THE USAGE OF GIS FOR THE DEVASTATED URBAN CENTERS MANAGEMENT AND PRESERVATION OF MONUMENTS/ CASE STUDY: NABI-JARJIS DISTRICT IN MOSUL CITY IN IRAQ

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ABSTRACT

After the liberation of Mosul in July 2017, wide areas in Mosul city have experienced large scale deterioration; especially in the right bank of the city, and Nabi-Jarjis district (where Alhadba Minaret and Nabi-Jarjis mosque located) appears to be one of the most affected parts in the City. In the current study, the debris of the Nabi-Jarjis district was studied in detail by finding the destroyed areas using GIS, then, by utilizing ArcGIS network analyst extension, the optimal route for collecting the debris from the Nabi-Jarjis district was found, considering archaeological sites as barriers. The proposed collection system focuses on reducing the time taken in the collection process and the distance traveled to reduce the economic and environmental costs of the proposed collection system. The results showed that the destruction was about 71.01% of the Nabi-Jarjis district total area, and according to land use, the residential buildings area accounted for about 81.99% of the total area that means remaining less than 10% habitable places in the region. Finally, as a final result of the current study, an optimal route for debris removal was given in a table that gives detailed information about the proposed route.

Keyword: Geographic information systems (GIS); Disaster waste management; Debris collection; optimal route; Nabi-Jarjis district in Mosul

INTRODUCTION

Mosul city has experienced large-scale deterioration after its liberation due to the severe damage that occurs to its infrastructure, urban fabric and cultural heritage (UNEP, 2018). Due to its densely constructed nature (Altuhafi *et al.*, 2013), the Nabi-Jarjis district (where Alhadbaa Minaret and Nabi-Jarjis mosque located) appears to be one of the most affected parts of the Mosul Old City. The Nabi-Jarjis Mosque is one of the Mosul Heritage Archaeological Mosques (Khoury, 2002). It is located in Al-Shaarín market on Nineveh Street near the markets of Sarj Khaneh. The mosque was built in the era of the Ottoman Empire in 1208 AH, with an estimated area of 2000 square meters (Khoury, 2002), it was re-maintained in 2009, however, it had been destroyed on July 2014. Another prestigious monument in the Nabi-Jarjis district is Alhadbaa Minaret, it is considered as one of the most important monuments in the city of Mosul dated back to 1172 AD and its location forms a focus in the oldest part of the Mosul old city (Greswell, 1997). Recently, the Minaret was almost destroyed, and according to that there are many efforts to rebuild the Minaret (Mosul Municipality, 2018), therefore the major requirement is to collect and isolate its debris that may spread in its nearby vicinity because it may be used in the Minaret rehabilitation and to prevent this debris to be removed with other nearby debris. According to this, the Minaret surrounding area has been chosen as a model for the debris removal planning process using the network analysis technique within GIS to preserve this historical and cultural landmark.

The need to remove the huge amounts of generated debris and preserving Alhadbaa Minaret ruins at the same time highlighted the importance of developing an appropriate and efficient management system for appropriate removal of the debris from Nabi-Jarjis region. Debris removing strategies differ from one country to another (Al-Ahmady and Jasim, 2019). The quantity and distribution of this debris, available equipment to remove them differs from one country to another, as well as human and financial resources, which leaves a wide range of options for the debris removing strategies (Asari *et al.*, 2013).

There are several algorithm solutions introduced by GIS technology that uses standard metrology (i.e. path length) to determine the optimal route for a particular destination (Parker, 2007). The use of this technology in waste collection and transportation can provide economic and environmental benefits by reducing accumulated time, traveled distance, fuel consumption and emission of pollutant gases (Chalkias and Lasaridi, 2009). The optimal route has been identified using GIS in many previous studies and research (Ansari *et al.*, 2015).

AIM OF STUDY

Current study aimed to calculate the destroyed area in the Nabi-Jarjis district in the right bank of Mosul, and then produce optimized route for trucks for debris removal from the study area to reduce travelled distance, collection time, and total collection costs, with focuses on preserving Alhadbaa Minaret ruins from being mixed with other debris due to its historical and cultural value, so it could be used in the Minaret rehabilitation.

STUDY AREA

The Nabi-Jarjis district is located within the old city in the right bank of Mosul city in Iraq, according to digital maps produced by GIS, the Nabi-Jarjis district is about 0.252 square kilometers in area and located at the 43°7'31.668" East longitude and 36°20'41.596" North latitude (38S 331782 4023833 UTM). Its pre-conflict population is over 7620 people within 1320 housing units (UNEP, 2017). The importance of this district refers to the presence of Alhadbaa Minaret which is considered one of the most important monuments in the city of Mosul, and its location forms a focus in the oldest part of the Mosul old city (Mahmood, 2015).

METHODOLOGY

Acquisition Data

Satellite images of the Old City are gathered from WorldView-2 satellite. The satellite multispectral images of the Old City in the years 2014 and 2017 of 0.5 m resolution is used. Raster images, maps input and processing conducted using ArcGIS network analyst extension.

Analysis of Satellite Image Data and Calculation of Destroyed Areas

Using satellite images, the destroyed areas in the Nabi-Jarjis district were identified using GIS by conducting a change detection process for two space images, the first was taken on 17/7/2014 (Fig. 1a) and the other on 18/7/2017 (Fig. 1b). The second was subtracted from the first one to distinguish changes between the two dates, Then, using the Arc map software the destroyed sites were identified by digitizing process using the Arc map software as shown in Figure (2), and the total destroyed area was calculated.

Fig. 1: (a) Satellite image, date 17/7/2014

Fig. 1: (b): Satellite image, date 18/7/2017

Fig. 2: Destroyed sites in the Nabi-Jarjis district

The percentage of destroyed areas was determined by applying the following equation:

$$\text{Percentage} = (\text{Destroyed Area} / \text{Total Area}) * 100\%$$

Then, crossing the destroyed areas' data with the land use layer using GIS gives results according to land use (residential, commercial, industrial, other uses), results were fixed in a table that will appear later in the results section.

The Optimal Route for Debris Removal

In the current study, Esri's Arc GIS Desktop version 10.4.1 with Network Analysis (NA) extension and Route solver was used in order to perform the optimal route determination process.

There were several inputs to the ArcGIS Network Analyst route solver to calculate the optimal route for debris removal. At first, the road network in the Nabi-Jarjis district was initially drawn from the satellite image taken on 17/7/2014 (Fig. 3) and the data was modified based on another taken on 18/7/2017 (due to the large deterioration in the Roads network after the liberation). Then, a network dataset of the Nabi-Jarjis district was constructed to ensure all street segments are connected at junctions. A layer for debris piles locations (Fig. 4) and other for archaeological sites -considered as barriers- (Fig. 5) were then added. The starting point for the debris collection route is located near the main street cause the route is preferred to start and end near the main road using physical and topographical barriers (O'leary *et al.*, 2002). Distance and time parameters were determined as meter for distance unit and minute for time, the vehicle used to collect debris is assumed to be a large truck of 18 tons which is currently available for Mosul Municipality, the program was given solve order, after several minutes, the optimal route for removing debris from the Nabi-Jarjis district was done.

Fig. 3: Road network in the Nabi-Jarjis district

Fig. 4: Debris piles locations

Fig. 5: Archaeological sites in the Nabi-Jarjis district

RESULTS AND DISCUSSION

Destroyed Areas

By analyzing the satellite images of the Nabi-Jarjis district, the destroyed areas were identified and calculated in square meters (Fig. 6).

It is clear from the Fig. 6 that wide areas in the Nabi-Jarjis district have been subjected to severe damage, and this is agreed with the report of the United Nations Environment Program (UNEP, 2017), where the report states that wide areas in the right bank of Mosul was heavily destroyed, and the most destruction is located in the old city regions (where Nabi-Jarjis district located) due to the dense fabric of this part of the city. Table 1 gives detailed information about destroyed areas in the Nabi-Jarjis district obtained from GIS analysis. The field survey revealed

that the most affected areas were the residential buildings (Figs. 7 & 8) show the destruction that happened to the region.

Fig. 6: The destroyed areas in Nabi-Jarjis district

Table 1: Destroyed areas in the Nabi-Jarjis district

Total area (m ²)	Destroyed area (m ²)	%	Destroyed Area in m ² according to land use		
			Residential	Commercial and industrial	Other uses
252934.77	179608.98	71.01	147279.36	6142.19	19422.9

Fig. 7: The destroyed residential area near Alhadba Minaret

Fig. 8: The destroyed commercial area near Alhadba Minaret

Optimal Route for Debris Removal

Most of the alleys in the Nabi-Jarjis district are narrow and small, therefore the process of debris removal takes several steps. Initially, small machines with labor force are used to transport the rubbles to places where large machines can reach, then rubbles is transferred to the temporary station where initial sorting is done, the remaining rubbles-which cannot be isolated-is transferred to the last destination which represents landfill site outside the city of Mosul. In the present study, the optimal route for debris removal from the affected areas was identified, Figure (9) illustrates the proposed route for the Nabi-Jarjis district.

Fig. 9: The optimal route for debris removal

As shown in Figure (9), the suggested route of the Nabi-Jarjis is as near as possible to the rubbles piles and follows the shortest route of undestroyed usable roads. Many of the roads inside the area

are currently out of service, part of which are currently maintained while others still damaged, so choosing a specific route for debris removal allows this process to be carried out concurrently with road maintenance. Because the roads in the study area may still not completely cleared of unexploded ordnance, therefore, the proposed route reduces the distance traveled and thus reduces the probability of accidents. Table 3 gives detailed information about the proposed debris removal route for the Nabi-Jarjis district. In table 3, the sequence field illustrated the order of the debris collection points to be passed by the vehicle that used for removing debris (table 2 illustrates coordinates for each stop point), arrive curb approach and the depart curb approach in table 3 gives the sidewalk location for route directions from the starting point until reaching the end point, (side of edge) gives the direction of the vehicle movements on the road network and any change between left and right means there is a turning point. (curb approach) gives the position of lifting debris for the vehicle, here (either side of vehicle) means that the debris is collected from both sides of the route, where the (cumulative distance) gives the total distance of the route-measured in meters- from the start till reaching the end. According to the Table 3, the total distance of the proposed route is 4959.69 meters, and the total time required for debris collection from the study area in each trip is 621.84 seconds.

Table 2: The stops coordinates

stops	Latitude	Longitude
1	36° 20' 27.284" N	43° 7' 36.573" E
2	36° 20' 28.883" N	43° 7' 36.954" E
3	36° 20' 31.864" N	43° 7' 35.527" E
4	36° 20' 31.543" N	43° 7' 36.729" E
5	36° 20' 32.476" N	43° 7' 36.287" E
6	36° 20' 30.885" N	43° 7' 39.747" E
8	36° 20' 31.105" N	43° 7' 43.776" E
9	36° 20' 32.396" N	43° 7' 47.812" E
10	36° 20' 33.257" N	43° 7' 49.470" E
11	36° 20' 37.785" N	43° 7' 53.461" E
12	36° 20' 34.178" N	43° 7' 48.253" E
13	36° 20' 34.997" N	43° 7' 48.847" E
14	36° 20' 35.711" N	43° 7' 49.411" E
15	36° 20' 35.056" N	43° 7' 47.619" E
16	36° 20' 36.530" N	43° 7' 48.391" E
17	36° 20' 36.398" N	43° 7' 46.619" E
18	36° 20' 33.941" N	43° 7' 41.416" E
19	36° 20' 34.130" N	43° 7' 43.510" E
20	36° 20' 35.833" N	43° 7' 43.889" E
21	36° 20' 35.769" N	43° 7' 33.142" E
22	36° 20' 37.096" N	43° 7' 46.150" E
23	36° 20' 38.416" N	43° 7' 30.400" E
24	36° 20' 39.152" N	43° 7' 32.415" E
25	36° 20' 40.442" N	43° 7' 31.384" E
26	36° 20' 43.142" N	43° 7' 28.705" E
27	36° 20' 41.790" N	43° 7' 32.449" E
28	36° 20' 41.086" N	43° 7' 34.177" E
29	36° 20' 43.060" N	43° 7' 35.130" E
30	36° 20' 43.905" N	43° 7' 37.434" E
31	36° 20' 41.814" N	43° 7' 37.290" E
32	36° 20' 40.314" N	43° 7' 36.551" E
33	36° 20' 38.767" N	43° 7' 37.783" E
34	36° 20' 41.653" N	43° 7' 35.325" E
35	36° 20' 42.821" N	43° 7' 38.267" E
36	36° 20' 40.851" N	43° 7' 39.185" E
37	36° 20' 41.701" N	43° 7' 40.101" E
38	36° 20' 41.139" N	43° 7' 40.857" E
39	36° 20' 39.906" N	43° 7' 40.531" E
40	36° 20' 41.193" N	43° 7' 42.663" E
41	36° 20' 39.774" N	43° 7' 42.084" E
42	36° 20' 38.985" N	43° 7' 45.072" E
43	36° 20' 39.701" N	43° 7' 45.733" E
44	36° 20' 40.763" N	43° 7' 43.512" E
45	36° 20' 41.406" N	43° 7' 46.273" E
46	36° 20' 40.437" N	43° 7' 46.070" E
47	36° 20' 39.575" N	43° 7' 47.705" E
48	36° 20' 39.093" N	43° 7' 46.942" E
49	36° 20' 43.987" N	43° 7' 39.336" E
50	36° 20' 44.995" N	43° 7' 40.345" E
51	36° 20' 44.146" N	43° 7' 41.140" E
52	36° 20' 46.493" N	43° 7' 42.633" E
53	36° 20' 45.722" N	43° 7' 43.426" E
54	36° 20' 44.943" N	43° 7' 45.349" E
55	36° 20' 44.896" N	43° 7' 47.319" E
56	36° 20' 43.424" N	43° 7' 48.387" E
57	36° 20' 47.373" N	43° 7' 47.099" E
58	36° 20' 40.796" N	43° 7' 47.288" E

Table 3: The proposed debris removal route information

Sequence	Arrive curb approach	Depart curb approach	Side of edge	Curb Approach	Cumul_Distance(m)	Cumul_Time (min)
1	Start	Right side of vehicle	Right Side	Either side of vehicle	0	10
2	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	68.615629	20.02058469
5	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	302.164802	30.11123413
3	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	228.640228	40.1798262
4	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	275.479066	50.26246992
6	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	500.459645	60.41260781
7	Left side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	625.81066	70.60035101
11	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	1148.971754	80.94504254
12	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1213.49407	91.30909076
57	Right side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	4831.262643	102.7584695
13	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1276.444737	113.141403
14	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1305.64708	123.5330971
15	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1331.707981	133.9326095
8	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	800.802215	144.1728502
16	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	1381.467183	154.5872903
17	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1430.275527	165.016373
9	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	938.094022	175.2978012
10	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	992.209234	185.5954639
18	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1504.023731	196.0466711
39	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	3174.889471	206.9991379
19	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	1580.177136	217.473191
38	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	3046.691898	228.3871986
36	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2718.550717	239.2027638
35	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	2671.321416	250.0041603
37	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	2883.127802	260.8690986
34	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2600.06286	271.6491175
33	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	2523.162559	282.4060662
32	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2447.35166	293.1402717
27	Right side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	2135.30922	303.7808645
29	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2262.695121	314.459673
30	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	2331.459431	325.1591108
40	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	3356.191843	336.1659684
31	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	2389.422413	346.8827951
28	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	2193.782945	357.54093
41	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	3446.01737	368.5747352
42	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	3491.425797	379.622163
43	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	3532.928943	390.6820416
44	Left side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	3581.818794	401.7565873
23	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1863.465625	412.315627
45	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	3632.193162	423.4052849
21	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	1693.602973	433.9133658
46	Right side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	3735.450002	445.0340008
22	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	1793.080928	455.5719251
49	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	3913.937183	466.7461062
48	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	3858.28401	477.9035914
47	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	3796.373802	489.0425036
20	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	1644.460222	499.5358417
26	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2087.970385	510.1622328
25	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	2025.884243	520.769998
24	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	1992.295259	531.3676866
54	Left side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	4382.673756	542.6824887
53	Right side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	4329.539208	553.9813505
55	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	4491.361497	565.328759
56	Left side of vehicle	Left side of vehicle	Left Side	Either side of vehicle	4545.551367	576.6924244
51	Right side of vehicle	Right side of vehicle	Right Side	Either side of vehicle	4060.514969	587.9105789
52	Left side of vehicle	Left side of vehicle	Right Side	Either side of vehicle	4202.447605	599.1713131
50	Left side of vehicle	Right side of vehicle	Left Side	Either side of vehicle	3948.472803	610.355855
58	Left side of vehicle	End	Right Side	Either side of vehicle	4959.696504	621.8437639

CONCLUSIONS

1. The destroyed area is estimated for about (0.179 km²) out of the total area of the Nabi-Jarjis district (0.252 km²), or about 71.01%.
2. According to land use, most of the rubble in the Nabi-Jarjis district belongs to the residential buildings, which accounted for about 81.99% of the total volume of the debris.
3. The total distance for the proposed route for each trip is estimated at 4959.69 meters, according to this, the total time required to collect debris from the study area in each trip is estimated at 621.84 seconds.
4. Debris removal process with the usage of a specific route within viable roads will allow road maintenance operations to be carried out simultaneously with debris removal.
5. The process of removing debris from the Nabi-Jarjis district has begun in an unplanned manner, burying large quantities in low lands near Mosul boundaries which may exacerbate many future risks such as floods. In such cases, today's solution will be the problem of tomorrow.
6. The lack of an appropriate debris management plan leads to the mixing of rubble (mostly concrete, stone and minerals) with other types of waste, including hazardous materials which reduces the chances of recycling the rubble, and here comes the role of finding the optimal route to remove the debris of the Nabi-Jarjis district as an effective planning tool minimizing collection time, distance travelled, and consequently financial and environmental costs for the proposed collection system.

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