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GIS-Based Prediction of Metro-Line Impact on Accessibility in Public Transport by Modelling Travel Time: A Case Study of North-Western Zone of Algiers, Algeria

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Abstract

In the context of the modernization of Algiers capital, the transport-sector efficiency is one of the actions undertaken to ensure its development. Among the projected means, the metro which enables a better accessibility. Indeed, the objective is to study the impact of the planned metro-line on the accessibility towards the major urban projects recently built in the north-western part of Algiers that has the mostly suffered by the isolation. This study was carried out using GIS and the cumulative opportunity indicator which is focused on travel-time calculation. The measurement of the access quality of the inhabitants to three major urban-projects (destinations) has done according to defined time-thresholds, including all the travel-components of public-transport. Two possible scenarios of different public-transport network were taken in consideration to demonstrate the accessibility changes. The results revealed the positive impact of the planned metro-line in reducing the unequal accessibility to various urban projects, notably the Al-Qods commerce and business centre and medical school, where the population benefiting of an access of less than 30 mins, will increase, respectively, from 30% to 44% and from 12.5% to 30%. However, the Algiers Opera is the least accessible destination, excluding the zones crossed by the metro-line, where only 8.4% of the population who will have access to this equipment at less than 30 mins.

Keywords: Accessibility; Public transport; GIS; Urban projects; Travel time; Algiers

Introduction

The urban expansion phenomenon known in the cities since the middle of 20th century, was followed by a succession of innovations in the transport modes (cars, metros, tramways etc.) allowing daily travels of long distances [1,2]. With the pendular migrations growth, these travels were increasingly confronted to the constraints, namely, transport times and costs increasing, congestion and pollution [3,4]. However, the access to different urban activities without constraints, presents today one of challenges for cities around the world. Increasingly, accessibility is identified as a key criterion to assess transport policies and a performance indicator that can link land use and transport [5]. Furthermore, the increasing interest in sustainable development has further underlined the importance of accessibility as a key indicator to assess urban form, the density and spatial distribution of people and activities, as well as urban policy [6-14]. Several authors cited in the literature, have developed better methods to improve the accessibility measurement. Hansen [15] was the first to undertake an empirical study of the accessibility based on the gravity model, in which he defined it as "the potential of opportunities for interaction". Many researchers have further developed the concept of accessibility by introducing new parameters, namely, Person-based accessibility measures founded on space-time geography [16,17] and utility-based accessibility measures (dependence between the different destinations and their perception by each individual) [18-20]. By the way, three articles propose a very interesting review of indicators and calculation methodologies, it concerns the works of Handy and Niemeier [21], Geurs and Ritsema van Eck [22] and Geurs and van Wee [23]. Due to the harmful effects such as air pollution and traffic congestion, yielded from the dependency of the private car on human and the environment [4,24] the accessibility by the public transport modes has increasingly become more important in the accessibility studies [25-31]. In fact, public transport systems contribute to a large share of the movement of people and have an extremely important socioeconomic role and lead to the equilibrium and the sustainable evolution of any region [32]. However, the transport service quality affects significantly the accessibility [33]. If satisfactory, accessibility will be favored, otherwise, the inadequacy between the offered services and the desired accessibility (low frequency, quasi-non-existent service at certain times, poor interconnection, etc.), makes certain places more or less inaccessible. The population growth and urban expansion phenomenon towards the peripheries in the capital Algiers, has increasingly driven important needs for travels. This phenomenon led to the opportunity of opening up urban transport activities by bus to private operators, but without bringing definitive and sustainable solutions owing to the absence to taking of real responsibility of transports in urban planning [34]. Recently, the transport mode based mainly on road transport, was reinforced by the opening of the first tramway East-line, first metro line and electrification of suburban railway networks. As far as our literature could ascertain, no information is available on the accessibility study in Algiers. The western part of Algiers which includes height municipalities, is considered important of a socio-economic point of view. In fact, these municipalities represent new emerging centers of economic activities and major urban projects (attractive poles), which generating increasingly important displacement flows. In return, this part constituted the less well-served zone by the public transports, which probably recurs to its recent urbanization

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compared to the eastern part, as well as to topographic constraints (mountain barriers), that characterizes the region (Figure 1). The studies conducted by the bureau d'études des transports urbains (BETUR 2013) in the context of the extension of the metro-lines expected in wilaya of Algiers, provided new information on public transport. In this regard, the objective of this study is to model the public transport by exploiting the data provided by BETUR (2013) using a geographical information system (GIS), to firstly analyze the accessibility on travel time by the public transport, by choosing three major urban projects as destination in North-western part of the capital, which will allow us to verify the hypothesis of a disparity in the level of access to these equipments. And secondly evaluate the effects of the programmed metro-line on the accessibility.

Study Area and Data Used

Study area

Algiers, the political, administrative and economic capital of Algeria, includes the largest concentrations of populations, activities, services and infrastructures in the country. It is spread out over an area of 809.22 km^2 and contains 57 municipalities grouped in 13 administrative units. Since the year 1962 (after independence), Algiers has seen a galloping population growth mainly due to the: rural exodus, unequal development in the other country regions, administrative centralization…etc. In fact, this city with a population of 979916 inhabitants in 1966, has recently recorded almost of 3 million of inhabitants, with an overall density of 3642 inhabitants per Km^2. This phenomenon was accompanied by an urban expansion towards the periphery where resides 72.61% of the total population of the Algiers (ONS 2008). In fact, this spreading is caused by the saturation of the central tissue, where the statistics of ONS show that the rate of the population growth that drifts from the hyper-center and city-center towards the periphery between 1987 and 1998, rose from -1.26% to -3.2%, and between 1998 and 2008, rose from -0.28% to -1.2%. This is expressed by a development of an important built-environment, even a disproportionate growth of former suburban agglomerations, which is translated by satellite swelling then a spatial link. This study focused on the north-western part of Algiers, which presents a natural constraint of accessibility. It extends over the Algiers Sahel, a coastal hills zone with variable altitudes generally more than 200 m and the highest elevation is culminated at 410 m in Bouzareah. It is constituted by 8 municipalities namely: Bouzareah, Beni-Messous, Chéraga, Dely-Brahim, Ben-Akoun, Ouled-Fayet, Draria and El-Achour (Figure 1), forming an urban unit with a heavy-urbanization rate exceeding 90% (RGPH 2008). This zone is part of Lot 4, established by BETUR under the preliminary studies of metro-line extension.

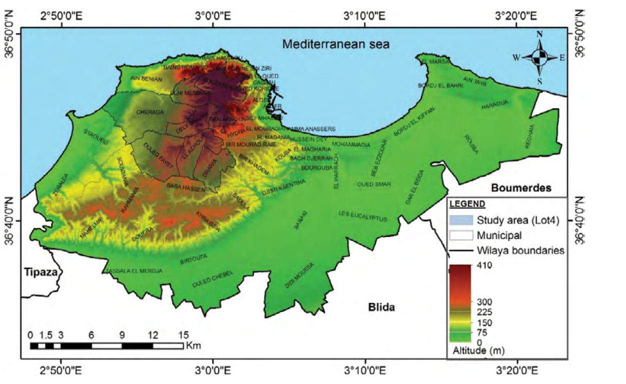

Figure 1: Study area.

In 2008, the population in the study area was 367,684 inhabitants, or 12.30% from the total of Algiers, and in 2013, this population reached 418,921 inhabitants. During this period, the average annual rate of growth equals to 2.79%, which is higher than that of Algiers (2%) (BETUR 2013). The largest population rate is recorded in the municipality of Draria (7.9%), and the lowest is recorded in the municipality of Bouzareah (1.6%). This heterogeneous growth is caused by the filling of the available land (separated by the relief). In 2025, the population should considerably increase and will reach 538,017 inhabitants (Figure 2).

Transportation little varied and a demand in addition

The development of the various economic-activity sectors in this area and the presence of major facilities have led to significant travel needs, notably Bouzareah, Cheraga and Ben-Aknoun, which represent the main travel sectors in the study area and in all Algiers (BETUR 2013). The public transport system of this area is based solely on a bus network, the train was excluded from the beginning due to the rugged terrain. In total, there are 43 public and private line-bus with a circulating fleet of 431 buses and an available capacity of 20 480 seats (BETUR 2013). The bus network is heterogeneously constructed, consequently the coverage of public-transport network is good in some municipalities such as Bouzareah, Beni-Messousand Ben-Aknoun, and insufficient or weak in other municipalities, in particular Ouled-Fayet and Dely-Brahim, with only one line-bus and El-Achour with no transport line (Table 1). This causes from day to day the problem of accessibility, locally between the municipalities that structure this area and in the whole of Algiers agglomeration. With the opening of Algeria to the global economic, the import of private-cars has allowed its wide use, which served as a temporary relief-buoy for the transport. However, the insufficient road-network that runs through the area is quickly submerged by traffic, which renders this area the most inaccessible.

Recently, various investment program for the heavy public-transport has been launched, namely: the realization of the first metro-line (in service) and its future extensions (under study and construction), the first tramway-line (in service) and its future extensions, the railway-line electrification and the new cableway lines. The superposition of all

Municipalities	Number of lines	Number of buses	Capacity (seats)
Bouzareah	15	129	6360
Beni messous	1	10	400
Cheraga	11	120	5460
Daly Brahim	1	25	1000
Ben Aknoun	12	126	6180
Ouled Fayet	1	8	560
Draria	2	13	520
El Achour	0	0	0
Total zone	43	431	20480

Table 1: Description of the public transport network of the study area.

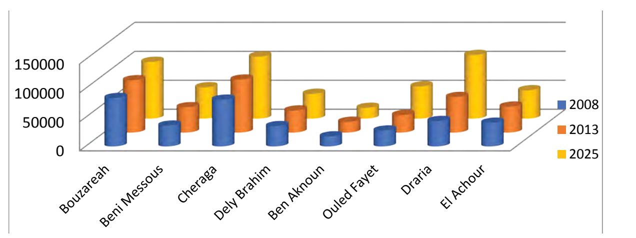

Figure 2: Population growth between 2008 and 2013 and projection of population by 2025.

these projects will allow a good connection between the hyper-centre and the east and south of the Algiers (BTEUR, 2013). Nevertheless, the western side of Algiers remains uncovered by this heavy network, which prompted the public authorities to evaluate in 2009, the suitability to construct a second metro-line linking the hyper-centre with the West of Algiers in connection with the first metro-line by 2025. This extension with a length of about 14 km, presents a bifurcation towards Chevalley, Delly-Brahim, El-Achour and Draria with approximatively 8 km by 8 stations and another towards Delly-Brahim, Cheraga and Ouled-Fayet with approximatively 6 km by 6 stations (Figure 3).

Data used

In the context of this study, some information is required to accomplish the work and to meet our objectives. In fact, population data were used to measure the accessibility to these major projects. These population data were obtained by BETUR for the year 2013, which were estimated on the basis of the RGPH, 2008. Information concerning the public-transport network and the road network were also used, and provided by BETUR, Transport Ministry and Transport Directorate of Algiers. It concerns on the one hand, road-network characteristics: the existing road types and their maximum speeds, and on the other hand, all that is related to the network of transport namely: line itineraries, their frequency at the peak period (15 h 00-18 h 00), existing stations and their locations, etc. Finally, information about the major urban projects were obtained from Plan Directeur d'Aménagement et d'Urbanisme (PDAU) of Algiers.

Methodology

The modeling approach used to measure the accessibility at the poles of major urban-projects in public transport, is based on two transport supply scenarios: 1) Scenario 1 (current situation): reflecting the situation of the transport network in the study area established in 2013 (base year). 2) Scenario 2 (Long-term situation): reflecting the transport network of the study area after the installation of the metro line by 2025. Figure 4 shows the steps taken in the methodology.

Study area splitting in micro-zones

To analyse the accessibility to major facilities, it is necessary to know the distribution of the population by micro-zones. On the basis of the spatio-functional homogeneity of urban tissues, BETUR has split the study area into 72 zones (Figure 5b). The distribution of the population in these micro-zones presents a wide disparity, for example, it is found

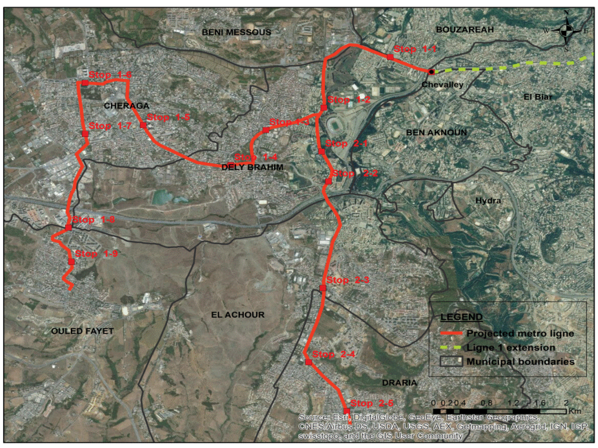

Figure 3: Metro-line programmed in the study area.

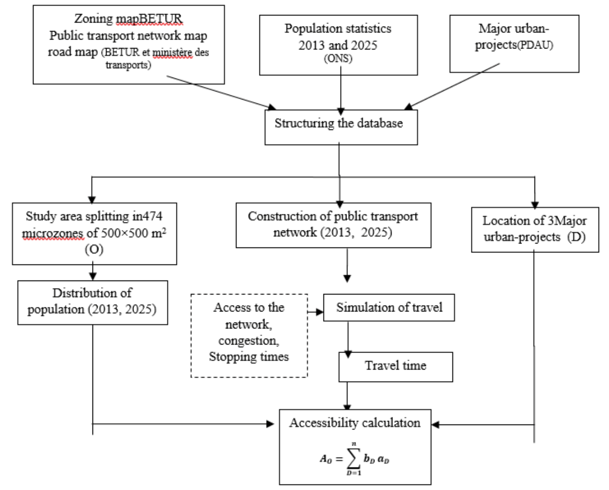

Figure 4: Methodology of the study.

Figure 5: (a) Number of population by zone BETUR. (b): Superposition of BETUR zones with micro-zones. (c) Number of population by micro-zones.

that an area of 16.64 km² regrouped 30,349 inhabitants while another area of 0.12 km² regrouped 208 inhabitants. Accordingly, splitting at a finer zonal level is necessary in order to have the variation of the distribution of the population within the same zone. Since no other organism was able to provide us the desired population data, we have disaggregated a number of populations (Pmz) at the micro-zone level [13,35] of 500 × 500 m² (Figure 5c) using equation 1.

$$P_{mz} = \frac{P_z}{N_{mz}} \tag{1}$$

where, Pz is the number of population provided from the BETUR zone (Figure 5a) and Nmz is the number of micro-zones (500 × 500 m) located within each BETUR zone (Figure 5b). The study area was split into 474 micro-zones, and their centroids represent all their characteristics and populations. In fact, all displacement from each micro-zone is carried out from its centroid. This means that an individual is not localized at a specific point in the micro-zone, but at its centroid. Accordingly, the accessibility measure becomes more realistic and more accurate than other aggregated spatial units have been used such as municipalities or BETUR zones, and these microzones allow a better and easier estimation of travel times.

Creation of transport network in the GIS

A transport network covering the entire study area was defined in order to represent the transport supply between the different zones. This was established in the GIS (Figure 6), as follows:

- A layer of roads with its attributes: type, empty speed, length.
- A layer of public-transport lines linked to the crossed road network.
- A layer of public transport stops.

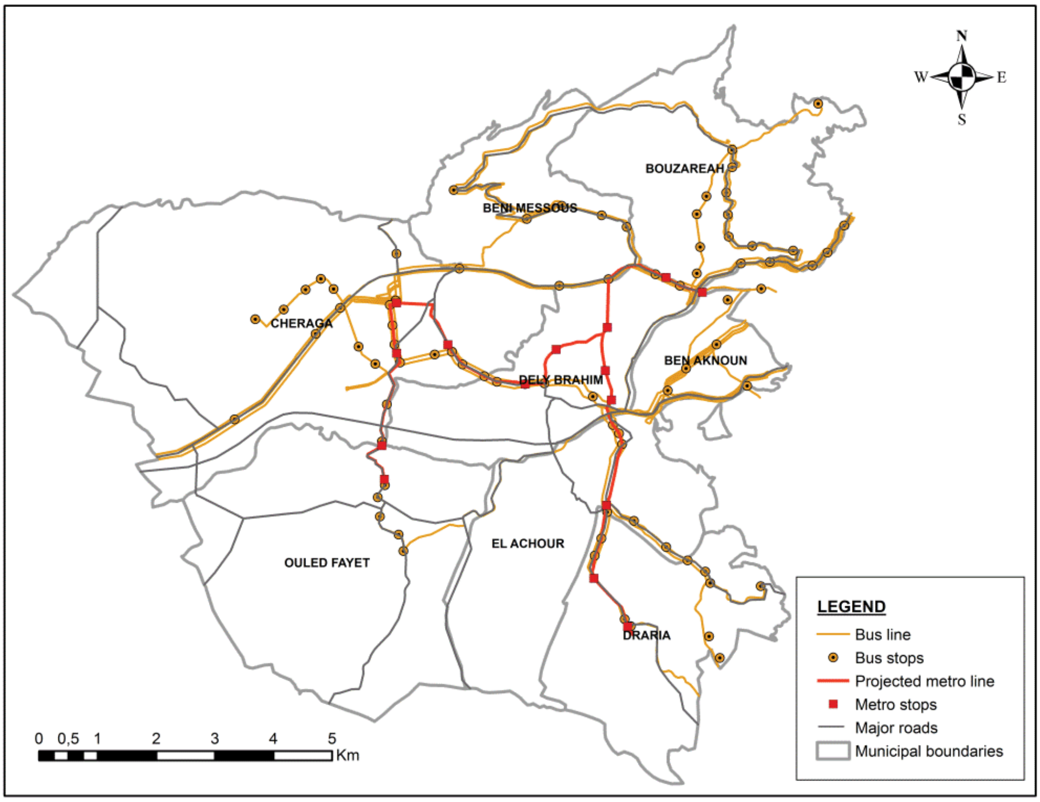

Figure 6: Public-transport network of the study area.

Destinations

Three major projects were chosen as destinations to measure the accessibility to their locations by public transport. The characteristics of these three destinations were given in the Table 2. These structuring projects have been implemented in recent years to contribute to Algiers's affirmation as a world city, as well as to participate in the structuring of urban tissue of the capital by promoting new centralities (PDAU 2010).

The projects are:

- The Algiers Opera, a major infrastructure dedicated to arts, it is the first building of this kind, called to raise the Algerian culture at global level.
- The Al-Qods business and commercial centre, a space for exchange and communication for professionals and also a space for sales and service delivery.
- The Medical school, which strengthened the infrastructure of the higher education sector and scientific research, particularly in the field of medicine.

Travel-time calculation

Our accessibility measure is based on the estimated travel-time between the origin zone (O) and the destination zone (D). For such needs, several elements should be primarily defined and calculated. The elements are:

Access time to the public-transport network: The splitting of the study area into micro-zones, which expresses more detail, allowed us to calculate the access time to the public-transport network for a crow-flies distance (a direct line), between the centroid of a micro-zone and the nearest network stop from this centroid, with a walking speed estimated at 4 km/h. This is also applied to the final walking (between stop and destination)

$$T_m = T_{mO} + T_{mD} \tag{1}$$

where,

$$T_{mO} = \frac{d_o}{4km} \times 1h \tag{2}$$

and,

$$T_{mO} = \frac{d_D}{4km} \times 1h \tag{3}$$

where, d_O is the distance between the origin and the nearest stop, and d_D is the distance between stop and the destination.

The waiting time of departure or in correspondence: The waiting time of departure or in correspondence (WT) is calculated from the frequency of the public-transport line borrowed. By suggesting that the user arrives randomly at the public transport station and does not know precisely the time of passage of the line, we have calculated the minimum average of the waiting time as follows:

$$WT = \frac{0.5 \times 60\,\text{mins}}{\textit{frequence per hour}} \tag{4}$$

where, 0.5 is a coefficient used to obtain the mean of the waiting time [28,30]

Destinations	Location	Area (m²)	Description
Opera of Algiers (cultural pole)	Ouled Fayet	35000	A large auditorium with a capacity of 1400 places, Dance halls, repetitions and Workshops, Cafeterias, ample parking.
Al Qods (commerce and service pole)	Chéraga	160500	Spaces of National and international representation, 430 commercial locals, 145 offices, 2 Restaurant, parking 1100 seats.
Medical school (scientific pole)	Ben Aknoun	42000	Departments of Medicine (6000 seats), de Pharmacy (2000 seats) and of Dental surgery (2000 seats), 13 Amphitheatres, 49 classrooms, 76 TD rooms and laboratories, 3 libraries et 5 Dental clinics (200 seats).

Table 2: Destinations characteristics.

Travel time by car: The travel time by car (TT) is calculated during the peak period between 15 h and 18 h according to equation 5, based on the length (L) of the road borrowed, its empty speed (V), as well as the frequency of the lines (fB), in order to take into account the delay on the roads due to traffic congestion. The bus stopping time (Ts) has also been taken into account, which is estimated to be one minute. The equation is as follows:

$$TV = \frac{L}{V} + T_s + f_B \tag{5}$$

We have preferred the shortest and fastest links and those offer the fewest correspondences.

Total travel time: The travel time (T_{VT}) presents the total travel time from the origin zone (O) to the destination zone (D), calculated as follows:

$$T_{vT} = T_{mo} + TA_1 + TV_1 + TA_2 + TV_2 + T_{mD} \tag{6}$$

Where, T_{VT} is the travel time, T_{mO} is the walking time from the origin to a nearest bus stop, TA_1 is the waiting time of public transport 1, TV_1 is the travel time of public transport 1, TA_2 is waiting time in correspondence (if there is), TV_2 is the travel time of public transport 2, T_{mD} is the walking time from the final stop to the destination.

Accessibility calculation

Once the travel time is calculated, accessibility will be calculated from each micro-zone (centroid) towards each previously cited equipment for both scenarios (Figure 6), according to the cumulative-opportunities indicator (isochrones) [36-39] as follows:

$$A_O = \sum_{D=1}^{n} b_D a_D \tag{7}$$

Where, A_O is the accessibility from the zone of the origin, a_D is the number of opportunities in the destination zone (population), b_D is a binary value, equal to 1 when the destination is within the predefined time threshold, otherwise it is equal to 0, and n is the destination number (in our case study, n=3).

This method identifies the number of people who can reach an equipment within a time threshold of a travel, which will enable us to compare the level of accessibility between the micro-zones and measure their changes induced by the new transport project (metro).

Results

The results presented in Figure 7 show, for each major project, two accessibility scenarios. The accessibility in the first scenario is calculated by taking into account the bus network and the second scenario by taking into account both the bus network and the programmed metro line. The accessibility to major urban projects was affected at 5 time intervals associated with the population served (Table 3). That, allowed us to distinguish the accessibility changes between the two scenarios at the micro-zone level.

Discussion

In the current situation, the comparison of the accessibility between the poles of major projects (Figures 7a, 7c and 7e) shows the privileged position of the Al-Qods business and commercial centre (Figure 7a), where almost of 30% of the population in the study area may access at less than 30 mins (Table 3). In fact, Al-Qods has a good accessibility in public transport thanks to the convergence of several bus lines directly serving this equipment. By 2025, the accessibility improvement is observed towards AlQods from the whole of the study area, notably in the vicinity of the metro line (Figure 7b), where the population coverage that may access at less than 30 mins has increased to 44% (Table 3).

The Metro impacts on the public-transport users have also been observed on accessibility towards the Medical school in Ben-Aknoun, as it will be served by the metro from the Chevalley station. The travel time has improved at less than 45 mins or less than 30 mins in the most remote areas and which represent the lowest accessibility today (Figures 7c and 7d). This is explained by the fact that these areas are linked to metro-line, serving the faculty, by efficient bus lines. Thereby, 50% of the population that has access to the Medical school with a travel time of more than 45 mins, will be reduced to 29% in 2025, where the 21% of the population will have access to less than 45 mins (Table 3). However, the Algiers Opera represents the least accessible destination (Figure 8), in fact, 81% of the population has low access to this equipment (Table 3). An increase in accessibility was identified in 2025, in certain areas crossed by the planned metro line or sited close to its stations, mainly the Dely Brahim and Cheraga municipalities, with a travel time less than 60 mins (Figure 8). However, the Algiers Opera is remained poorly served by public transport, despite the extension of the metro line to Ouled Fayet, due to the absence of a bus line connecting Opera and metro. The nearest bus stop is sited at about 20 mins from this equipment, so a combination with walking is necessary for the collective transport users to reach it. To better understand the results, the Figure 8 showed the cumulative population access to the three major urban projects by public transport in function of time. These cumulative curves showed accessibility gaps between the two present and future scenarios. Therefore, these curves showed the impact of the planned metro line on the accessibility towards these major urban projects. For Al-Qods and medical school, the greatest gap of access is observed at 45 mins. The population access to AlQods and Medical school at this time increased respectively, from 64% to 78% and from 52% to 71% in the long term (by 2025). On the other hand, for the Algiers Opera, the gap is more remarkable at the longer access time (60 mins). The 19% of the population having access to this equipment in 2013, have evolved over the long term to reach 54% of the population that can access it in this time by collective transport.

Conclusion

The aim of this study was to analyse the accessibility in travel time of public-transport and to predict the impact of the planned metro-line on the accessibility to three major urban projects in the north-western part of Algiers. The accessibility calculated using the conceptually model

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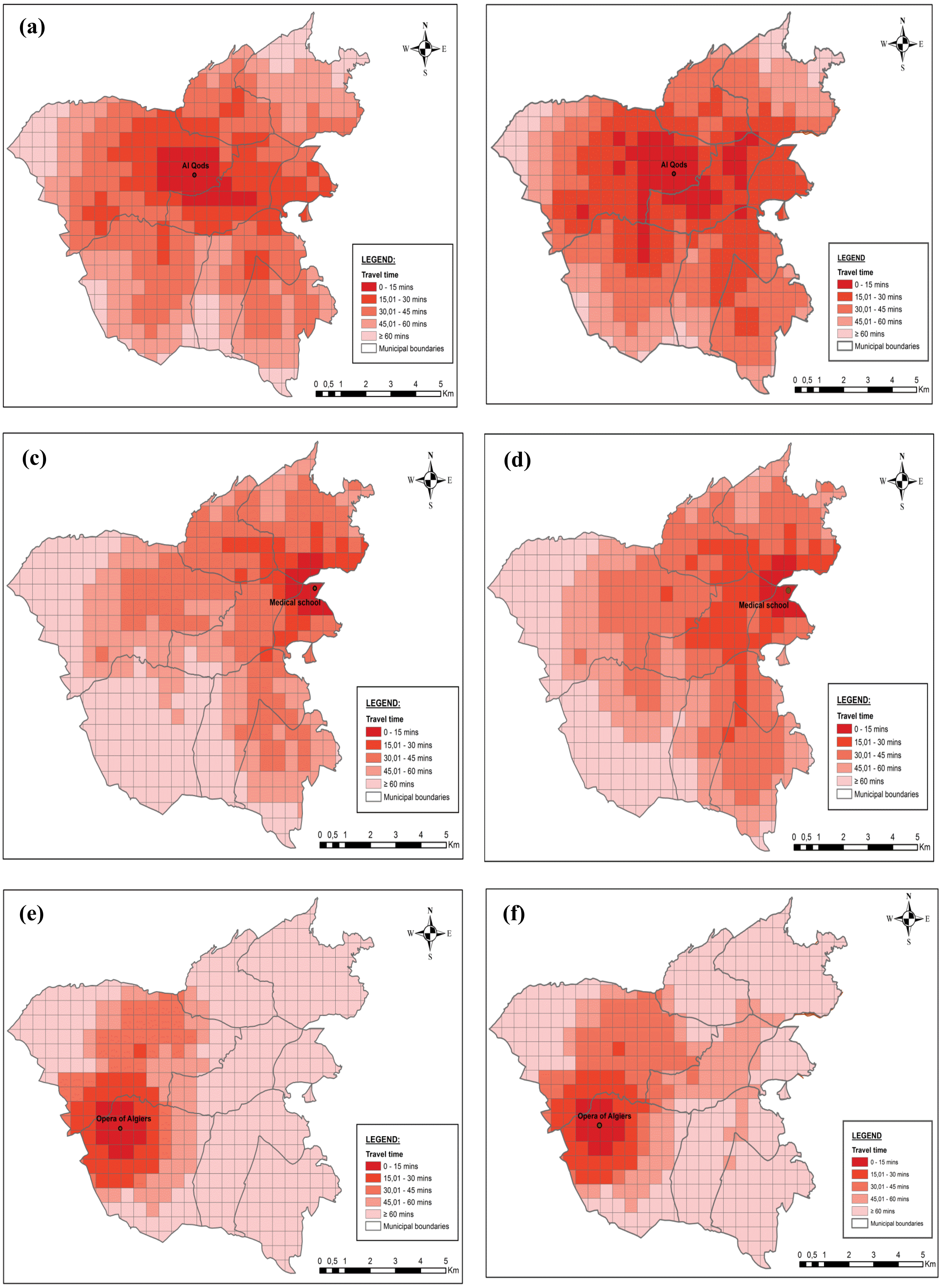

Figure 7: Accessibility to major urban projects by public transport (based on isochrone measurement). (a) : Accessibility to Al Qods, scénario 1. (b) : Accessibility to Al Qods, scénario 2. (c) :Accessibility to the Medical school, scénario 1. (d) Accessibility to the Medical school, scénario 2. (e) : Accessibility to the Opera Algiers, scénario 1. (f) : Accessibility to the Opera of Algiers (scénarion 2).

	Al-Qods business and commercial center				Medical school				Opera of Algiers			
	Pop served (Scenario 1)	%	Pop served (Scenario 2)	%	Pop served (Scenario 1)	%	Pop served (Scenario 2)	%	Pop served (Scenario 1)	%	Pop d served (Scenario 2)	%
0-15 mins	37879	9.1	82781	15.38	21349	5.1	32281	6	3956	0.9	12202	0.9
15.01-30 mins	86325	20.6	148566	27.6	31003	7.4	129124	24	9418	2.2	40385	7.5
30.01-45 mins	145981	34.8	188306	35	166457	39.7	220914	41	22640	5.4	90947	16.9
45.01-60 mins	90793	21.7	102223	19	132349	31.6	125276	23.3	41518	9.9	145540	28.4
≥ 60 mins	57943	13.8	16141	3	67763	16.2	30422	5.6	341389	81.5	248943	46.2
Total	418 921	100	538017	100	418 921	100	538017	100	418 921	100	538017	100

Table 3: Coverage rate of the population according to the time thresholds.

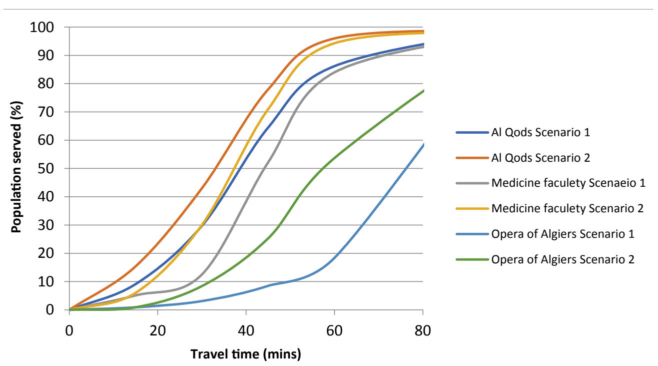

Figure 8: Cumulative curve of the population accessible by time to the different urban projects for the two scenarios.

based on GIS is a powerful tool, (i) to confirm an early drawn hypothesis on the possible existence of a disparity in the supply of public-transport. And (ii) to make the results more visible and easy to interpret. Furthermore, the cumulative opportunities indicator approach is used to compare the level of accessibility between the micro-zones in the study area in terms of travel-time calculation and to measure their changes induced by the future metro-line towards the three major urban projects. This accessibility model could be a significant contribution to making decision, where actions could be taken by actors involved in public decision for accessibility, in order to ensure sustainably the daily-service requirements for these three major urban projects which can participate in metropolitan area. The results revealed the positive impact of the planned metro-line in reducing inequalities in terms of accessibility to various urban projects, notably the Al Qods commerce and business centre and medical school, where the population coverage benefiting of an access less than 30 mins, will increase, respectively, from 30% to 44% and from 12.5% to 30%. However, the Algiers Opera is the least accessible destination as it is remained poorly connected to public transport, excepting the zones crossed by the metro-line, where only 8.4% of the population who will have access to this equipment at less than 30 mins. The main beneficiaries are the inhabitants of the served areas or located near the new infrastructures, and those who reside in zones furthest from the metro-line but connected with efficient bus-lines serving the equipment concerned.

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