Firefighting Stations Allocation Model for the State of Kuwait

Hana O. A. Al-Omar, Kuwait University, Kuwait*

ABSTRACT

The objective is to determine the best re-allocations of the stations to easily reach the accident location with both the least cost and time possible, with the best firefighting effective required facilities. This objective required dividing the six governorates into 133 areas served in 6 minutes efficient response time. The final findings of this study were 30 reallocated stations, which managed effectively to cover all 133 required areas. This has been shown on included maps of the six governorates. The goal linear programming model idea was not discussed in the emergency field research of the "State of Kuwait," specifically in the firefighting emergency service. Moreover, this modeling can be expanded to cover all other types of emergency service topics such as health, paramedics, and police stations.

KEYWORDS

Emergency Services, Goal Linear Programming Model, Optimal Allocation

INTRODUCTION

This paper is basically focused on a firefighting service in the state of Kuwait, for which we are about to use the mathematical model of the service based on the firefighting stations' location. We consider the firefighting service as a continuous and necessary human-threat risk management that depends on fatal time management. The latter also requires the ease of information accuracy flow from the source of a tragic incident (emergency location) to an emergency call center "211," which is a high-tech recipient to ease and shorten the response time of the closest firefighting station to the emergency incident location.

The "Kuwait Firefighting Service Department," so-called, had "38" active firefighting stations by the year 2013, according to their annual statistical reports published in their official homepage back then (www.kfsd.gov.kw). But, according to our research methodology, we end up with "30" working firefighting stations for the required emergency location service. We asked for the response time to not exceed 6 minutes to rescue and help in life threat situations.

Nowadays, the name "Kuwait Firefighting Service Department" has been changed by the year 2020 to "Kuwait Firefighting Force" with the updated homepage (www.kff.gov.kw).

DOI: 10.4018/IJORIS.334126 *Corresponding Author

LITERATURE REVIEW

Emergency service is defined as "an emergency service and/or repair given by the medical, firefighting, and/or police facilities in both private or public sectors." This definition was given by Marianov (2017), Santiago, Chile.

The emergency service is an old topic and a necessity that aids to pause threats to rescue lives or properties. When the properties are considered in the emergency location service (ELS), a study in Spain conducted by Silva with Serra (2008) shows that the degree of danger and human life threats should have a higher priority than routine incidents calls or emergency service.

In a study in East Asia (Japan), the transfer time of patients to hospitals had the priority. So, the study considered transfer-time minimization as an emergency project management (EMG) situation. Accordingly, the latter shows the essential role of ambulances, paramedics, and hospital staff (Sonoda & Ishibai, 2015).

Japan has been considered one of the most famous countries in natural (earthquakes) or man-made disasters since 1950. Those disasters are exponentially increasing with the emergency facilities' location, as mentioned by the authors Boonmee et al. (2017). They proposed the facility location optimization model to meet the emergency humanitarian needs.

Moreover, relating to the emergency threat demand in China, such as demographic growth in China besides natural disasters, the importance of the coverage of the response time rises up. So, Yuhan and Jie (2019) suggested a multicoverage optimal location model for emergency medical services (EMS) facilities. This suggestion focused on finding a scientific solution that adds a valuable travel time (minutes) to overcome rescue difficulty. This shows that the facility location plays an efficient role in response time to rescue lives or properties. Another study from China mentioned that the necessity of modeling came from the emergency service demands that urge the importance of facilities' location, which proposed a model called the robust optimization approach to emergency mobile facility routing (Li et al., 2020). Furthermore, an infrastructure restoration network plan is more crucially required when natural/man-made disasters are mentioned. This suggested the study from the United States of America (Iloglu & Albert, 2019) that uses a maximal multiple coverage and network restoration model to help emergency managers to schedule 1) effective restoration activities on the actual disaster time and 2) long-term recovery planning.

One of the optimization approaches is an advanced life support (ALS) optimization model, which was used in Thailand for an ambulance facility location problem. This model was proposed by Sumrit and Thongsiriruengchai (2020) when trying to minimize the arrival time of the ambulance to be less than "8 minutes" in Bangkok, Thailand. This was achieved by the availability location of the parking area to meet the rescue service time.

Another approach called a biobjective (deterministic and probabilistic) approach was used in Brazil (Belo Horizonte) by de Oliveira et al. (2020). The study findings had been applied on the facility location problem in EMS for coverage demand in Belo Horizonte, Brazil.

Finally, if the uncertainty is related and considered for ELS, an applied mathematical model has been suggested by Zokaee et al. (2016). This study was held in the Alborz area in the Tehran province of Iran because this area is totally vulnerable and has an uncertain cost factor for earthquakes. The authors used a three-level relief humanitarian logistics chain between suppliers, distribution centers, and affected areas. Uncertainty rises or relates to the cost of demand and supply besides any related parameters. The proposed model aims to maximize the people satisfaction in the affected areas as well as minimize the total cost of the relief chain.

Regarding the Arabian Gulf countries encountered research history, it was advisable to look for the research that shed a light on the goal programming for service, which happened to be a good opportunity to find it under the title of "the traffic portal vehicles allocation model for Riyadh" (Algadhi & Hasan, 1994). So, I found that we may consider a parallel effort in the State of Kuwait regarding emergency service, which is the goal of this study to apply the allocation method of goal programming to find the best allocation of the firefighting stations covering the ultimate areas of the State of Kuwait.

Finally, the upcoming successive sections of this research are going to cover an allocation and reallocation study of the general proposed emergency service model of the Kuwait firefighting stations as a special case study.

THE MATHEMATICAL MODEL

In this section, we describe the goal linear programming mathematical model, which has been applied to allocate firefighting stations to all different areas of the State of Kuwait in the year 2013 so as to increase the response speed action toward any fire accident service request within a 6 minute response time limit. In the following section, the required input data for the model, besides a goal programming formulation model overview, is given first, followed by a detailed description of the specific model. Finally, all necessary detailed input data's description in this model's application is well-presented.

Goal Linear Programming Model Formulation

Usually, a goal is the desired result. Basically, this result may be underachieved, fully achieved, or overachieved, which is relatively applied through a managerial action that directly contributes to the degree of a goal achievement. Symbolically, 1 unit of an applied effort to activity x_j might contribute an amount a_{ij} toward the achievement of the ith goal (Algadhi & Hasan, 1994).

The target level for the ith goal, b_i, is fully achieved

$$\sum_{j=1}^{n} a_{ij} x_j = b_i .$$

To allow for underachievement or overachievement, let

d_i^- = negative deviation from the ith goal (underachievement)

d_i^+ = positive deviation from the ith goal (overachievement).

From this, the ith goal can be started in general terms as

$$\sum_{j=1}^{n} a_{ij} x_j + d_i^- - d_i^+ = b_i \; i = 1,2,\ldots,m .$$

It is required that one or both deviational variables (d_i^- or d_i^+) be zero in the solution, since it is not possible for both deviations, namely, overachievement and underachievement to occur simultaneously.

The goal programming model must be able to incorporate goal statements, with both ranking and weighting as appropriate. Let

P_k = ranking coefficient for all deviations having the kth priority of being avoided

w_{ik}^- = relative weight of the d_i^- in the kth rank

w_{ik}^{+} = relative weight of the d_i^{+} in the k[th] rank.

With *m* goals, the goal linear programming model may be formulated mathematically as requiring the minimization of the linear weighted ranking function

$$\sum_{i=1}^{m}\sum_{k}P_k\left(w_{ik}^{-}d_i^{-}+w_{ik}^{+}d_i^{+}\right)$$

statements, with both ranking and weighting as appropriate. Subject to the appropriate linear constraints:

$$\sum_{j=1}^{n}a_{ij}x_j+d_i^{-}-d_i^{+}=b_i \quad i=1,2,\ldots,m\,.$$

$$x_j, d_i^{-}, d_i^{+} \geq 0 \quad i=1,2,\ldots,m\,,\ j=1,2,\ldots,n\,.$$

Goal programming seeks satisfactory levels of attainment, which represent the best overall possible outcome.

The Firefighting Station Allocation Model

The major objective of this research is to find the best firefighting station allocation and/or reallocation scheme. This would be of great help in reducing the rescue time challenge facing the firefighting head management in the State of Kuwait, which is clearly by the best human effort resource utilization to improve service level given by the firefighting stations that apparently increase human safety. The goal is to reach the desired ultimate coverage areas of the State of Kuwait.

To reach the goal of this research, we used the goal programming introduced in the Goal Linear Programming Model Formulation section earlier. This is based on the official urban divisions in the State of Kuwait to ease the firefighting stations to respond to any fire accident occurring in any area of those divisions in a prespecified response time limit.

The model tries to satisfy the following goals:

(i) Reduce the time limit needed to respond to any fire accident call.
(ii) Reduce the firefighting facilities' usage cost to reach the accident.
(iii) Increase the firefighting facilities system effectiveness by introducing the idea of covering parts priority factors as follows:
    (1) Number of fatal injuries and property damage occur in each part.
    (2) Number of injury accidents.
    (3) Number of rescue accidents.
    (4) Number of properties damage or loss.
    (5) Number of firefighting public services in accident locations.

The mathematical allocation model can be stated as follows (Algadhi & Hasan, 1994):

Minimize $P_1\sum_{i=1}^{N}w_i d_i + P_2 d^{+}$

subject to:

$$\sum_{i=1}^{N} x_i + d^- - d^+ = C \tag{1}$$

$$y_i + d_i = 1 \;\; i = 1,2,\ldots,N \tag{2}$$

$$\left(\sum_{i\in j} x_i\right) - y_i \geq 0 \;\; i = 1,2,\ldots,N \tag{3}$$

$$\sum_{i\in j} x_i \geq 1 \;\; i = 1,2,\ldots,N \tag{4}$$

$$x_i, y_i = 0 \, or \, 1 \;\; i = 1,2,\ldots,N \tag{5}$$

$$d^-, d^+ \geq 0 \, and \, integers\,, \tag{6}$$

where,

i $\equiv$ an index of city part or zone;
N $\equiv$ a constant total number of city parts;
J $\equiv$ an index of the group parts which can be served by one firefighting station for a specified period of time;
P_1 $\equiv$ the first given priority to avoid uncovering city parts by firefighting stations;
P_2 $\equiv$ the second given priority to avoid exceeding the maximum number of firefighting stations available at the city parts;
C $\equiv$ a constant number of firefighting stations available;
w_i $\equiv$ a constant weight assigned to city part i based on the high-priority factors previously mentioned;
d_i $\equiv$ a binary variable which represents the uncoverage status for part i, that is, $d_i = 1$ if part i is uncovered by the firefighting station and $d_i = 0$ otherwise;
d^+ $\equiv$ an integer variable which represents the additional number of firefighting stations needed to cover all parts of the city (positive deviation);
d^- $\equiv$ an integer variable which represents the number of stands by firefighting stations, that is, those exceeding the need (negative deviation);
x_i $\equiv$ a binary variable indicating whether a firefighting station is physically located at part i $(x_i = 1)$ or not $(x_i = 0)$;
y_i $\equiv$ a binary variable which represents the coverage status for part i, that is, $(y_i = 1)$ if part i is covered by a fire station and $(y_i = 0)$ otherwise. It is the complementary variable of d_i.

In the above mathematical model, our objective is to find the best optimization model that covers the most possible (maximum) number of city parts with the least possible (minimum) utilized number of firefighting stations. It consists of two priority parts, for which P_1 is the highest priority, covering the city parts based on their weight importance w_i. The second priority, P_2, tends to minimize the positive deviations d^+ from the available firefighting stations C. Also, the model constraints are developed as follows:

Constraint (1) requires the sum of the firefighting stations that cover the city parts besides the stand-by stations d^-, if any, must equal to the total available number of stations C. But, in case of no stand-by stations, the additional ones d^+ might be needed.

Constraint (2) ensures that all the city parts are totally covered by station service, as the y_i is a binary variable (taking values 0 or 1 by constraint (5)). Also, the sum of d_i and y_i should be unity, which makes d_i take value 0 or 1. Note that d_i is included in the above objective function so as to be forced to take 0 value for the city parts that have high weights in the weights criteria allocation (Goal Linear Programming Model Formulation section).

Mainly, the city coverage policy is illustrated by:

Constraint (3) ensures the city parts are covered by the firefighting stations inside the city boundaries or by one or more stations in the neighboring parts (all within a 6 minute time period).

Constraint (4) ensures at least one firefighting station serving group J of the city parts, which can be covered by only one station separately.

Constraint (5) ensures the binary values of the x_i, y_i variables, where the 0 value of x_i indicates that there is no need for the firefighting station in part i, since it will be covered by the adjacent parts. When the value of y_i is 0, it means part i is not covered.

The last constraint (6) ensures the nonnegativity of the integer values of d^-, d^+ variables.

However, the previous allocation model is gradually illustrated in the coming sections.

Data Collection (Kuwait Fire Force Data History)

The decision of data collection had taken place in the academic year 2016/2017. For which an official letter had been used to ask for the required data officially from the General Firefighting Service Department of the State of Kuwait. As mentioned before, the latter name is officially changed to Firefighting Force of the State of Kuwait during the COVID-19 crisis in the year 2020.

Data were collected from the Kuwait Firefighting Force, specifically from the Force Archives data. This was facilitated by the help of the Department of Public Relations Head, Lieutenant Colonel Mr. Majed Al-Otaibi.

Frankly speaking, this process faced many limitations related to availability, accessibility, and time or effort consumed. For this paper, we asked for specific data to fit the requirements of goal programming optimization.

To make the idea and the coverage time limit related to the required area, a small, color-coded graph was prepared/used to clarify the emergency location service idea to the decision-makers in the firefighting department (see Figure 1).

Figure 1 shows the required areas covered in less than 6 minutes, which is this paper's concern, and colored as green for accessibility and service efficiency.

Mainly, a specific sheet was prepared to help in the data collection process under the study when response time coverage is either less than 6 minutes or more. However, because of the data availability restriction, only less than 6 minutes constraint was utilized. Systematically, firefighting station names with area coverage were prepared according to the following frequencies under study:

1. Number of fire accidents.
2. Number of rescued cases.
3. Number of injuries or deaths.
4. Number of lost properties.
5. Number of public services.

To illustrate that in-depth, we elaborate in the Study Area Partition section.

Figure 1. Color-coded hot areas

Study Area Partition

According to the previous declarations of the data collection history, the process by itself was very slow because it was covering six major governorates, namely:

1. Al-Asma.
2. Al-Ahmadi.
3. Hawalli.
4. Al-Jahra.
5. Al-Farwaniya.
6. Mubarak Al-Kabir.

These were all required in the fourth quarter of the year 2013 (see maps in Figures 2 and 3).

The collection phase faced several limitations, as I mentioned earlier, regarding how to be collected, and/or arranged in sheets, checked, rechecked, and cross-checked.

Also, the Captain Mr. Mohammad Al-Najjar, who was responsible for finding and arranging the data from the Force Archives data, had other official responsibilities in his work for several times, including the typing/arranging of the required data along with the legal migration papers limitations for the labor. This, mainly, had prolonged the process flow of the data collection phase.

Afterward, I received the data as a Microsoft Word file. Then I started the organizing phase. In this phase, I rearranged the data again as an Excel worksheet. The Excel sheet made the process smoother and easier in tracking and transferring from Arabic-version data to English-version data. I renamed each firefighting station and area as variables, namely, x_i ‘s ($i = 1, \ldots, 30$) variables and x_i ‘s ($i = 31, \ldots, 133$) variables, respectively, which in total, stations and areas made 133 variables.

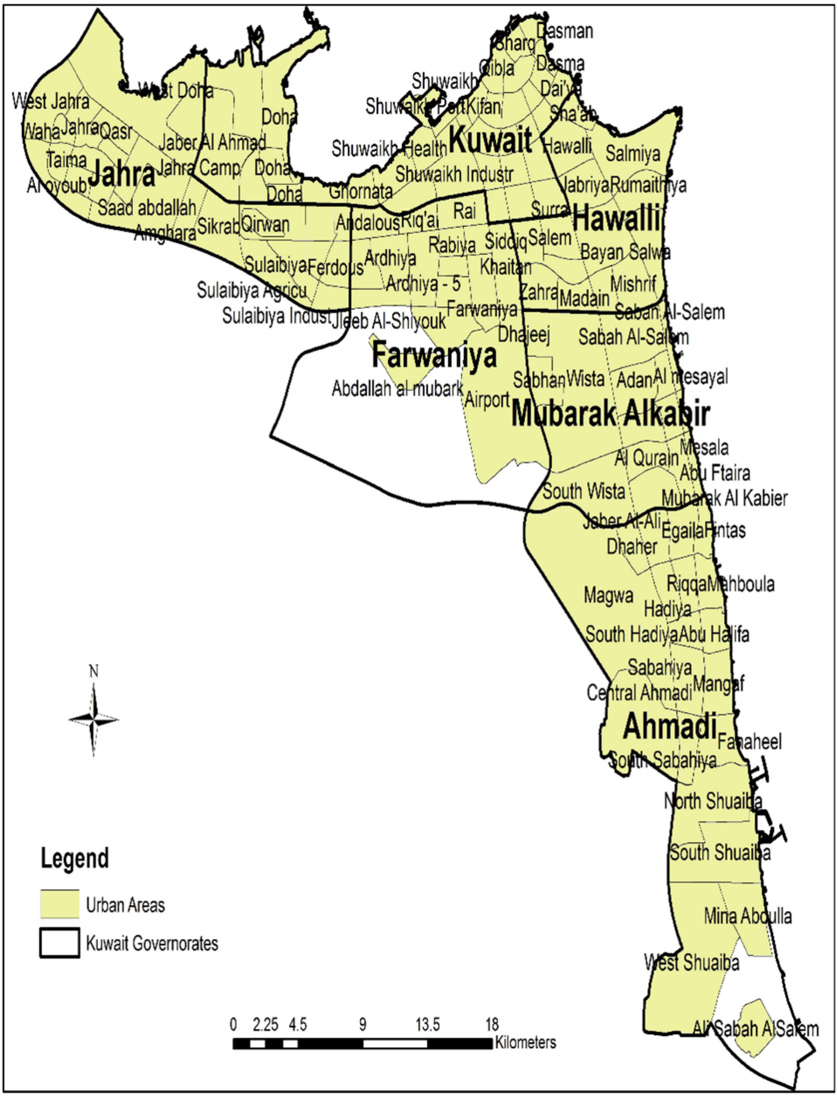
The upcoming sections are related to the application of the mathematical goal programming model allocation technique, which was mentioned previously in The Firefighting Station Allocation Model section.

Coverage Priority Measure (w_i)

By the moment, we quantify the important factors for assigning the covering priority measure (w_i) for each city, a composite measure can be developed to find (w_i) . So, we denote the above important factors (variables) as follows:

$V_{1i} \equiv$ fire accident
$V_{2i} \equiv$ rescue operation
$V_{3i} \equiv$ death or injury

Figure 2. Kuwait detailed map



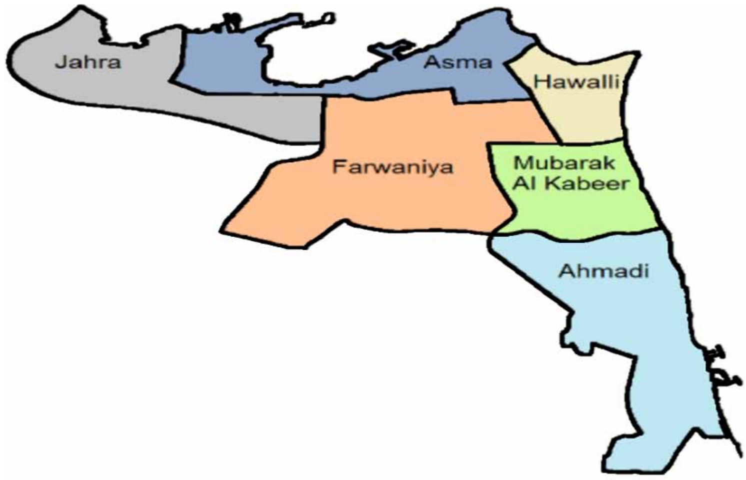
$V_{4i} \equiv$ property losses
$V_{5i} \equiv$ public services

Then, based on the above variables, we manage to calculate the simple weighted assignment scheme using the following general form, which is:

$$w_i = a_1 V_{1i} + a_2 V_{2i} + a_3 V_{3i} + a_4 V_{4i} + a_5 V_{5i},\ i = 1, \ldots, 133,$$

where a_1, a_2, a_3, a_4, a_5 are considered a subjectively judged parameter.
Our specified model application using the specified scheme is:

Figure 3. Kuwait governorates map



$$w_i = 2V_{1i} + 2V_{2i} + 4V_{3i} + 1V_{4i} + 1V_{5i},\ i = 1,\ldots,133\,.$$

The Model Results

After we utilized the importance measurements (w_i) for each of the 133 city parts (Coverage Priority Measure (w_i) section), the objective function of the mathematical goal programming model was constructed (The Firefighting Station Allocation Model section). It includes 133 binary variables d_i, which indicates the uncovering of part i and the variable d^+, which refer to the number of firefighting stations needed to cover all city parts. Moreover, the available number of firefighting stations, the constant C in the constraint (1), was assumed to be equal to 133 (i.e., one station to each city part). With such an assumption, we presume there is no effect on the final solution. The value of the d^- in the final solution will indicate the negative deviation (i.e., stand-by firefighting stations). It is very possible to assume a very small value for the constant C, where, in this case, the value of the $d^{\mp}$ in the final solution will indicate the positive deviation (i.e., additional firefighting stations needed).

At this stage, we developed a computer program routine using the statistical analysis software/ operation research package, Solver, which is available in Excel worksheets for Windows.

The final allocation results of the Solver outcome can be summarized as follows:

(1) All of the 133 parts of six major governorates of the State of Kuwait were covered by firefighting station service since all y_i's variables had a value of unity ($\mathrm{y}_i = 1$ means that the part i is covered by the firefighting station service).

(2) The value of d^+, d^- were 0 and 103, respectively. This gives us the necessity of having the utilization of 30 firefighting stations in the different parts of the city to cover the 133 parts of the six governorates. The initialization of the computer program assumes that there were 133 firefighting stations available (C), as mentioned earlier.

(3) The different locations of the 30 firefighting stations are shown in Figure 4.1 in Appendix A. Also, the neighboring parts of these locations will be covered. Besides, it shows that a part

can be covered by a neighboring part with a firefighting station assigned to it (see Table 4.1 in Appendix A). This is shown even so clear in-depth, where each governorate map is magnified separately in Appendix B.

Summary and Conclusion

The objective of this research was to find the optimal firefighting station allocation or reallocation to achieve a prerequired period of 6 minutes response time. A goal programming approach was utilized to minimize the number of city parts that were left uncovered by the firefighting station service in combination with the minimum number of these firefighting stations.

To apply the goal programming allocation model, we had to divide the six governorates into 133 city parts, such that a firefighting station can circulate to any part in a 6-minute time period. Even the neighborhoods were included in each part to be covered, which allowed the required firefighting station to easily cover this neighborhood in a 6-minute period.

Furthermore, a priority scheme was used to establish an importance measure (w_i), such that higher values of (w_i) get a higher priority to be covered by the firefighting station. This (w_i) measure depends on several factors, including the historical reports of the fire accidents, rescue operations, death/injury factor, property losses, and public services in each of the city parts. The related data had been provided by the State of Kuwait's Fire Force Archives Data Department.

The allocation results showed that it is possible to cover all city parts by only 30 firefighting stations, such that the response time should not exceed 6 minutes. Noting that, these 30 reallocated firefighting stations should have mainly the responsibility of responding to fire accidents calls. If other accidents were referred to as duties of firefighting stations, then additional firefighting units are included. Also, we found that the locations 1, 2, and 3 had been replaced by the 31, 32, and 33 locations in the final optimal solution (see Table 4.1 in Appendix A), which indicates the necessity of building new firefighting stations in the latter locations. Besides, they were in the original data covered by them, which clarified the relationship. Table 4.1 shows the optimal firefighting stations with related well-covered city or area parts. Also, this result shows the importance of the managerial implications to the policymaking of the firefighting force management of the State of Kuwait.

At the time of the data collection, we started with 38 firefighting stations. However, because the 6-minute response timeline constraint was the first necessity, eight stations were canceled. Also, the allocation management was the second necessity to cover the most possible areas with the least number of firefighting stations considering a 6-minute response time constraint. But if there is heavy traffic, the response time could be 8 minutes or more with the more than 30 firefighting stations requirement, which is not considered in our study plan. So, this scenario could be left for any future research by adding longer time limits, besides the number of road intersections with heavy or light traffic constraints.

AUTHOR NOTE

Frankly speaking, this research was not possible to complete without the guidance of my adviser in this goal programming topic, covering all six governorates of the State of Kuwait, namely, Professor Mohamad Kamal Hasan, who really gave me his endless support and knowledge. Not to mention using the Solver routine in the Excel package to provide me with final optimal results. Also, I cannot thank enough the GIS maps expert Dr. Ahmed Khattab Azzam (Lead GIS – PARSONS), who managed to allocate the wanted areas with coverage time limit firefighting stations on the maps in Appendices A and B. Last but not least, this research was not there if the data were not available without the help of the Head of Public Relations of the Kuwait Firefighting Force, Lieutenant Colonel Mr. Majed Al-Otaibi.

REFERENCES

Algadhi, S. A. H., & Hasan, M. K. (1994). A traffic patrol vehicles allocation model for Riyadh. *Scientific Journal of Economics and Commerce, Ain Shams University*. https://faculty.ksu.edu.sa/sites/default/files/8_a_traffic_patrol_vehicles_allocation_model_for_riyadh.pdf

Boonmee, C., Arimura, M., & Asada, T. (2017). Facility location optimization model for emergency humanitarian logistics. *International Journal of Disaster Risk Reduction*, *24*, 485–498. doi:10.1016/j.ijdrr.2017.01.017

de Oliveira, C. P., de Sa, E. M., & Cruzeiro, F. V. (2020). *A multi-period and bi-objective approach for locating ambulances: A case study in Belo Horizonte, Brazil*. https://www.researchgate.net/publication/347124592_A_multi-period_and_bi-objective_approach_for_locating_ambulances_a_case_study_in_Belo_Horizonte_Brazil

Iloglu, S., & Albert, L. A. (2019). A maximal multiple coverage and network restoration problem for disaster recovery. *Operation Research Perspectives*, *7*, 100132. Advance online publication. doi:10.1016/j.orp.2019.100132

Kuwait Fire Force. (n.d.). *Kuwait Fire Force webpage*. https://www.kff.gov.kw/kfsdportal/faces/applications/common/pages/main.jsf

Li, J., Lai, K. K., Fu, Y., & Shen, H. (2020). Robust optimization approach to emergency mobile facility routing. *Science Progress*, *104*(1), 1–16. https://journals.sagepub.com/doi/10.1177/0036850420982685 PMID:33423609

Marianov, V. (2017). *Location models for emergency service applications. Institute for Operations Research and the Management Sciences*. INFORMS. doi:10.1287/educ.2017.0172

Silva, F., & Serra, D. (2008). Locating emergency services with different priorities: The priority queuing covering location problem. *The Journal of the Operational Research Society*, *59*(9), 1229–1238. doi:10.1057/palgrave.jors.2602473

Sonoda, T., & Ishibai, K. (2015). Project on information-support solution in emergency medical service. *Fujitsu Scientific and Technical Journal*, *3*, 39–49. https://www.researchgate.net/publication/286460966_Project_on_Information-support_Solution_in_Emergency_Medical_Service

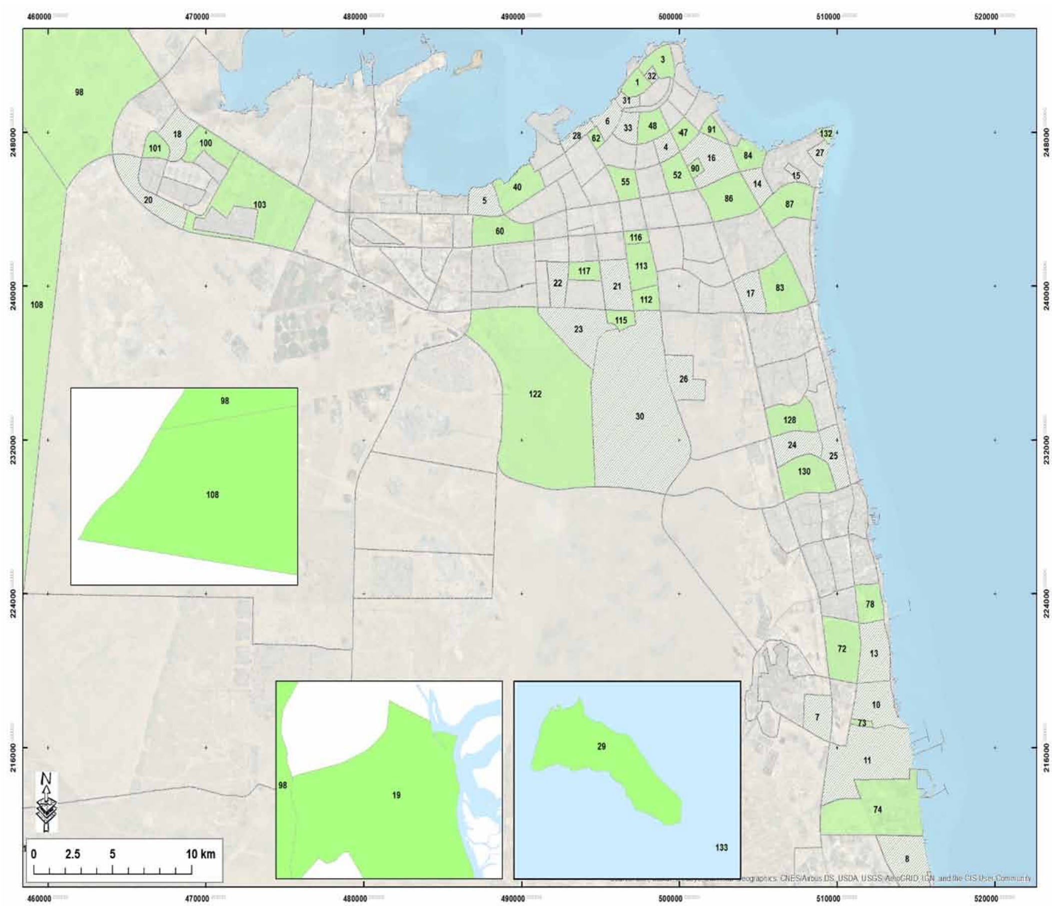
Sumrit, D., & Thongsiriruengchai, K. (2020). *An optimization model for advanced life support ambulance facility location problem*. https://www.semanticscholar.org/paper/An-Optimization-Model-for-Advanced-Life-Support-Sumrit-Thongsiriruengchai/3d638b12bd9c677f5d739b75146838dcc4fb8f40

Yuhan, Y., & Jie, Y. (2019). Multi-coverage optimal location model for emergency medical services (EMS) facilities under various disaster scenarios: A case study of urban fluvial floods in the Minhang District of Shanghai, China. *Natural Hazards and Earth System Sciences*, *20*, 181–195. https://nhess.copernicus.org/articles/20/181/2020/nhess-20-181-2020-relations.html

Zokaee, S., Bozorgi-Amiri, A., & Sadjadi, S. J. (2016). A robust optimization model for humanitarian relief chain design under uncertainty. *Applied Mathematical Modelling*, *40*(17–18), 7996–8016. doi:10.1016/j.apm.2016.04.005

APPENDIX A

Figure 4. Study area partition scheme of the State of Kuwait and optimal firefighting station locations



APPENDIX B

Table 1. Optimal emergency service areas and stations within 6-minute response time

Station	Served Areas
x_4	$x_4, x_{47}, x_{48}, x_{52}, x_{55}$
x_5	x_5, x_{40}, x_{60}
x_6	x_6, x_{28}, x_{62}
x_7	x_7

continued on following page

Table 1. Continued

Station	Served Areas
x_8	x_8
x_9	x_9, x_{69}
x_{10}	x_{10}, x_{17}, x_{74}
x_{11}	x_{11}, x_{12}
x_{12}	x_{12}
x_{13}	$x_{13}, x_{72}, x_{73}, x_{78}$
x_{14}	$x_{14}, x_{84}, x_{86}, x_{87}$
x_{15}	x_{15}
x_{16}	$x_{16}, x_3, x_{52}, x_{86}, x_{90}, x_{91}$
x_{17}	x_{17}, x_{83}
x_{18}	$x_{18}, x_{98}, x_{100}, x_{101}, x_{103}, x_{108}$
x_{19}	$x_{19}, x_{18}, x_{98}, x_{99}$
x_{20}	x_{20}
x_{21}	$x_{21}, x_{112}, x_{113}, x_{115}, x_{116}, x_{117}$
x_{22}	x_{22}
x_{23}	x_{23}, x_{115}, x_{122}
x_{24}	x_{24}, x_{128}, x_{130}
x_{25}	x_{25}
x_{26}	x_{26}, x_{25}
x_{27}	x_{27}, x_{132}
x_{28}	x_{28}
x_{29}	x_{29}, x_{133}

continued on following page

Table 1. Continued

Station	Served Areas
x_{30}	x_{30}, x_{115}
x_{31}	x_{1}
x_{32}	x_{1}
x_{33}	x_{1}, x_{4}, x_{48}

Figure 5. Optimal firefighting stations for Asma

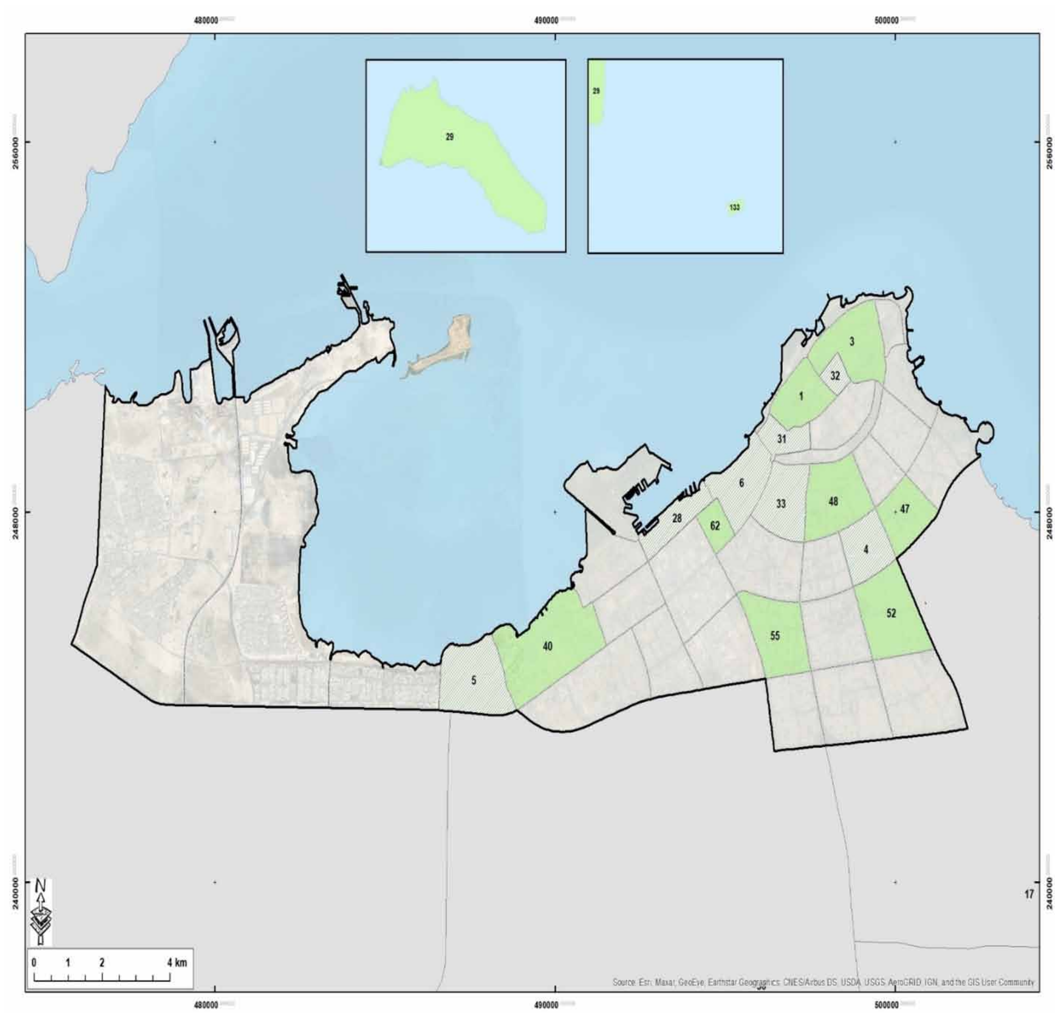


Figure 6. Optimal firefighting stations for Al-Jahra

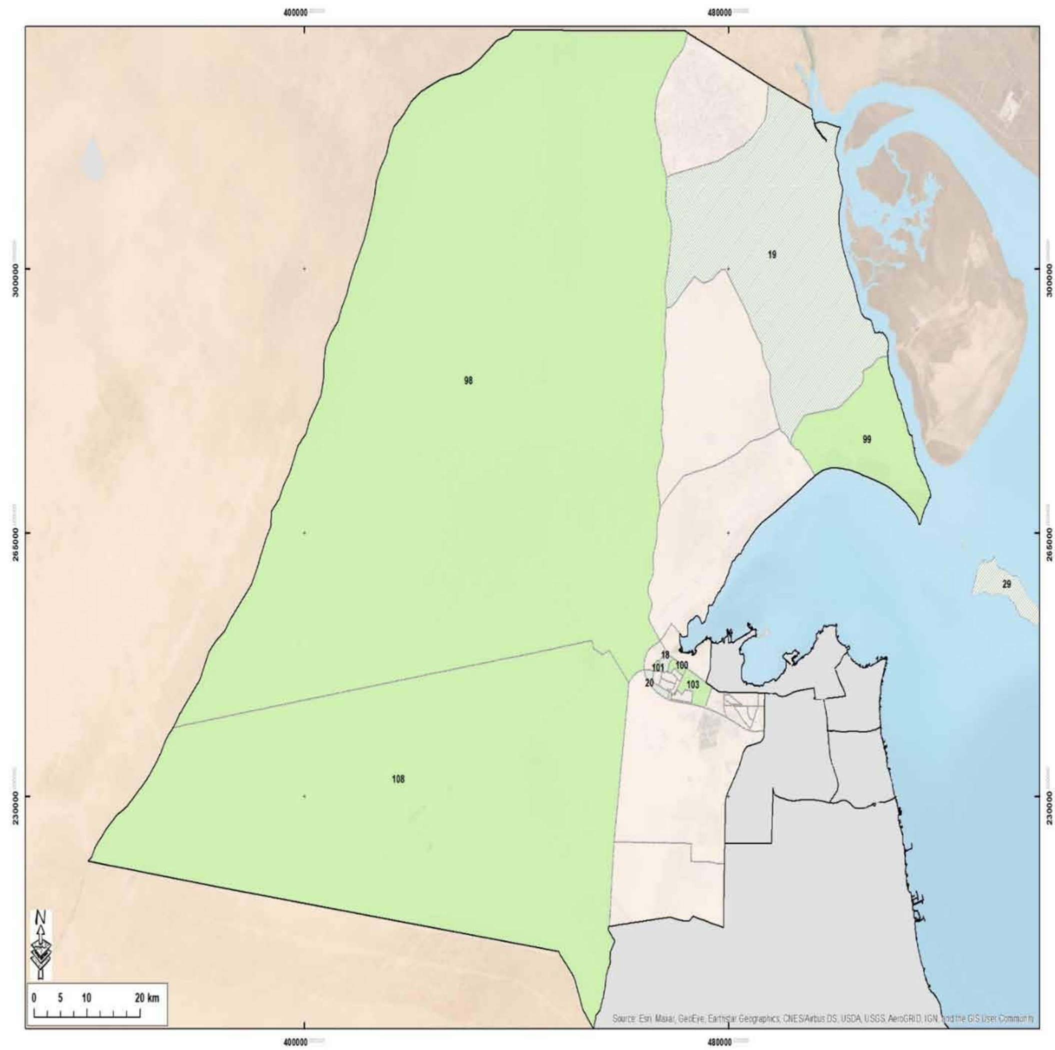


Figure 7. Optimal firefighting stations for Hawalli

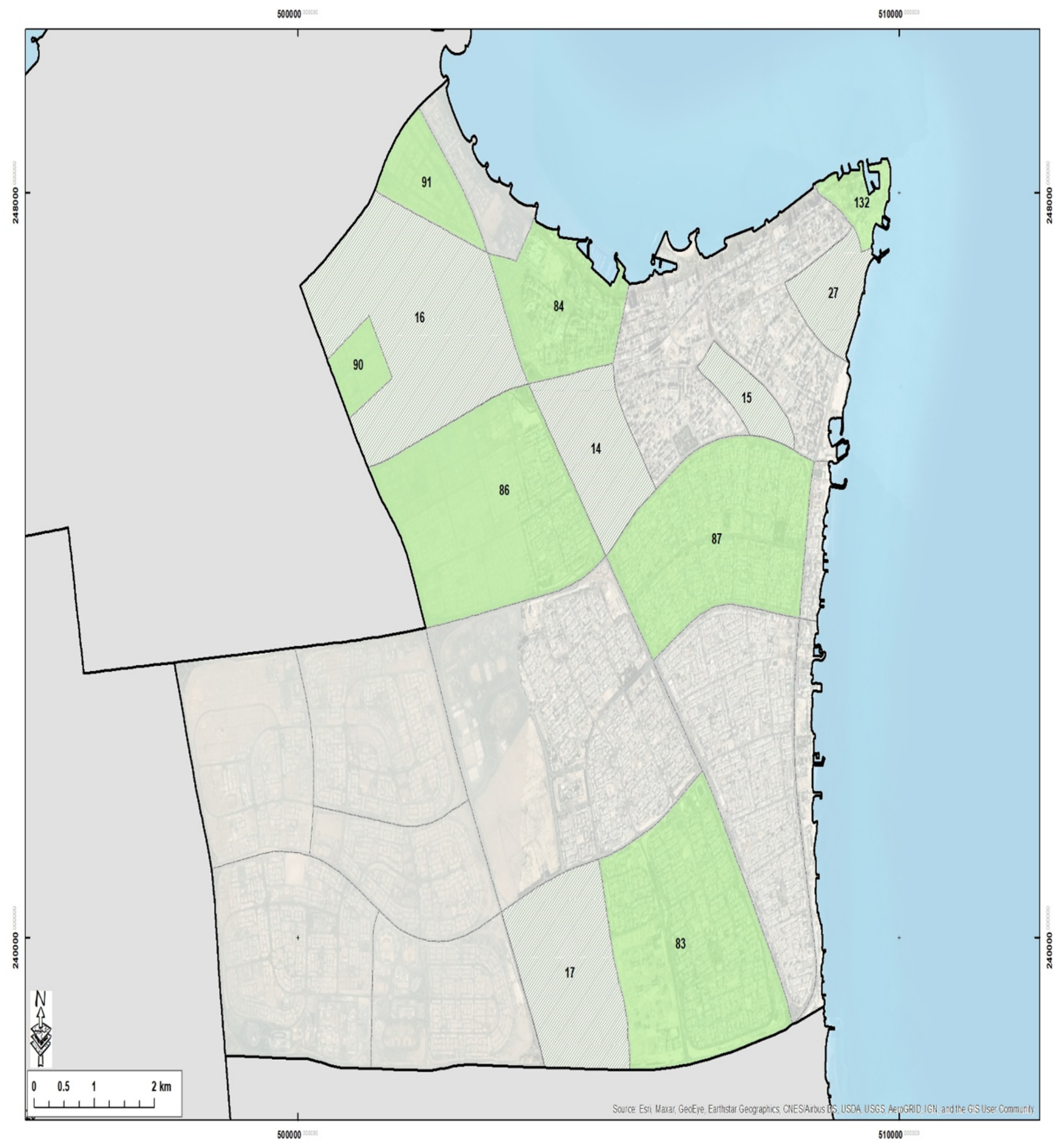


Figure 8. Optimal firefighting stations for Al-Farwaniya

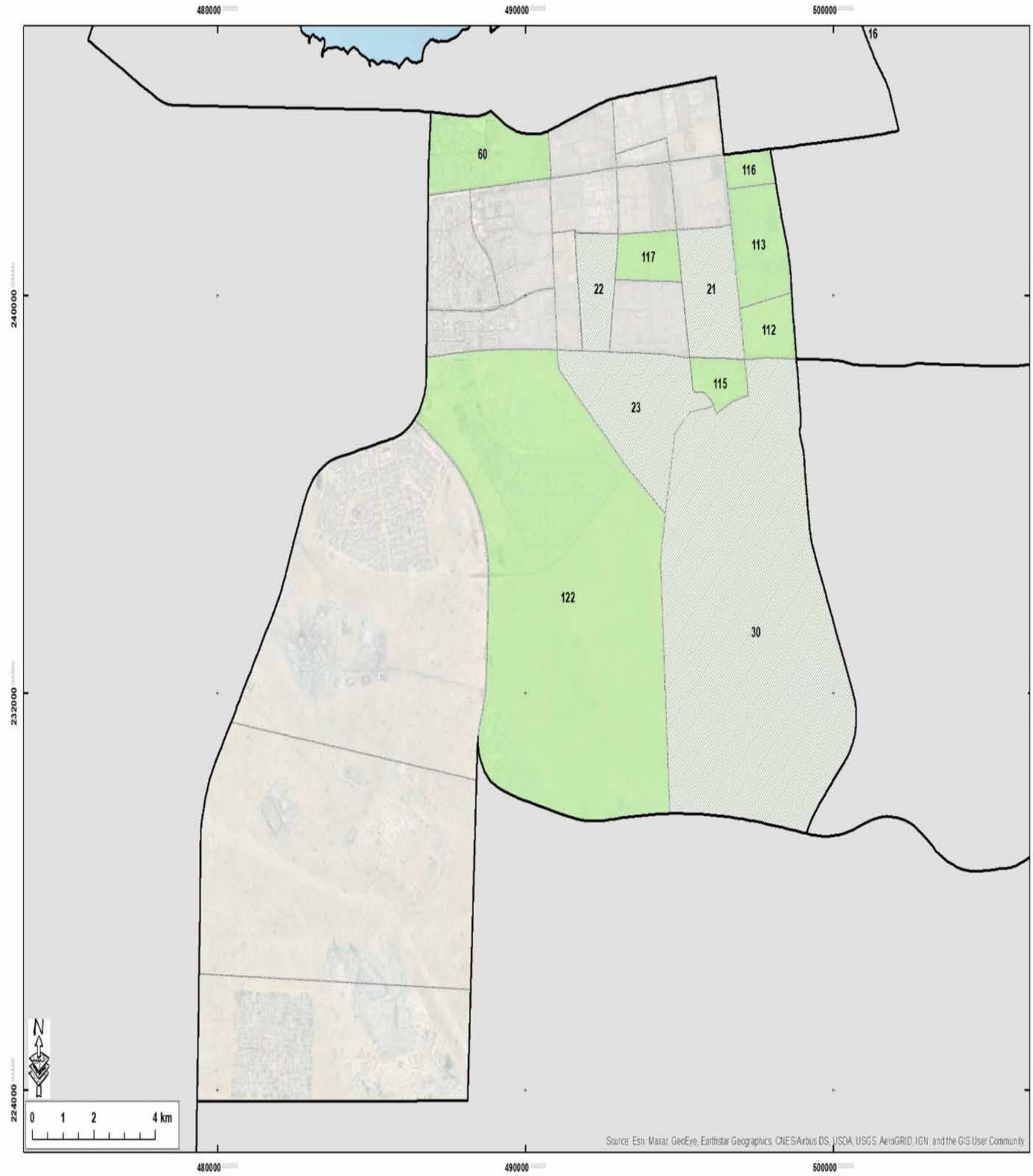


Figure 9. Optimal firefighting stations for Mubarak Al-Kabir

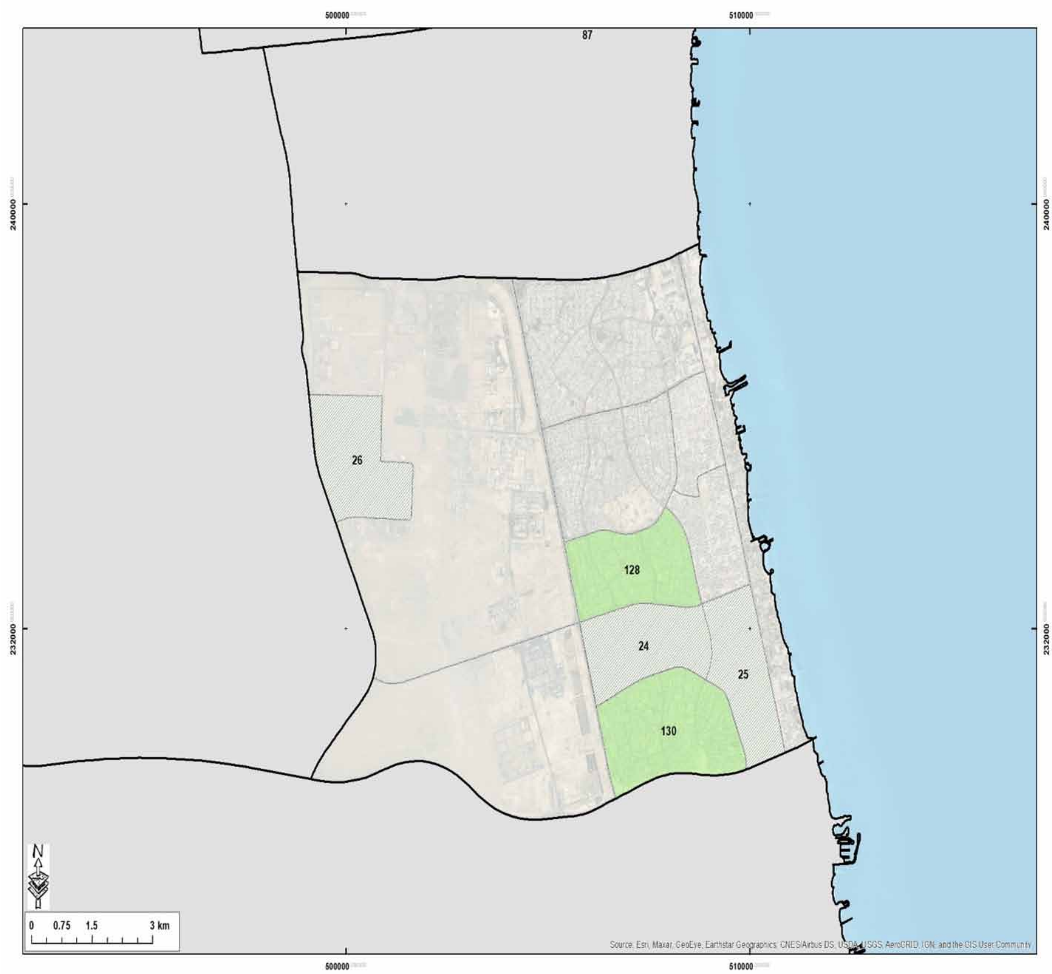
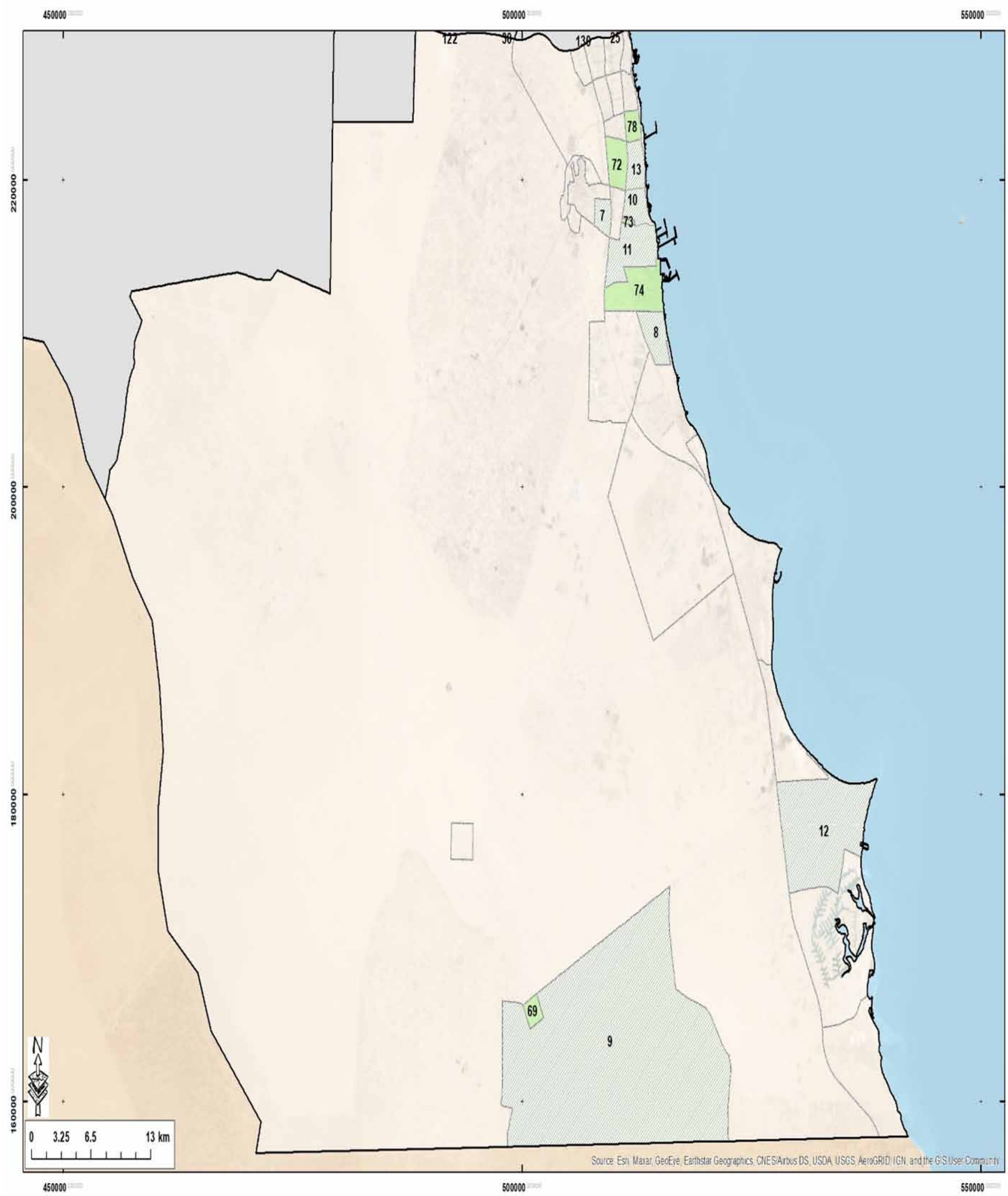


Figure 10. Optimal firefighting stations for Al-Ahmadi



Hana O. A. Al-Omar has a BSc in computer science and mathematical statistics from Kuwait University. They also decided to continue a master's degree in statistics and operations research also from Kuwait University with their professors' encouragement. Then, they joined Kuwait University as a teaching assistant. Additionally, they completed their PhD in statistics and operations research in 2004 from the American University in London (science management – operations management). Still working at Kuwait University, College of Business Administrations, where they are teaching Math-Stat in the Information Systems and Operations Management Department. Their area of interest is related to statistics and operations research regarding modeling and decision-making. Aside from science, they managed to have their TOT certificate from the Educational Clinic for Consulting and Training in 2019. Regarding their hobbies, they were an international volleyball athlete and retired in 2003, but nowadays, they are a talented musician (flutist). They perform in official KU recitals and/or in private or public theaters.