Location-Allocation of Hospitals in Perth

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Abstract

The COVID-19 pandemic underscored the critical need for accessible healthcare services, particularly for large urban populations. This study addresses the problem of optimizing the location of testing clinics in Perth, Western Australia, a region with insufficient public hospital facilities to meet the healthcare demands of its 2.1 million residents. The Western Australian Government's long-term plans include expanding the number of testing clinics to ensure comprehensive coverage, especially during pandemic situations. This research employs Geographic Information System (GIS) and location-allocation models using ArcGIS Pro and Network Analyst to analyze the current service capabilities of existing public hospitals and identify optimal locations for new testing clinics. By applying the Maximize Coverage model, which aims to cover the maximum population within a 5-kilometer radius, the study reveals that only 10% of the population is currently within the desired proximity to a public hospital. Consequently, additional testing clinics are essential to enhance service coverage. Through detailed spatial analysis, the study proposes 35 new testing clinic locations, increasing the coverage to 50.33% of the population, a significant improvement over the existing situation. The methodology includes loading and analyzing various datasets, such as road networks, census data, and hospital locations, to create a comprehensive location-allocation layer. The results highlight the inadequacies in the current healthcare infrastructure and provide actionable insights for government planning and resource allocation. The study emphasizes the importance of using advanced GIS and network analysis tools in public health planning, demonstrating that strategic placement of healthcare facilities can substantially improve accessibility and service delivery. The findings underscore the necessity of expanding healthcare facilities in Perth to prepare for future health crises and ensure equitable access to essential health services for all residents. This research contributes to the broader understanding of location-allocation problems in public health and showcases the practical application of GIS in optimizing healthcare delivery systems.

Keywords: COVID-19 pandemic, location-allocation, network analyst, *spatial analysis, testing clinic*

Introduction

In this study a real-world problem is introduced. This problem is related to location choice of testing clinics in the Perth region in Western Australia. In covid-19 pandemic situation, it is important to precognition of infected population. But the number of existing hospitals which are not private is less in Perth. And also, it is not sufficient to serve all the population. So, the improvement of services in health sector is must for preparing for the risky situations such as covid-19.

Perth is the fourth most populous city in Australia and Oceania, with a population of 2.1 million (80% of the state) living in greater Perth in 2020 ("Perth, Australia Metro Area Population 1950-2020"). Lack of health facilities commensurable to the population is a considerable problem. According to the long-term plans of Western Australian Government the number of testing clinics including of existing public hospitals in Perth should increase for the purpose of serving all population. This increase of hospital capacities (testing clinics) should satisfy health necessity under covid-19 situation at least the present population. The next issue is where to locate the testing clinics. Then the Western Australian Government wants to know ahead of time where to locate the testing clinics.

The location-allocation study which explicitly study for the problem of locating health facilities in all countries under covid-19 situation is this. In this study, hope to solve the problem of locating testing clinics in Perth of Western Australia to prepare for pandemic of covid-19. Actually, Western Australian Government wants to find out how well the existing public hospitals would currently serve the population and, if necessary, to know ahead of time where to set up testing clinics that are no greater than 5Km from demand points.

Literature Review

Location-Allocation

Location allocation is used to choose the best location for facilities to serve a set of demand locations. The locations may be trying to cover the most amount of demand, minimize costs to reach the demand, or maximize market share. Location is often considered the most important factor leading to the success of a private- or public-sector organization. Private-sector organizations can profit from a good location, whether a small coffee shop with a local clientele or a multinational network of factories with distribution centers and a worldwide chain of retail outlets. Location can help keep fixed and overhead costs low and accessibility high. Public-sector facilities, such as schools, hospitals, libraries, fire stations, and emergency response services (ERS) centers, can provide high-quality service to the community at a low cost when a good location is chosen. All location-allocation analyses solve the same problem, but the best location is not the same for all types of facilities. For instance, the best location for a hospital is different than the best location for a manufacturing plant. So, there are one more than location allocation problem types.

Location Allocation Network Analysis

The ArcGIS location allocation analysis solve the problems. Location-Allocation analysis layer offers seven different problem types to answer specific kinds of questions, including questions like those posed in the two examples above. The seven problem types are the following:

1. Minimize impedance
2. Maximize coverage
3. Maximize capacitated coverage
4. Minimize facilities
5. Maximize attendance
6. Maximize market share
7. Target market share

Minimize Impedance chooses facilities such that the sum of weighted impedances (demand allocated to a facility multiplied by the impedance to the facility) is minimized. This problem type is traditionally used to locate warehouses, because it can reduce the overall transportation costs of delivering goods to outlets. Since Minimize Impedance reduces the overall distance the public needs to travel to reach the chosen facilities, the minimize impedance problem without an impedance cutoff is ordinarily regarded as more equitable than other problem types for locating some public-sector facilities such as libraries, regional airports, museums, department of motor vehicles offices, and health clinics.

Maximize Coverage chooses facilities such that as much demand as possible is covered by the impedance cutoff of facilities. In this graphic, the solver was directed to choose three facilities. This is frequently used to locate fire stations, police stations, and ERS centers, because emergency services are often required to arrive at all demand points within a specified response time. Note that it is important for all organizations, and critical for emergency services, to have accurate and precise data so that analysis results correctly model real-world results.

Pizza delivery businesses, as opposed to eat-in pizzerias, try to locate stores where they can cover the most people within a certain drive time. People who order pizzas for delivery don't typically worry about how far away the pizzeria is; they are mainly concerned with the pizza arriving within an advertised time window. Therefore, a pizza-delivery business would subtract pizza-preparation time from their advertised delivery time and solve a maximize coverage problem to choose the candidate facility that would capture the most potential customers in the coverage area. (Potential customers of eat-in pizzerias are more affected by distance, since they need to travel to the restaurant; thus, the attendance maximizing or market share problem types would better suit eat-in restaurants.) Maximize Capacitated Coverage chooses facilities such that all or the greatest amount of demand can be served without exceeding the capacity of any facility. In this graphic, each facility has a capacity of one, and the solver was directed to choose three facilities. Although the demand point on the bottom of the map is within the impedance cutoff of a facility, it's not allocated, because doing so would surpass a facility's capacity.

Maximize Capacitated Coverage behaves like either the Minimize Impedance or Maximize Coverage problem type but with the added constraint of capacity. (If Impedance Cutoff is set to <none>, it behaves like a capacitated version of Minimize Impedance.) You can specify a capacity for a facility by assigning a numeric value to its Capacity property. If the Capacity property is null, the facility is assigned a capacity from the Default Capacity property of the analysis layer. Use-cases for Maximize Capacitated Coverage include creating territories that encompass a given number of people or businesses, locating hospitals or other medical facilities with a limited number of beds or patients who can be treated, or locating warehouses whose inventory isn't assumed to be unlimited.

Minimize Facilities chooses facilities such that as many demand points as possible are within the impedance cutoff of facilities. Additionally, the number of facilities required to cover all demand points is minimized. In this graphic, the solver was able to cover all demand points with only two facilities. This is the same as Maximize Coverage but with the exception of the number of facilities to locate, which in this case is determined by the solver. When the cost of building facilities is not a limiting factor, the same kinds of organizations that use Maximize Coverage (emergency response, for instance) use Minimize Facilities so that all possible demand points will be covered. Minimize Facilities is also used to choose school bus stops when students are required to walk a certain distance before another school bus stop is provided closer to the student's residence.

Maximize Attendance chooses facilities such that as much demand weight as possible is allocated to facilities while assuming the demand weight decreases with distance. The demand points, represented by pie charts in this graphic, show how much of their total demand is captured by the facility. Specialty stores that have little or no competition benefit from this problem type, but it may also be beneficial to general retailers and restaurants that don't have the data on competitors necessary to perform market share problem types. Some businesses that might benefit from this problem type include coffee shops, fitness centers, dental and medical offices, bowling alleys, and electronics stores. Public transit bus stops are often chosen with the help of Maximize Attendance. Maximize Attendance assumes that the farther people have to travel to reach your facility, the less likely they are to use it. This is reflected in how the amount of demand allocated to facilities diminishes with distance. You specify the distance decay with the impedance transformation

Maximize Market Share chooses facilities such that the largest amount of allocated demand is captured in the presence of competitors. You specify the number of facilities you want it to choose. The market share problem types require the most data because, along with knowing your own facilities' weight, you also need to know that of your competitors' facilities. The same types of facilities that use the Maximize Attendance problem type can also use market share problem types given that they have comprehensive information that includes competitor data. Large discount stores typically use Maximize Market Share to locate a finite set of new stores. The market share problem types use a Huff model, which is also known as a gravity model or spatial interaction.

Target Market Share works in the presence of competitors and tries to choose the fewest facilities necessary to capture the market share that you specify. The market share problem types require the most data because, along with knowing your own facilities' weight, you also need to know that of your competitors' facilities. The same types of facilities that use the Maximize Attendance problem type can also use market share problem types given that they have comprehensive information that includes competitor data. Large discount stores typically use the Target Market Share problem type when they want to know how much expansion would be required to reach a certain level of the market share or see what strategy would be needed just to maintain their current market share given the introduction of new competing facilities. The results often represent what stores would like to do if budgets weren't a concern. In other cases where budget is a concern, stores revert to the Maximize Market Share problem and simply capture as much of the market share as possible with a limited number of facilities.

Background Studies

As already mentioned, an optimal location-allocation is a process that evaluates facilities' location in terms of various criteria. Evaluating population accessibility and compatibility of healthcare facilities with other neighboring land-uses are 2 of the most important criteria in selecting the best locations. In addition to the 2 above-mentioned criteria, the present study focused on other important criteria, including population density in different areas, area of lands according the standards of Iran's ministry of health, and proximity to road networks. Better accessibility can save patients' traveling time to hospitals in emergency situations, reduce traveling costs, and improve equity in health. Indeed, paying attention to compatibility criteria can result in increasing patient satisfaction due to elimination of the destructive effects of facilities, such as noise pollution. ((Rahman and Smith, 2020)

Commonly, women from low socio-economic background are vulnerable to pregnancy-related complications (Iliyasu, Abubakar, Galadanci, & Aliyu, 2010; Obiechina, Okolie, Eleje, Okechukwu, & Anemone, 2011). The peculiarity of their vulnerability predisposes them to finding quicker and cheaper avenues to seek health care. The primary health care (PHC) maternity facilities are to serve this large population of women and their newborns. Services in Nigerian PHC facilities are not completely free, and the costs of available services are relatively determined by staff working in the facility (Aluko et al., 2022)

This study has shown that Geographic Information System and Remote Sensing technology can be used to critically evaluate the distribution and accessibility of healthcare facilities. Making it possible for experts to find out the current locations of health care centers and their coverage, to find out which parts of the study area (population) might be seriously uncovered (or under-served) within the World Health Organization standard distance of 5 km and to find out the best locations to construct new health centers with the aim of optimizing or improving geographic accessibility to health centers. The desire to maximize the total number of demands covered within the threshold of service distance or time by locating the candidate facility near the population density was achieved (Donnell, 2007). This is the desire of any government in providing its citizen with social amenities and services. (Kemboi and Waithaka, 2013).

Objectives

This study integrates GIS and geospatial analytical methods based on location-allocation models with the following objectives:

1.To show how well the existing public hospitals would currently serve the population.

2.To locate the new testing clinic which is served for the 100% population in Perth.

This study utilizes Geographic Information Systems (GIS) and geospatial analytical methods, particularly focusing on location-allocation models, to address critical healthcare accessibility issues in Perth. The primary objectives of the study are twofold.

Firstly, it aims to evaluate the effectiveness of existing public hospitals in serving the current population. By analyzing various factors such as patient demographics, hospital capacities, and geographical distribution, this research seeks to determine how well these facilities meet the healthcare needs of residents. This assessment will identify areas where public hospitals are either over or underutilized, providing insights into potential gaps in service delivery and highlighting the need for strategic improvements.

Secondly, the study aims to identify optimal locations for a new testing clinic that would be accessible to 100% of the population in Perth. By applying location-allocation models, the research will evaluate various site options based on criteria such as population density, accessibility, and proximity to existing healthcare facilities. This analysis will help in determining the most effective location for the clinic, ensuring it is conveniently situated to serve all residents without any barriers.

Ultimately, this study's findings will contribute to enhancing healthcare accessibility in Perth, providing actionable recommendations for policymakers and stakeholders to improve public health services and ensure equitable healthcare access for the entire population.

Methodology

Study Area

Perth is the capital and largest city of the Australian state of Western Australia. It is the fourth most populous city in Australia and Oceania, with a population of over 2.14 million people, which account for 8.58% of the national population. Perth's population density is 317.7 people per square kilometer. Perth is part of the South West Land Division of Western Australia, with most of the metropolitan area on the Swan Coastal Plain between the Indian Ocean and the Darling Scarp. The city has expanded outward from the original British settlements on the Swan River, upon which the city's central business district and port of Fremantle are situated.

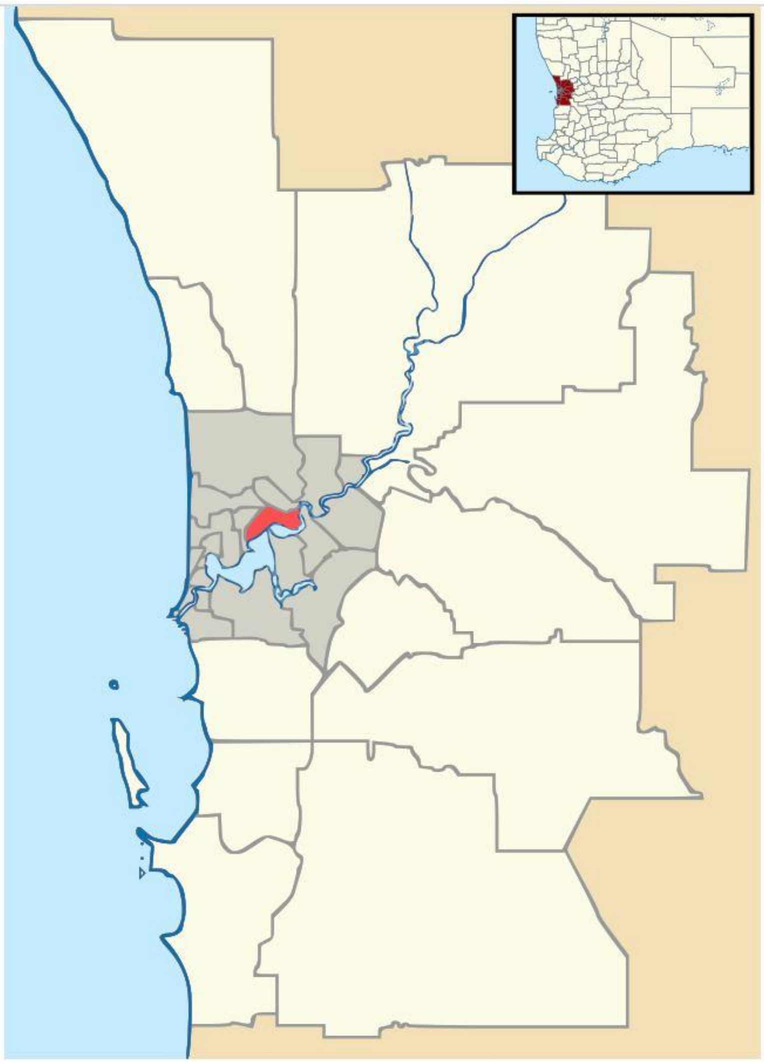

Figure 1: Map of Perth.

Data Used

For this location Allocation analysis need different types of data related to the study area such as road network, data on the locations of centroid of census, existing hospitals and the locations which is going to be used as testing clinics. These data is obtained from different places as follows.

To perform location-allocation analysis in Network Analyst requires a network dataset. This is basically a street centerline file that has attributes, such as speed limits or travel times, assigned to each road segment. A network dataset can be built using Network Analyst. In this case, the network dataset that is included with Data and Maps for ArcGIS has been included in the sample dataset and will be used.

For this analysis, to simulate the population at the suburb level, Australian bureau statistics is used. The Australian Bureau of Statistics is the independent statutory agency of the Australian Government responsible for statistical collection and analysis and for giving evidence-based advice to federal, state and territory governments. For that used the given link for the census geo-packages and download Geopackage_2021_G03_WA_GDA2020. In here having SAL_2021 dataset and extracted Total_total as the field.

https://www.abs.gov.au/census/find-census-data/geopackages?release=2021&geography=WA&table=G03&gda=GDA2020

Data for the location of existing hospitals in Western Australia obtained by downloading. From the existing hospital dataset, all of those hospital data that are not private in the metropolitan area is used. The hospitals which are not private is obtain from the following link.

https://en.wikipedia.org/wiki/List_of_hospitals_in_Western_Australia

For the future testing clinics location, used a point shape file which is created with random locations in Perth by assuming all are having same facilities and conditions.

1. Find out Existing Situation

A: Getting Stared

ArcGIS Pro 2.9 and Network Analyst will help the county make more informed decisions on mobile clinic locations.

1. Open ArcGIS Pro and create a new project based on the **Map.aptx** template. **Perth_LocationAllocation** as project name and set the path for the location.
2. In the **Catalog** pane, which is on the side of the application by defalt, right-click **Folders** and choose **Add Folder Connection.** The **Add Folder Connection** dialog box appears. Browse to the folder named **HospitalPrj_Data** and press **OK.** A connection to the Data folder is created.
3. Expand the **HospitalPrj.gdb** and then expand **Infrastructure**. Drag the **roads_ND** (Network Dataset) into view. Right-click **roads_ND** in the **Contents** pane and choose **Zoom To Layer to view** the Perth area.
4. In the **Contents** pane, uncheck **roads_ND** to display the base map only.

By default, network datasets built with traffic data show traffic conditions for the current time when they are added to the map. This network dataset includes historical traffic, so you are seeing typical traffic conditions for the current time and day of the week. Not all roads in this network dataset include traffic, so only the ones that do are shown by default. The area covered by the network dataset is where you can perform network analyses. Viewing the network dataset isn't required to perform an analysis, so next, you will hide it.

B: Loading Existing Hospitals and the Population Data

In the **Catalog** pane, right-click the **Metropolitan_Public_hospital** and **TracksCentroids** layers and choose **Add to Current Map.** The **Metropolitan_Public_hospital** and **TracksCentroids** layers are added to the **Contents** pane and to the map.

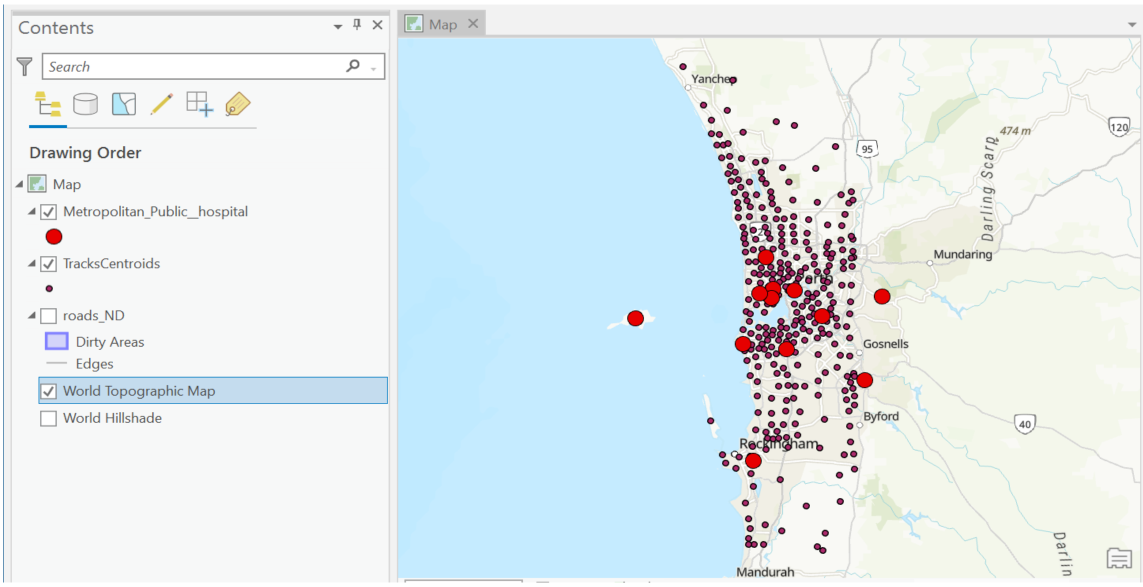

Figure 2: Map of Centroid of Census and Existing Public Hospitals.

C: Create the location-allocation layer

A location-allocation layer provides the structure and properties needed to set up and solve the location problem. It also contains the results after solving.

On the **Analysis** tab, in the **Workflows** group, click **Network Analysis** > **Location-Allocation.** The location-allocation layer is added to the **Contents** pane. It includes the sub layers that hold the inputs and outputs of the analysis. Location-allocation is referencing the Perth network dataset because the network was in the **Contents** pane when the location-allocation layer was created.

In the **Contents** pane, click **Location-Allocation** to select the group layer**.** The **Location-Allocation Layer** tab appears. Click **Location-Allocation Layer** to see the tab's controls. Used these controls to define the location-allocation results you want to generate.

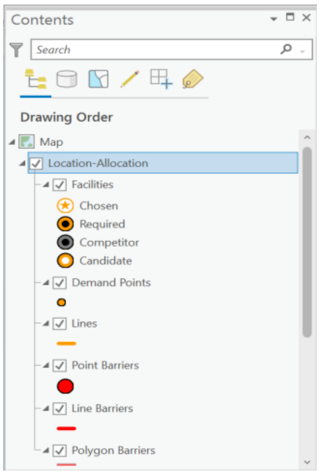

Figure 3: Create Location-Allocation Layer.

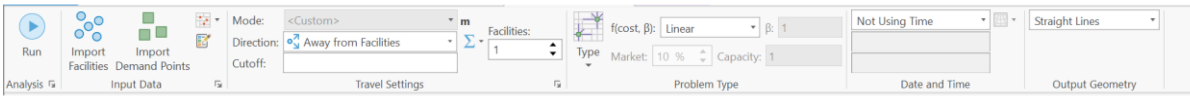

Figure 4: Setting Parameters for Network Analysis.

D: Add a required facility

On the **Location-Allocation Layer** tab, in the **Input Data** group, click **Import Facilities.** The **Add Locations** window appears. Make sure **Input Network Analysis Layer** is set to **Location-Allocation** and **Sub Layer** is set to **Facilities.** Click the drop-down menu below **Input Locations** and choose **Metropolitan_Public__hospital.** This is the point feature class you previously added to the map. In the **Field Mapping > Property** section, choose **Facility Type.** From the **Default Value** drop-down menu, choose **Required.**

These Hospitals are permanent, so the tool should always use them. Once added to the Facilities layer, these points are automatically added to the map.

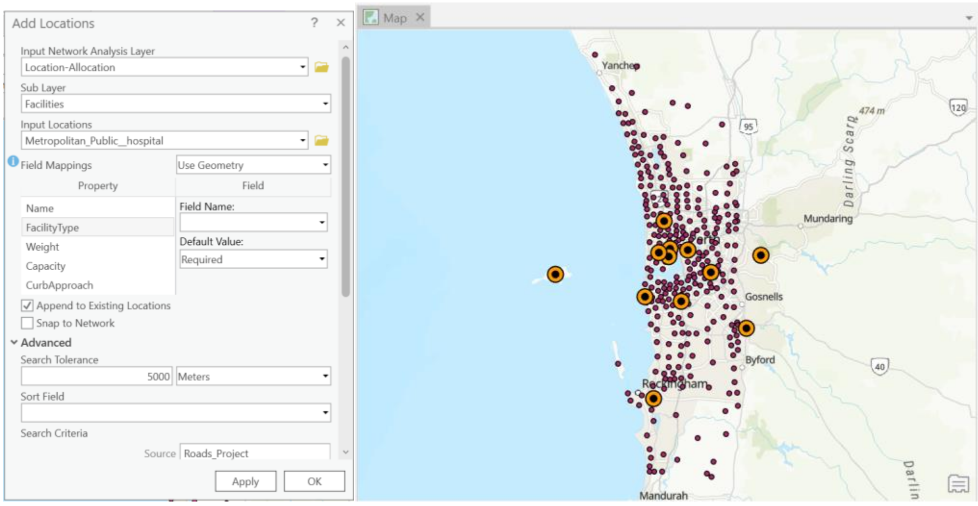

Figure 5: Setting for Add Required Facilities.

E: Add demand Points

On the **Location-Allocation Layer** tab, in the **Input Data** group, click **Import Demand Points.** The **Add Locations** window appears. Make sure **Input Network Analysis Layer** is set to **Location-Allocation** and **Sub Layer** is set to **Demand Points.** Click the drop-down arrow for **Input Locations** and choose **TracksCentroids.** This is the point feature class you previously added to the map.

From **Field Mapping > Property,** choose **Weight.** From the **Field Name** drop-down list, choose **TotPop**. Leave the default settings for the rest of the parameters and click the **OK** button.

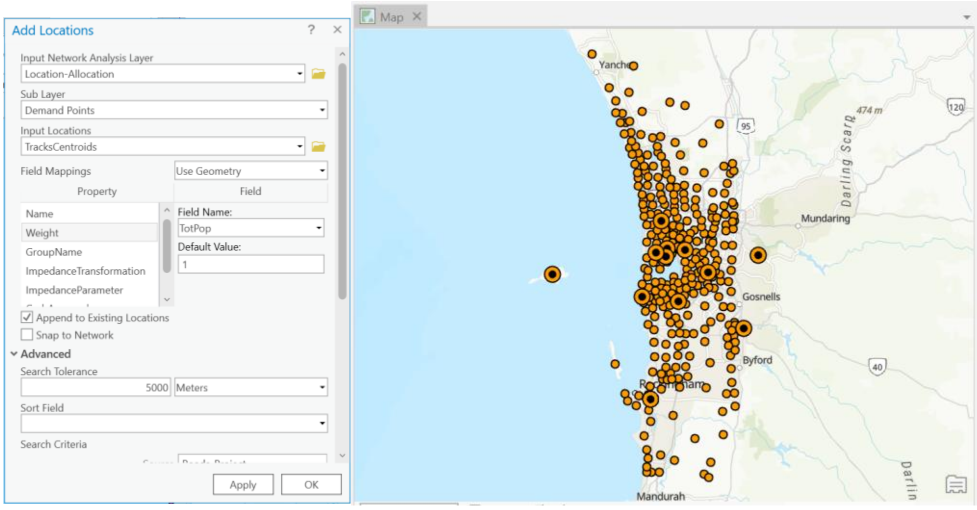

Figure 6: Setting for Import Demand Points.

F: Set up properties of the location-allocation analysis

On the **Location-Allocation Layer** tab, in the **Problem Type** group, click the arrow under **Type** and choose **Maximize Coverage.** Direction of travel to **Demand to Facility** to simulate patients traveling to clinics. Under **Facilities** choose 12 for the twelve permanent public hospitals. Set impedance **Cutoff** to 5000 to indicate that 5 Km is the maximum distance a patient would be willing to travel to a hospital for a test.

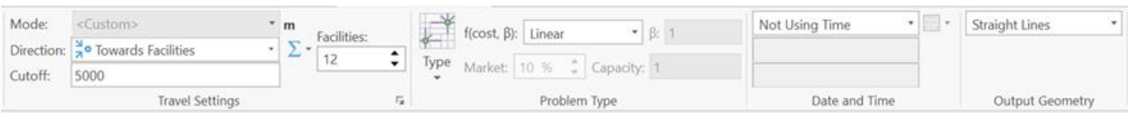

Figure 7: Parameters for Existing Coverage Analysis.

The result will be discussed in Result section as Result method 1

2.Find out New Testing Clinic Locations

All necessary data such as Road Network dataset, Demand points, Existing Hospitals and also the Candidate points added to the new map template and started the analysis to find out the new locations for the testing clinics.

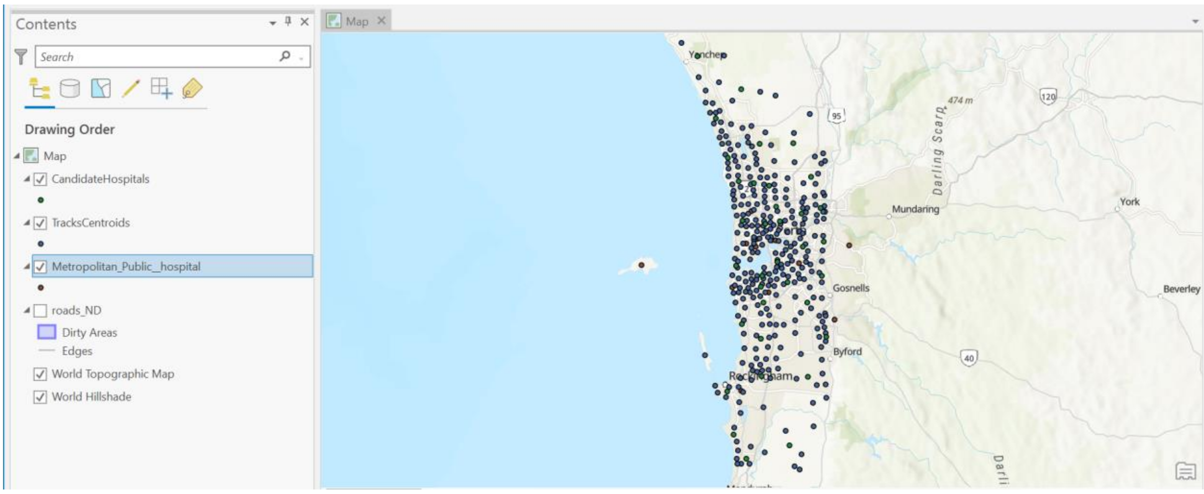

Figure 8: Map of Centroid of Census, Existing Public Hospitals and Candidate.

Create a new location allocation layer and import candidate facilities using add locations by setting as follows. Click the drop-down menu below **Input Locations** and choose **CandidateHospitals.** This is the point feature class you previously added to the map. In the **Field Mapping > Property** section, choose **Facility Type.** From the **Default Value** drop-down menu, choose **Candidate.**

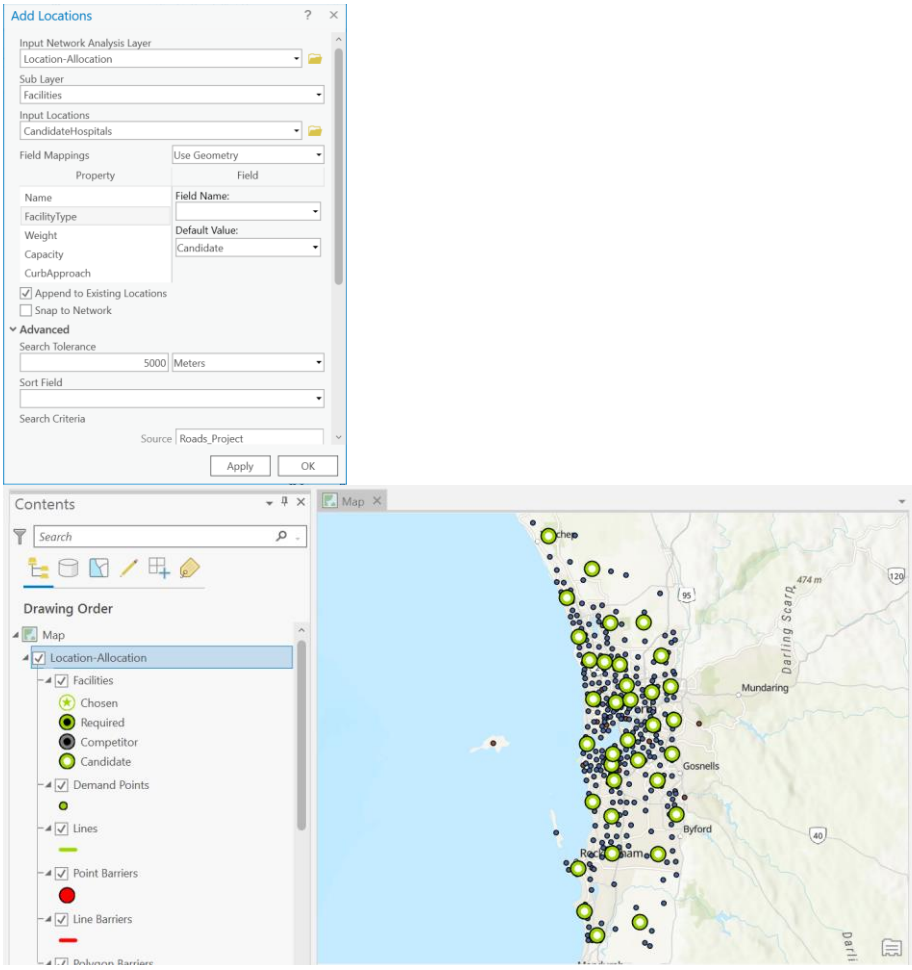

Figure 9: Map of Adding Candidate Facility.

Import population file as demand points and setting.

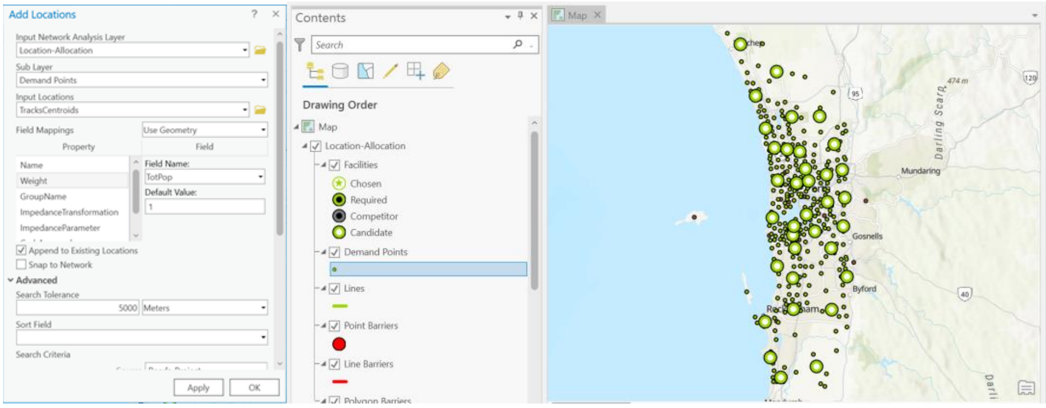

Figure 10: Import Demand Points.

Add existing public hospitals setting required points.

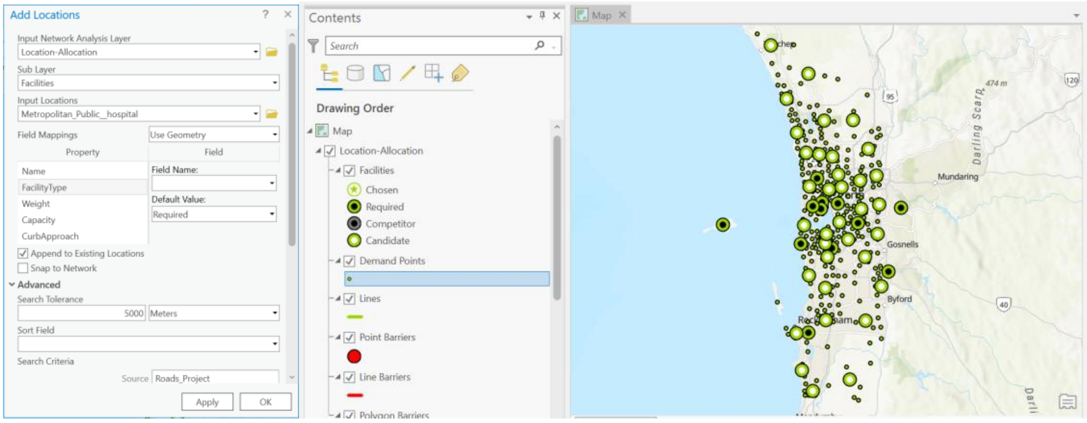

Figure 11: Import Required Facility.

Add 12 Existing Public hospitals, 35 Candidate points as Testing clinics and 306 demand points centroid of census tracks.

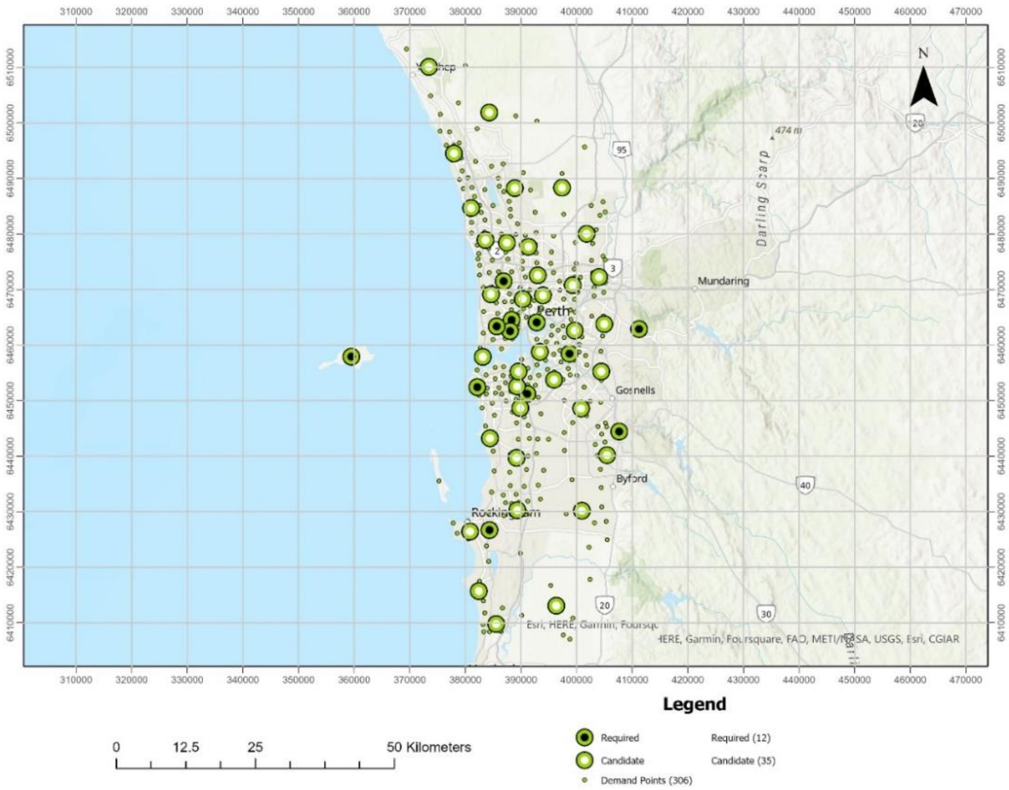

Figure 12: Map of Adding Facilities.

Set up properties of the location-allocation analysis like this. Set parameters same as in figure 7. On the **Location-Allocation Layer** tab, in the **Problem Type** group, click the arrow under **Type** and choose **Maximize Coverage.** Direction of travel to **Demand to Facility** to simulate patients traveling to clinics. Under **Facilities** choose 47 for the twelve permanent public hospitals and 35 new Testing Clinics. Set impedance **Cutoff** to 5000 to indicate that 5 Km is the maximum distance a patient would be willing to travel to a hospital for a test. Finally click **Run** for the analysis to get the result of Locations for testing Clinics.

Results

Find out the result for existing situation in Perth

When the analysis is complete, it should show that 30 of 306 residents are within 5 Km distance of a public hospital. This is about 10% of the population. More testing clinics will be needed to provide acceptable service to residents.

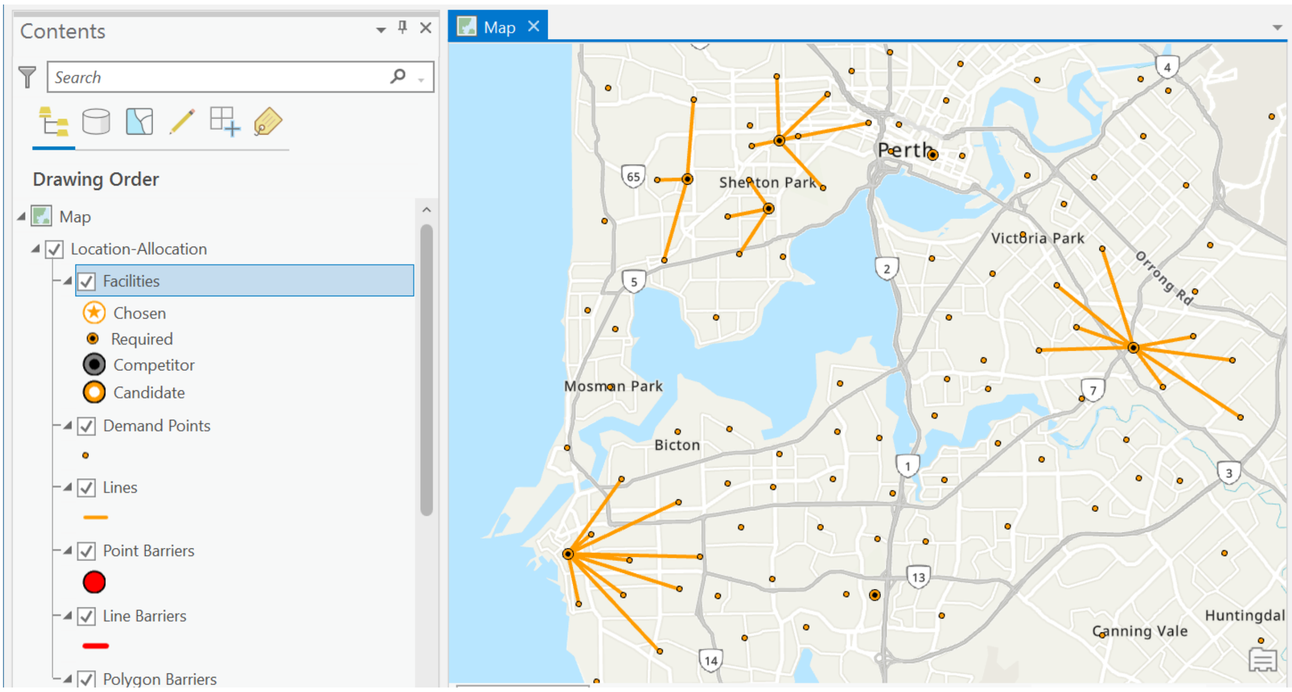

Figure 13: Map of Coverage Display.

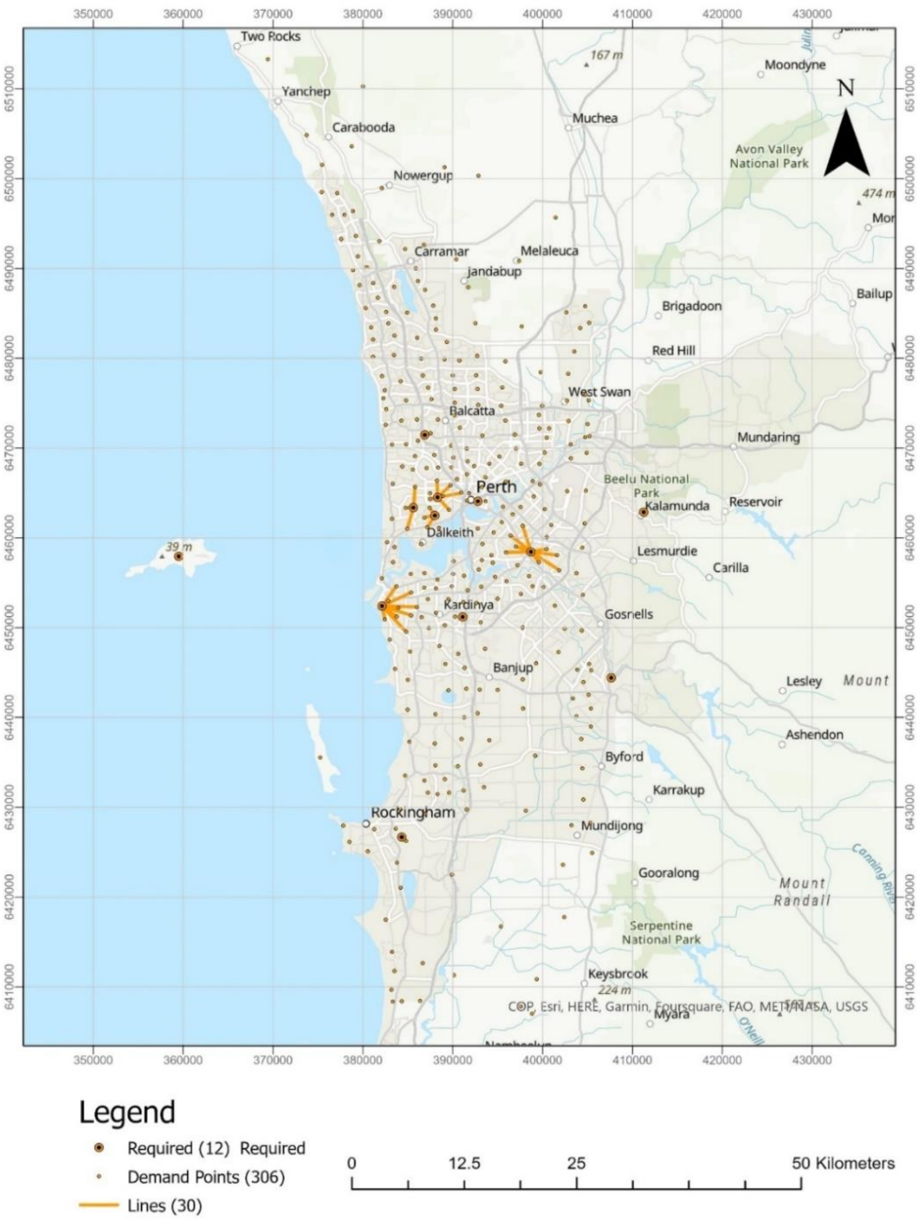

Figure 14: Map of Existing Situation Analysis.

Find out new locations for testing clinics

The result of the analysis will show the optimal choices for 35 candidates to host testing clinics, indicated by red stars and as well as the existing public hospitals shown with black-green circles. Non optimal testing clinic locations are shown in white-green circles.

In this figure look at lines to see that 154 of 306 residents are in 5 Km from a Testing clinic. That is 50.33% of residents, which is a substantial improvement.

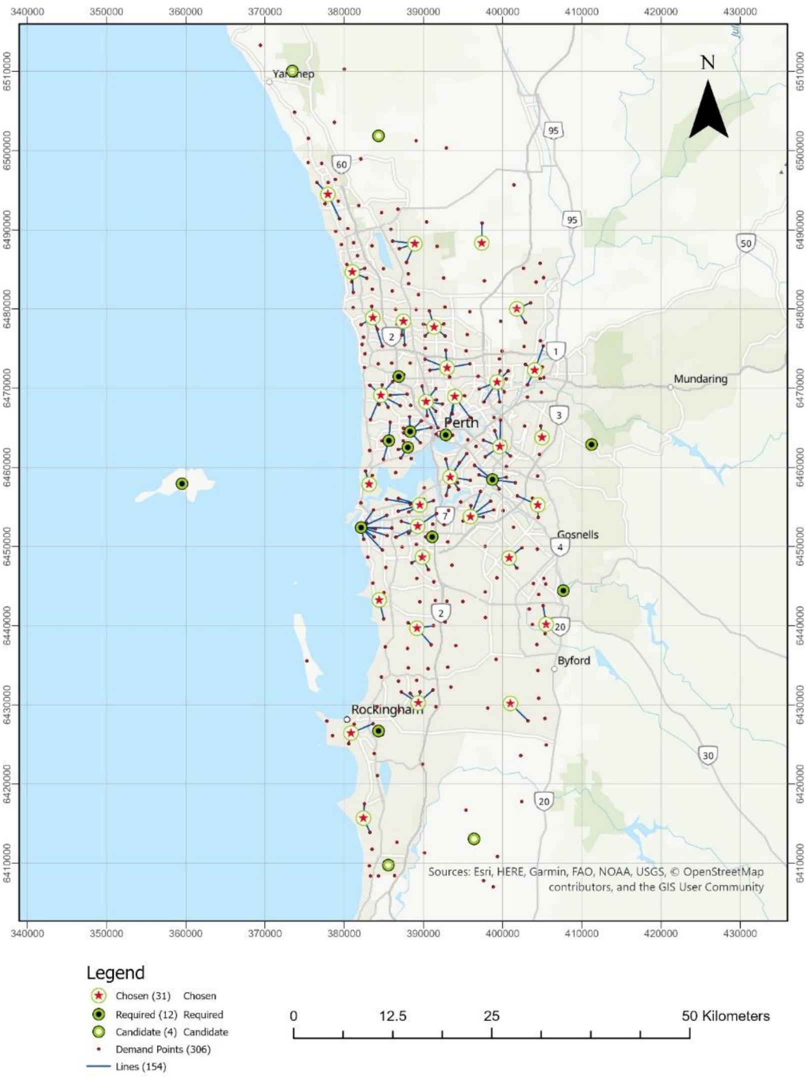

Figure 1: Map of New Testing Clinics

Discussion

Most of the public hospitals are situated in centroid of the Perth. No hospitals to cover the entire area of the Perth. It can be clearly identified that the existing public hospitals cannot cover the non-centric area of Perth surely. Figure 15 shows that how to serve the existing hospitals for the population. Access from the centroid of the census tracks to hospital is analyzed along the road. So, the reality of the access is coming to the analysis from the road network data set.

Figure 13 shows some demand points are very closer to the hospital location. But they are not selected from the analysis with a line because it is not easy to access the hospital due to the highway which is laying among the hospital and the centroid of census tracks.

Figure 15 shows that only few suburbs which are in centroid of Perth are covered by the existing public hospitals and rest of the area cannot obtain the service by the public hospital. So, the health situation is in a risky level.

The existing facilities in the health sector is not enough to save the population from covid-19 situation by knowing ahead and cannot treating before coming to the critical level of infections by testing. So, the necessity of boarding the health sector facility is clearly identified. Then the next step is to increase the 10% of coverage to 100% for a safety of population.

Candidate points randomly cover the whole area of Perth by equally spread. But some population points are not detected in analysis because of the difficulties of accessing to the nearest hospital. But the progress of the new analysis is in a sustainable level. By increasing the testing clinic can reach the 100% of coverage.

Conclusion

The primary aim of this study is to show how well the existing public hospitals would currently serve the population and to locate the new testing clinic which is served for the 100% population in Perth. Using GIS to optimally locate the additional clinics is far superior to “just eyeballing.” This analysis uses the actual street network and an analysis of the demand that factors in 5Km travel distance for patients. By using ArcGIS Pro with the Network Analyst extension and the datasets for existing public hospital’s locations, population, testing clinic locations, and a network dataset, analysis is done.

First importing data to a location-allocation layer, then the network analysis is run and finally as a result it gives less percentage of population coverage. So clearly identified that necessity of another testing clinics for pre preparing for a Covid-19 situation. Assuming some 35 locations randomly covering whole Perth area as candidate, network analysis is done again. The result appears a considerable improvement of the testing facility coverage. It shows that increasing number of testing clinics and doing network analysis to locate is the best way of finding optimal locations to protect the population in covid19 situation.

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