**UNIVERSITI PUTRA MALAYSIA**

***DEVELOPMENT OF GEOSPATIAL MODEL FOR TUBERCULOSIS PREDICTION IN GOMBAK, SELANGOR, MALAYSIA***

**NUR ADIBAH BINTI MOHIDEM**

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# DEVELOPMENT OF GEOSPATIAL MODEL FOR TUBERCULOSIS PREDICTION IN GOMBAK, SELANGOR, MALAYSIA

By

**NUR ADIBAH BINTI MOHIDEM**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree Doctor of Philosophy**

**October 2021**

# DEDICATION

*All praise and thanks to Allah S.W.T. for the guidance, strength, power of mind, and protection. Indeed, we belong to Allah, and indeed, to Him we return.*

*This thesis is wholeheartly dedicated to my parents who have been source of inspiration; who continually provide their doa', emotional, and financial support.*

*Thanks to my family members and friends; who shared positive words and encouragement during all these years.*

*With love, respect, and a bunch of memories.*

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

**DEVELOPMENT OF GEOSPATIAL MODEL FOR TUBERCULOSIS PREDICTION IN GOMBAK, SELANGOR, MALAYSIA**

By

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**October 2021**

**Chair : Associate Professor Malina Binti Osman, MD, M.Comm.Health**
**Faculty : Medicine and Health Sciences**

Background: Tuberculosis (TB) cases have increased drastically over the last two decades and remains as one of the deadliest infectious diseases in Malaysia. Preventing and controlling the disease is not only depend on molecular epidemiology but there is also a need to explicitly understand spatial epidemiology, which assesses the distribution of disease in different locations. However, there is a lack of studies clarifying the spatial evaluation of both sociodemographic and environmental factors with the TB cases in the country. Objective: This study utilized the geospatial technologies i) to investigate the trend and spatial pattern of TB cases; ii) to investigate the spatial distribution of TB cases and its association with the sociodemographic and environmental factors; iii) to develop the prediction model of TB cases; and iv) to develop a web-GIS application for plotting TB cases. Methodology: The sociodemographic data of 3325 cases of TB such as age, gender, race, nationality, country of origin, educational level, employment status, health care worker status, income status, residency, and smoking status from January 2013 to December 2017 in Gombak were collected from the MyTB web and Tuberculosis Information System (TBIS) file. Environmental data consisting of air pollution data such as air quality index (AQI), carbon monoxide (CO), nitrogen dioxide ($NO_2$), sulphur dioxide ($SO_2$), and particulate matter 10 ($PM_{10}$) were obtained from the Department of Environment Malaysia from July 2012 to December 2017, whereas weather data such as rainfall were obtained from the Department of Irrigation and Drainage Malaysia and relative humidity, temperature, wind speed, and atmospheric pressure were obtained from the Malaysian Meteorological Department in the same period. Global Moran's I, kernel density estimation, and Getis-Ord Gi* statistics were applied to identify the spatial pattern of TB cases. Ordinary least squares (OLS) and geographically weighted regression (GWR) models were used to determine the spatial association of sociodemographic and environmental factors with the TB cases. Multiple linear regression (MLR) and artificial neural network (ANN) were applied to develop the prediction model of TB cases. A web-GIS application was set up in the Python Shapefile (PHP) CodeIgniter framework with the aid of ArcGIS JavaScript Application Programming Interface (API) 3.7 and HyperText Markup Language (HTML), Cascading Style Sheet (CSS), JavaScript, and PHP as programming languages. The ESRI map was used as the base map and combined with the web GIS technology via ArcGIS API. Results: Spatial autocorrelation analysis indicated that the cases were clustered ($p$<0.05) over five-year period and years 2016 and 2017. Kernel density estimation identified the high-density regions while Getis-Ord Gi* statistics observed the hotspot locations, whereby its were consistently located in the southwestern part of the district. This could be attributed to the overcrowding of inmates in the Sungai Buloh prison located there. The GWR model based on the environmental factor (GWR2) was the best model to determine the spatial distribution of TB cases based on the highest values of $R^2$ i.e. 0.98 and local $R^2$ > 0.70, which consisted of 2006 cases of TB. The ANN was found to be superior to MLR with higher adjusted $R^2$ values in predicting TB cases, in which the ranges were from 0.35 to 0.47 compared to 0.07 to 0.14. The sensitivity analysis of the relative important of each input variable illustrated that using both the sociodemographic and environmental data through ANN3, with highest adjusted $R^2$ value of 0.47, errors below 6, and accuracies above 96%, revealed the best performance in predicting TB cases than using the sociodemographic and environmental data individually for each ANN model. The web-GIS application displays the location of TB cases and its sociodemographic factors on an interactive map. Conclusion: This study identified the spatial variability in the association between risk factors and TB cases, and visualized the high risk areas using a user-friendly web mapping application, which helps in improving case detection and targeted surveillance. The prediction of TB cases were possible with the utilization of geospatial data.

Keywords: artificial neural network; environmental; geographically weighted regression; sociodemographic; spatial; tuberculosis; web-GIS

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBANGUNAN MODEL GEOSPATIAL BAGI RAMALAN BATUK KERING DI GOMBAK, SELANGOR, MALAYSIA**

Oleh

**NUR ADIBAH BINTI MOHIDEM**

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Latar belakang: Kes batuk kering telah meningkat secara mendadak sepanjang dua dekad yang terakhir ini dan ianya kekal sebagai salah satu daripada penyakit berjangkit yang paling membawa kepada kematian yang tinggi di Malaysia. Mencegah dan mengawal penyakit ini bukan sahaja bergantung kepada epidemiologi molekul, tetapi terdapat juga keperluan untuk memahami secara eksplisit tentang epidemiologi spatial yang menilai taburan penyakit di beberapa kawasan. Walau bagaimanapun, terdapat kekurangan kajian sebelum ini yang menghuraikan penilaian daripada segi spatial untuk kedua-dua faktor sosiodemografi dan alam sekitar dengan kes TB di negara ini. Objektif: Kajian ini menggunakan teknologi geospasial i) untuk mengkaji pola dan corak spatial untuk kes batuk kering; ii) untuk mengkaji taburan spatial untuk kes batuk kering dan kaitannya dengan faktor sosiodemografi dan alam sekitar; iii) untuk membina model ramalan untuk kes batuk kering; dan iv) untuk membangunkan aplikasi web-GIS untuk plot kes batuk kering. Metodologi: Data sosiodemografi bagi 3325 kes batuk kering seperti umur, jantina, bangsa, kewarganegaraan, negara asal, tahap pendidikan, status pekerjaan, status petugas kesihatan, status pendapatan, status tempat tinggal dan status merokok dari Januari 2013 hingga Disember 2017 di Gombak diperoleh daripada laman web MyTB dan fail Sistem Maklumat Tuberculosis (TBIS). Data alam sekitar yang terdiri daripada bahan pencemar seperti indeks kualiti udara (AQI), karbon monoksida (CO), nitrogen dioksida ($NO_2$), sulfur dioksida ($SO_2$) dan partikal terampai 10 ($PM_{10}$) diperoleh dari Jabatan Alam Sekitar Malaysia dari Julai 2012 hingga Disember 2017, manakala data cuaca seperti hujan diperoleh dari Jabatan Pengairan dan Saliran Malaysia dan kelembapan relatif, suhu, kelajuan angin dan tekanan atmosfera diperoleh dari Jabatan Meteorologi Malaysia dalam tempoh yang sama. Global Moran's I, ramalan kepadatan kernel dan statistik Getis-Ord Gi* digunakan untuk mengenal pasti corak spasial untuk kes batuk kering. Model kuadrat terkecil biasa (OLS) dan model geografi regresi berwajaran (GWR) digunakan untuk menentukan hubungan kait daripada segi spasial antara faktor sosiodemografi dan alam sekitar dengan kes batuk kering. Regresi linear berganda (MLR) dan rangkaian neural buatan (ANN) digunakan untuk membangunkan model ramalan untuk kes batuk kering. Aplikasi web-GIS dibangunkan dalam kerangka Codeygniter Python Shapefile (PHP) dengan bantuan ArcGIS JavaScript Application Programming Interface (API) 3.7 dan HyperText Markup Language (HTML), Cascading Style Sheet (CSS), JavaScript dan PHP sebagai bahasa pengaturcaraan. Peta ESRI digunakan sebagai peta dasar dan digabungkan dengan teknologi web GIS melalui ArcGIS API. Keputusan: Analisis autokorelasi spasial menunjukkan bahawa pola taburan bagi kes batuk kering adalah secara kluster ($p$<0.05) dalam tempoh lima tahun dan pada tahun 2016 dan 2017. Anggaran kepadatan kernel telah mengenal pasti kawasan berkepadatan tinggi, manakala Getis-Ord Gi* telah menunjukkan lokasi titik panas, yang mana kedua-duanya secara konsisten terletak pada bahagian barat daya di daerah tersebut. Perkara ini mungkin disebabkan oleh ramai banduan yang dijangkiti dengan penyakit batuk kering di penjara Sungai Buloh iaitu kawasan di mana terletaknya titik panas tersebut. GWR2 yang berdasarkan kepada faktor alam sekitar adalah model terbaik untuk menentukan taburan spasial untuk kes batuk kering berdasarkan nilai $R^2$ yang tertinggi iaitu 0.98 and $R^2$ tempatan > 0.70, yang mana terdiri daripada 2006 kes batuk kering. ANN didapati lebih baik berbanding MLR berdasarkan nilai $R^2$ terubah suai yang lebih tinggi dalam meramal kes batuk kering, iaitu julatnya antara 0.25 hingga 0.47 berbanding dengan 0.07 hingga 0.14. Analisis sensitif terhadap setiap pemboleh ubah input yang berkepentingan relatif menunjukkan bahawa menggunakan kedua-dua data sosiodemografi dan alam sekitar melalui ANN3 dengan nilai $R^2$ terubah suai yang tertinggi iaitu 0.47, kesalahan di bawah 6 dan ketepatan yang melebihi 96% telah menunjukkan prestasi terbaik dalam meramal kes batuk kering berbanding menggunakan data sosiodemografi dan alam sekitar secara berasingan untuk setiap ANN model. Aplikasi web-GIS memaparkan lokasi kes batuk kering dan faktor sosiodemografi pada peta interaktif. Kesimpulan: Kajian ini telah mengenal pasti kepelbagaian spasial dalam hubungan antara faktor risiko dan kes TB dan dapat memberi gambaran tentang kawasan-kawasan yang berisiko tinggi melalui penggunaan aplikasi web-GIS pemetaan yang mesra pengguna, iaitu dapat membantu dalam meningkatkan pengesanan kes dan aktiviti pengawasan yang bersasar. Ramalan kes batuk kering telah berjaya dibuktikan melalui penggunaan data geospasial.

Kata kunci: rangkaian neuron buatan; alam sekitar; geografi regresi wajaran; sosiodemografi; spasial; batuk kering; web-GIS

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ACB | Acid Fast Bacilli |
| ANN | Artificial Neural Network |
| aOR | Adjusted Odds Ratio |
| API | Application Programming Interface |
| AQI | Air Quality Index |
| ARIMA | Auto Regressive Integrated Moving Average |
| BIREME | Biblioteca Regional de Medicina |
| BMC | BioMed Central |
| CAB | Commonwealth Agricultural Bureaux |
| CI | Confidence Interval |
| CINAHL | Cumulative Index to Nursing and Allied Health Literature |
| CO | Carbon Monoxide |
| CSS | Cascading Style Sheet |
| DOAJ | Directory of Open Access Journals |
| EMBAS | Excerpta Medica Database |
| GIS | Geographic Information System |
| GWR | Geographically Weighted Regression |
| HIV | Immunodeficiency Virus |
| HTML | Hypertext Markup Language |
| IR | Incidence Rate |
| MeSH | Medical Subject Heading |
| MDR-TB | Multidrugresistant-Tuberculosis |
| MLR | Multiple Linear Regression |
| MOHM | Ministry of Health Malaysia |

| | |
|---|---|
| $NO_2$ | Nitrogen Dioxide |
| OECD | Organisation for Economic Co-Operation and Development Average |
| OLS | Ordinary Least Squares |
| OR | Odds Ratio |
| $PM_{10}$ | Particulate Matter 10 |
| PHP | Python Shapefile |
| RSM | Response Surface Methodology |
| $SO_2$ | Sulphur Dioxide |
| TB | Tuberculosis |
| TBIS | Tuberculosis Information System |
| TST | Tuberculosis Skin Test |
| VIF | Variance Inflation Factor |
| WHO | World Health Organization |
| WOS | Web of Science |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background of Study

Tuberculosis (TB) is a chronic infectious disease that is mainly caused by *Mycobacterium tuberculosis*. TB particularly attacks the lungs, a form known as pulmonary TB, but it can spread to other parts of the body, which is known as extra-pulmonary TB. The disease is spread from one person to another through the air. Contact with a person that has active TB may result in infection, in which either the disease is active or remains as latent TB. Droplets of nuclei carrying tubercle bacilli are exhaled into the air when a patient with active TB coughs, sneezes, talks or spits. The susceptible people that inhale this droplet will have symptoms such as fever, weakness, fatigue, loss of appetite, night sweats, coughing, and weight loss.

TB is one of the top ten leading causes of death for infectious disease worldwide, above the human immunodeficiency virus (HIV). About 10 million TB cases and 1.4 million deaths from the disease occurred in 2019. Although the TB incidence reduced slowly each year by approximately 2%, WHO's End TB strategy was not fast enough to reach the milestone of a 20% reduction between 2015 and 2019 because only a 9% reduction occurred. Although the numbers of deaths caused by TB are falling globally each year, the 2020 milestone of reducing deaths by 35% is not on track because only a 14% reduction was found between 2015 and 2019 (World Health Organization [WHO], 2019).

About 33,000 new TB cases occur each year and six people per day die due to the disease in Malaysia, more than those who die of dengue. In 2019 alone, the TB incidence rate was 92 cases per 100,000 population; this rate was relatively lower than the Asian record, but captured about one quarter of the total in South-East Asia (Ministry of Health Malaysia [MOHM], 2019). Although Malaysia is classified as an intermediate TB burden country with a notification rate of the disease less than 100 cases for every 100,000 people, the incidence rate is still high compared to the OECD (Organisation for Economic Co-operation and Development) average (WHO, 2019). The goal for the National Strategic Plan for TB control (2016-2020) to reduce TB mortality by 25% in 2020 was unsuccessful (MOHM, 2019). The number of TB cases (5,071) was the highest in Selangor for 2019, overtaking Sabah, which had reported the highest number in the previous year (MOHM, 2020). Gombak had one of the highest TB incidences in Selangor in 2019, creating a worrying situation of public health awareness.

The relationship between TB cases and sociodemographic factors such as being elderly, male, foreigner, having an urban residence, a low level of education, no permanent income, being unemployed, and being a smoker, have been well described in high income countries such as those in Latin America (Bustamante-Rengifo et al., 2020) and Portugal (Sentís et al., 2020). However, inconsistent evidence exists on the relationship between sociodemographic factors and TB cases in middle income countries, with some studies finding no significant relationship between sociodemographic factors and TB cases in Indonesia (Erawati and Andriany, 2020) and Iran (Serpoosh et al., 2020). Interestingly, some studies in Nigeria (Ehondor et al., 2019) and Pakistan (Laghari et al., 2020) observed a significant relationship between sociodemographic factors and TB cases. The conflicting findings from these studies in middle income countries bring into doubt whether variables used in assessing sociodemographic characteristics at the global level are appropriate at the national level. Furthermore, environmental factors create some queries because some studies have found a significant association between weather and air pollution factors with TB cases (Li et al., 2020; Liu et al., 2021; Xu et al., 2021), whereas other studies showed a weak association between weather (Zhang et al., 2019) and air pollution (Huang et al., 2020) factors with TB cases. This present study will contribute to the on-going debate, especially in a middle income country like Malaysia that is diverse in sociodemographic characteristics and environmental conditions across states and districts.

Over the last two decades, many studies (Cusack et al., 2020; Hansen et al., 2020) have focused on the biomedical aspects of TB, the aim of which is finding a cure. The conclusions of these studies are debatable, as the statistical independence of the variables was based on a molecular analysis of the disease risk, which does not consider geographic referencing. Non-geospatial data that does not consider the patients' location used in previous studies to determine the relationship between risk factors and TB cases (de Jezus et al., 2021; Mirzazadeh et al., 2021; and Taye et al., 2021). Alternatively, current researches are more focuses on how to improve the risk estimation of the disease in specified high-risk population groups and its transmission from one area to another using geospatial data.

Space is crucial in describing epidemic and distribution of the disease. Recently, there has been growing interest in the field of spatial epidemiology (Atiq et al., 2020; Corsi et al., 2020), which is an extension of ecological studies that examines the distribution of disease in different locations to better understand the disease ecology. The integration of spatial and epidemiological approach has gained momentum as researchers have used it for more advanced statistical analysis, rather than only as visual representations of the findings in the form of maps. The capability of the Geographic Information System (GIS) to integrate and manipulate complex data has emerged as a powerful tool in epidemiological studies, and one which can analyse the disease occurrence from a geospatial dimension. The tools of the GIS enable researchers to better understand the geographic variations of disease, identify hotspot areas, and assess the risk factors of disease, which subsequently become the benchmarks to predict the future occurrence of the disease that has not yet been a concern to control the

TB disease. This gap could make the impact of TB disease never decrease. Hence, there is a need to improve the intervention by integrating screening and contact tracing with geospatial approach that could be a better solution for TB control program in high risk areas compared to traditional clinic based screening alone. Existing studies (Ahmad et al., 2021; Kaur et al., 2020; Tan et al., 2020) are largely limited in scope, methodological rigor, or both, in terms of the spatial epidemiological research of TB cases in Malaysia. None of the local studies have combined both sociodemographic and the environment as risk factors with TB cases.

The early prediction of TB cases based on geospatial data is important for case investigations and control measures. Traditional forms of data analysis such as Multiple Linear Regression (MLR) (Kigozi et al., 2020), Response Surface Methodology (RSM) (Amer et al., 2020), and Auto Regressive Integrated Moving Average (ARIMA) (Yang et al., 2020) are inefficient in extracting both linear and non-linear data for prediction models. Conversely, machine learning techniques provide support for the decision-making process in monitoring and managing TB cases. The data can be classified using different algorithms; one of them is the artificial neural network (ANN), which has been used in this study.

Sufficient understanding of the spatial distribution of TB cases is crucial for disease monitoring, resource allocation, and public health policy in Gombak. The maps and prediction model of TB's geospatial analyses cases can help to elaborate the associated factors of TB infection at the target locations. Therefore, it is important to develop the geospatial model for TB prediction that would allow an earlier warning system in reducing transmission of the disease in that district. This study aimed (i) to investigate the trend and spatial pattern of TB cases, (ii) to investigate the spatial association between sociodemographic and environmental factors with TB cases, (iii) to develop prediction model that incorporates the combination of sociodemographic and environmental factors influencing the TB cases, and (iv) to develop a web-GIS application for plotting the location of TB cases.

## 1.2 Problem Statement

When the WHO declared TB as a global health emergency in 1993, this increased the level of concern and public health awareness. In 2020, the disease became the second deadliest infectious disease worldwide, killing 1.4 million people per year (WHO, 2020). Malaysia managed to reduce the number of TB cases from more than 30,000 in 1960 to fewer than 6,000 cases in the mid-1980s but the cases gradually increased from the mid-1990s (WHO, 2015). TB is making a comeback and is responsible for most deaths of infectious diseases in Malaysia (MOHM, 2019). According to the Practice Guideline for the Control and Management of Tuberculosis (2012), the screening of TB should be carried out in high-risk groups. The guideline is in line with the WHO's End TB strategy (2014), while more studies are required to assess the effectiveness and feasibility of preventive treatment among high-risk groups. Therefore, the surveillance of TB in high-risk populations in the targeted area is a must, in order to reduce the unprecedented growth of the TB epidemic in Malaysia.

An extensive literature search and research reports have utilized molecular epidemiology studies (Fakhruzzaman et al., 2019; Jani et al., 2020; Tan et al., 2020). However, spatial epidemiology studies are relatively insufficient in Malaysia, but have been recognized as effective approaches in monitoring disease transmission over space. Analysis of TB cases in different areas is challenging because each case in any single location is small, making it difficult to produce an accurate estimation of the underlying disease risk without connecting the characteristics of another case from a neighboring location (Knorr-Held et al., 1998). Therefore, this study employed the trend and spatial pattern of TB cases, the findings from which were used to detect the high risk areas.

When a TB case is reported, the local health authority investigates the area where the case occurs within seven days, and contact tracing will be carried out to control the spread of the disease. This is done by finding people that had close contact with patients that became infected with TB; thus, they can get testing and diagnosis if needed. Unfortunately, the investigation does not measure the appropriate geographical information about the locality of reported TB cases. Using GIS, the local health authority is able to monitor the surrounding location near the reported cases before new cases are notified to the respective district health offices. Therefore, GIS, with its capability in data handling, manipulation, and analysis, acts as an enhanced warning system in identifying the high-risk areas. There is always a major gap with regard to a GIS-based analysis when it comes to infectious diseases like TB in Malaysia, which is yet to be filled. This study is focused on analyzing the spatial distribution of TB cases from 2013 to 2017 in the Gombak using the GIS applications such as kriging, spatial autocorrelation, kernel density estimation, hot spot analysis, and regression techniques.

Although environmental pollution has been proven to make people more susceptible to TB infection (Mokhtar et al., 2017), the role of air pollution and weather factors on TB cases in Malaysia is still an area of long-standing confusion and dispute. Environmental factors should not be overlooked, as the distribution of TB cases in Malaysia is complex due to the dynamic transmission of the disease and the heterogeneity of the living environment (Abdul Rassam et al., 2017). This unresolved problem is due to the lack of a concerted effort in investigating the influence of the environmental conditions, or even being combined with the sociodemographic characteristics of TB cases. An evaluation of both sociodemographic and environmental factors with the TB cases would be able to explain the spatial variability in the association between these two risk factors and TB cases in the study area. With this intention in mind, the prediction of TB cases with respect to the significant independent variables of sociodemographic and environmental factors is essential in disease control.

Unfortunately, one of the barriers in visualizing the spatial data of TB cases in real-time during a disease investigation is the lack of adequate skills to effectively use the existing software, because trained personnel are needed to operate it. Consequently, a web-GIS application is able to facilitate the displayed location of TB cases and their sociodemographic characteristics from time to time with a user-friendly interface. Interactive mapping is useful for public health officers in the MOHM who have expertise in biomedical sciences to display the geographically-referenced data without the need for specialist training in programming and spatial statistics.

## 1.3 Significance of the Study

Despite the increase of TB cases year by year and in different areas in Gombak, there is a huge information gap on the spatial pattern of TB cases. This study could contribute to a new knowledge in the spatial epidemiology field of TB in Malaysia, specifically Gombak. By identifying the clusters of high-density regions and hotspot locations, public health officers from Gombak District Health Office could investigate the potential transmission areas to control the spread of TB among the targeted population.

The environment is one of the important factors that may explain the dynamic transmission of TB as the disease is vulnerable since it can transmit from one person to another through the air and close contact. Nevertheless, public health officers from MOHM excluded environmental data in the TBIS because they only reported sociodemographic data into the file during the surveillance. Following this matter, the inclusion of environmental data by measuring the values of weather and air pollution variables in the areas of reported cases could uncover new knowledge in terms of environmental health by investigating the effect of the environment on the spread of TB in Malaysia. Furthermore, earlier studies did not consider the spatial variability of the association between sociodemographic and environmental factors with TB cases because the researchers solely used sociodemographic (Dangisso et al., 2020; Gelaw et al., 2019; Wang et al., 2019), environmental (Carrasco-Escobar et al., 2020; Zhang et al., 2019), or both sociodemographic and environmental (Bonell et al., 2020; Wang et al., 2019) factors with TB cases separately in one study. Hence, the current study could extend the previous research by comparing the performance of spatial variability between sociodemographic, environmental, and both sociodemographic and environmental factors with TB cases using various ordinary least squares (OLS) and geographically weighted regression (GWR) models.

The prediction model determined in the previous study is limited because the total of TB cases was averaged at the district level, and analysed as polygon shape in Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) software, which caused loss of individual location of each TB case (Mollalo et al., 2019). Therefore, each TB case in the current study was geocoded according to the longitude and latitude of patients' address in point shape and provided a comparison of predictive accuracy between different datasets fitted in the ANN models with a similar configuration with GWR models. Maintaining the coordination of each TB patient is vital for the public health officers to track back the location while investigating the possible source of transmission. The prediction model could be a sophisticated tool that could save time by generating an early warning system, reducing human resources, providing cost-effective techniques by allocating the budget for TB prevention, and improving the decision-making during the intervention program. Therefore, this study will explore a new research area in the prediction model development for TB cases based on geospatial data.

Web-GIS application for one of the communicable diseases in Malaysia only displays the location of dengue cases without integrating with its associated factors (Rizwan et al., 2018). Therefore, the current study could expand the previous research by including sociodemographic variables of TB cases in the application. An interactive map could assist public health officers in visualising the location of TB cases in a user-friendly manner since they do not need programming or GIS knowledge or abilities to effectively use the application, which could enlarge screening and contact tracing. It is also designed for future updates, so that it can be adopted for other diseases, such as COVID-19 and cholera cases.

## 1.4 Objectives of the Study

### 1.4.1 General Objective

The general objective of this study is to develop a model to predict the TB cases in Gombak.

### 1.4.2 Specific Objectives

This study is designed to achieve the following specific objectives:

1. To investigate the trend and spatial pattern of TB cases from 2013 to 2017 in Gombak.

2. To investigate the spatial association between sociodemographic and environmental factors with TB cases from 2013 to 2017 in Gombak.

3. To develop prediction model that incorporates the combination of sociodemographic and environmental factors influencing the TB cases.

4. To develop a web-GIS application for plotting the location of TB cases from 2013 to 2017 in Gombak.

## 1.5 Study Hypothesis

1. There are significant associations between sociodemographic and environmental factors with TB cases from 2013 to 2017 in Gombak.

## 1.6 Study Framework

This thesis presented the novel approach for prediction of TB cases by integrating the spatial input variables extracted from different GWR models and visualizing the geocoded data into web mapping application. The main goal of this study was to evaluate the applicability of the ANN models using spatial data in conjunction with GWR models in assessing the association between sociodemographic and environmental factors with TB cases. This study was carried out in the Gombak area. Initially, sociodemographic, population, environmental, geographical, and topographical data were collected from different government agencies. The location of each TB patient was geocoded from Google Earth and then, it were imported into ArcGIS. Then, environmental data undergo interpolation using kriging to obtain the interpolated value and joining the value with the location of each reported TB case.

Figure 1.1 illustrated a brief description of the framework employed in this study. For monitoring the trend of TB cases, specific objective 1 was accomplished through incidence rate and heat mapping of TB cases across different sub-district and years. Furthermore, assessing the spatial pattern of TB cases also achieved in the specific objective 1 through spatial autocorrelation, kernel density estimation, and hotspot analysis. For further evaluation of the spatial epidemiology by appraising the association between sociodemographic and environmental factors with TB cases, the regression analysis from global scale using OLS and local scale using GWR were utilized. This evaluation was carried out for specific objective 2. From the GWR models, the level of associations for each explanatory (independent) variable in different combinatory set of independent variables such as sociodemographic, environmental, and both sociodemographic and environmental factors were determined by estimation of local coefficient raster while the level of associations for each set of independent variables were identified using local $R^2$.

Considering the trend of TB cases across five-year period and association between sociodemographic and environmental factors with TB cases, different MLR and ANN models were developed in predicting TB cases based on the same independent variables used in the GWR models. This model construction was performed in specific objective 3. The performance of MLR and ANN models was compared to evaluate further on the relationship between sociodemographic and environmental factors with TB cases according to adjusted $R^2$ values. Then, the best model obtained by different ANN algorithm were compared based on the mean absolute error and prediction accuracy.

Finally, the location of reported TB cases acquired from ArcGIS were plotted in the web mapping application; namely Portal TB Gombak to display the spatial distribution of TB cases and its sociodemographic characteristics in an open source tool and user-friendly way. This web development was accomplished in specific objective 4.

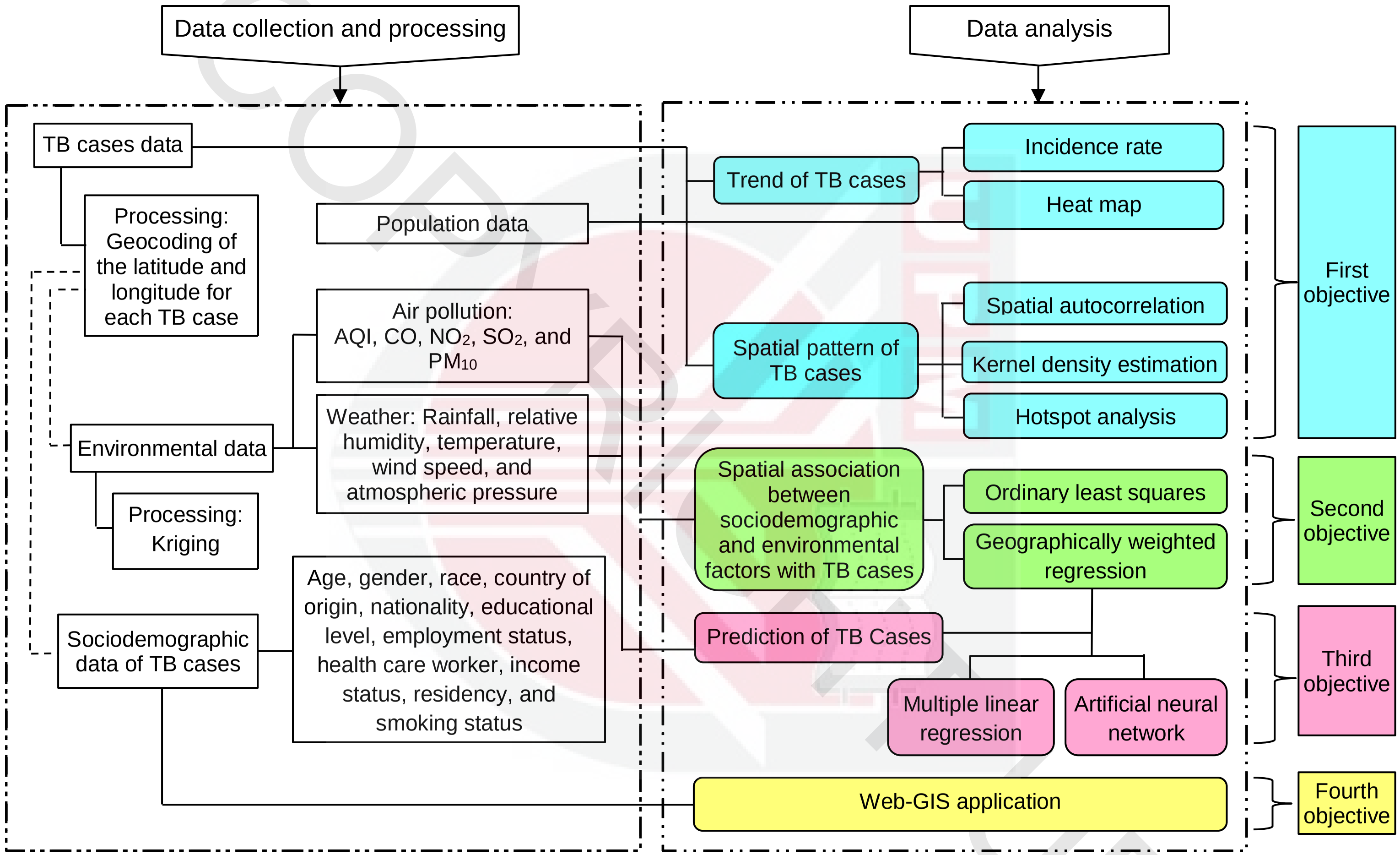


**Figure 1.1 : Study framework**

## 1.7 Outline of the Thesis

The thesis comprised 8 chapters and outlined as follows:

Chapter 1 describes the general overview of TB cases distribution and its challenges. The background of study, problem statement, significance of the study, objectives of the study, study hypothesis, study framework, and outline of thesis also are included in this chapter.

Chapter 2 confers the literature on the concept of TB including aetiology, pathogenesis, epidemiology, environmental factors, trend of TB cases, and role of GIS in spatial epidemiology. This chapter also encompasses the comprehensive reviews on the available methods for spatial distribution of TB cases, cases prediction, and web mapping application of the disease.

Chapter 3 presents the general description of the study area, study design, collection of sociodemographic data and location of each TB patient, population data, environmental data, geographical data, and topographic data. Geocoding the address of reported TB cases and interpolating the environmental data, and ethical consideration were also included in this chapter. The data analyses were demarcated according to the specific study objectives and elaborated in their respective chapters i.e. Chapter 5, 6, and 7.

Chapter 4 provides the systematic literature on demographic, socio-economic and behavioral factors of TB cases in Malaysia.

Chapter 5 deliberates on the spatial study "Association of sociodemographic and environmental factors with spatial distribution of tuberculosis in Gombak, Selangor, Malaysia" to accomplish the specific study objectives 1 and 2.

Chapter 6 is devoted for the "Prediction of tuberculosis cases based on sociodemographic and environmental factors in Gombak, Selangor, Malaysia: A comparative assessment of multiple linear regression and artificial neural network models" to accomplish the specific study objective 3.

Chapter 7 is dedicated to the "Development of a web-geographical information system application for plotting tuberculosis cases in Gombak, Selangor, Malaysia" to complete the specific study objective 4.

Chapter 8 summarizes the findings attained from the study, and includes the overall discussion, conclusion, study contribution, limitation, and recommendations regarding the assessment of spatial distribution of TB cases and cases prediction.

can potentially be under-reporting of cases among people who sought care or were diagnosed in private health care services.

## 5.5 Conclusion

This study identified the spatial distribution of TB cases in Gombak from January 2013 to December 2017. The cases were higher during August and November each year, with a slowly rising trend and no obvious peak over the five years. TB cases also showed a positive global spatial autocorrelation in 2016 and 2017. The clustering areas of TB cases mainly concentrated in the south-west region where the Sungai Buloh prison is located. The geospatial non-stationary analysis suggested that GWR2 was the best model to determine the distribution of TB cases with the highest $R^2$ i.e. 0.98. This study also found that sociodemographic factors such as gender, nationality, employment status, health care worker status, income status, residency, and smoking status; and environmental factors such as AQI (lag 1), CO (lag 2), $NO_2$ (lag 2), $SO_2$ (lag 1), $PM_{10}$ (lag 5), rainfall (lag 2), relative humidity (lag 4), temperature (lag 2), wind speed (lag 4), and atmospheric pressure (lag 6) played an important role that affected TB cases in varying degrees and different areas in Gombak.

The strongest association between income status and atmospheric pressure at lag 6 with TB cases was found in this study, suggesting that these two factors could be the key controlling variables that determine the overall casualties caused by TB cases in Gombak. Therefore, the MOHM should give more priorities towards TB control in these areas. This study provided a better understanding of the spatial approach in epidemiology. It also highlighted prison as an important environmental setting for prospective TB surveillance.

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the Gombak based on the inclusion of local data characteristics. If successful, these advantages could also be expanded to other regions with similar characteristics.

## 6.5 Conclusion

This study found that the ANN was better in evaluating the relationship between the associated risk factors, i.e., sociodemographic and environmental factors, and predicting the number of TB cases compared to the regression analysis. The newly developed models, ANN1, ANN2, and ANN3 are potentially novel tools that can assist the respective public health authorities in providing better control over the on-going transmission of TB across Gombak. ANN3, in consideration of sociodemographic and environmental factors, revealed the best performance in predicting TB cases. By providing the ranking of the importance value for predictors using ANN models, mitigatory actions could be taken at their earliest, and the authorities would thus be able to strategize for the most effective controlling method, one that would save cost, time, and manpower.

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