial support, and make recommendations about the best way to restructure the project, in addition, choosing the authority that oversees the development, operation and maintenance of the Metro network, taking into account the building, operating, and transport mechanism
6. Renovation of the road and transportation network to increase access to many areas, which leading to an increase in the value of land, land use change, and economic returns.
7. Restructuring of many areas, based on the new Metro network, where there is a relation between traffic moving in the City and the use of land as the source of origin and distention, in addition, distributing services and activities sites based on easy access to it, in order to achieve appropriate economic return.

8. Added waiting grouped areas near Metro stations, whether horizontal or vertical parking to encourage private car users to use the Metro.
9. Development of suburban areas that are the Metro up to it, through creation of Metro service centers pulls them some activities accumulated in the central City due to its ease of access and cheap price of land.
10. Re planning pedestrian paths within surrounding areas of Metro stations with adequate widths for these paths and linking them by elements of coordination of the site and taking into account the visual elements and aesthetic.

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