CASE STUDY

Effects of ambient air pollutants on cardiovascular disease hospitalization admission

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BACKGROUND AND OBJECTIVES: Air pollution is associated with population growth and economic advancement. Severe cardiovascular complications that require extensive medical service are aggravated by air pollutants. This study illustrates the trend and correlation of cardiovascular disease hospital admission with air pollutants in Sabah for the past 9 years (2010–2019). The additional information obtained from this study will be useful to enhance proper environmental management and reduce air pollution in the cities of Sabah.

METHODS: Ecological study design was utilized with cardiovascular disease hospital admission and ambient air pollutants in Sabah retrospective data. Data were collected from four districts with established continuous air quality monitoring stations. Collected data were analysed spatially and statistically. Autoregressive integrated moving average modelling was implemented to forecast the cardiovascular disease hospital admission.

FINDINGS: Kota Kinabalu recorded the highest hospital admissions for cardiovascular disease, followed by Sandakan, Tawau and Keningau. The cardiovascular disease hospital admission prevalence rate in Kota Kinabalu was 12.45 per 1,000 population, followed by Sandakan, Tawau and Keningau (4.54; 4.18; and 5.88 per 1,000 population) in 2019. The cardiovascular hospital admissions increased in Kota Kinabalu, Sandakan and Tawau. The nitrogen dioxide (<0.04 ppm), carbon monoxide (<9 ppm), ozone (<0.05 ppm) and PM10 (<100 µg/m³) gases detected are below the national standard limit levels. In the later years of the series, the ozone and fine particulate gases intensify. Carbon monoxide has the highest positive correlation with cardiovascular disease hospital admission compared to other air pollutants. The autoregressive integrated moving average (0,1,1) with carbon monoxide and ozone as external regressors is the model with minimum Akaike information criterion.

CONCLUSION: The carbon monoxide concentration in ambient air illustrates a potential risk for the increasing cardiovascular disease hospital admission number in Sabah. The study findings provide evidence-based source for the healthcare management team, policymakers, and community to sustain clean and safe ambient air.

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ABSTRACT

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INTRODUCTION

Cardiovascular disease (CVD) is the prime cause of death in man, which accounts for 31% death worldwide (CVD-WHO, 2020). In Europe, CVD death was established to be twice that of cancer. The mortality rate diverges according to countries. Russia and Ukraine recorded immense mortality rates among the older group. Meanwhile, in France, most younger generations are diagnosed with CVD (Nichols et al., 2014). Almost half of the cardiovascular cases reported are from populated Asian countries (Soenarta et al., 2020). Cardiovascular disease prevalence is tripling in India among the younger generation (Chauhan et al., 2013). Cardiovascular disease had been a prominent cause of death among males for the past 13 years in Malaysia (DOSM, 2019). Cardiovascular diseases were related to the high number of Daily Adjusted Life Years (DALYs) loss (2.5 million DALYs) (Plass et al., 2014). In 2016, almost 7 million premature deaths were associated with air pollution, and low- and middle-income countries contributed to 80% of these deaths. Various adverse health outcomes such as respiratory infections, heart disease, stroke, and lung cancer are known to be related to air pollution (AQPAHO, 2020). Carbon monoxide (CO) is high in urban areas because of ongoing human activities and transportation. Inhaled CO binds with haemoglobin in the blood which triggers carbon monoxide-induced cardiac incoherence (Meyer et al., 2011). Every 10 microgram per cubic meter (μg/m³) increase in fine particulate matter (PM2.5) in the long term may increase cardiovascular mortality risk by 11%. Meanwhile, short-term exposure to nitrogen oxide (NOx) is also associated with cardiovascular effect development. Air pollution enhances endothelial dysfunction and platelet activation favoring thrombus formation (Bourdrel et al., 2017). Up to 2 billion individuals suffer from chronic CVD sequelae. CVD accounts for expenditures of nearly United States Dollar (USD) 317 per year. The treatment for cardiovascular disease accounts for USD 1 for every USD 6 paid to the healthcare system. Even health care facilities will be helpless to cope with the healthcare air pollution and climate change consequences if this condition persists (Richardson et al., 2014). Air pollutants are a serious public health threat because of the large-scale environmental risk vulnerability towards the population. Air pollution has increased along with the population growth and economic advancement over the decades (Brown, 2008). Air pollution emissions depend on industrial expansion, technology utilization, fuel consumption increase, vehicle emission, and burning. A total of 70 million tons of pollution were liberated into the atmosphere by the United States in 2019 according to the Environment Protection Agency (EPA), potentially creating an accumulation of particles and acids (USEPA, 2016). Low- and middle-income countries experience immense urban air pollution particularly in the Eastern Mediterranean, Southeast Asia, and Western-Pacific regions, in which annual mean residue is 10 times higher than the World Health Organization standard level. Asian and Pacific countries are the most disturbed by air pollution whereby 90% of the population is exposed to air particles that potentially lead to adverse health effects (WHO, 2016). In addition, climate change can accelerate ambient air pollutant levels causing serious health consequences (Forsberg et al., 2012). The autoregressive integrated moving average (ARIMA) model was first established in 1976 to predict infectious disease and applied as an early warning alarm for control and prevention measures (Luz et al., 2008). The ARIMA model is shown to have be highly predictive on medical condition and precision for short term exposure (Yi et al., 2014). This model has also been implemented in predicting environmental parameters, such as air pollutants (Konovalov et al., 2009). A Madrid study evaluated an intervention program in the city by forecasting the air pollutant level (Pedro et al., 2017). Furthermore, researchers advanced the ARIMA application to investigate the associations between environmental factors and health effects (Imai et al., 2015). Disease trends can be described and forecasted with the environmental variable by implementing the ARIMA model (Sharafi et al., 2017). This study aimed to describe the cardiovascular disease hospital admission trend and correlation with air pollutants in four districts (Kota Kinabalu, Sandakan, Tawau, and Keningau) and develop a forecasting model for cardiovascular disease hospital admission. The data from respective districts were collected from 2010 to 2019.

MATERIALS AND METHODS

This ecological study design reviews retrospective data on CVD hospital admission and air-borne environmental variables for the past 9 years (2010–2019), comparing four districts in Sabah. The study was carried out in Kota Kinabalu, Sandakan, Tawau, and Keningau, which have established continuous
air quality monitoring (CAQM) stations for air pollutants (NO₂, O₃, CO, and PM₁₀). The number of hospital admission for CVD was extracted according to WHO ICD classification (WHO ICD code: I00-I99) from Malaysia Health Informatic Centre. Air quality data were retrieved from the Malaysia Department of Environment from the stations located adjacent to the study hospitals. The mean daily ambient concentrations of particulate matter less than 10 microns (PM₁₀) in μg/m³, nitrogen dioxide (NO₂) in part per million (ppm), ozone (O₃) in ppm and CO in ppm were collected. The obtained data were re-coded into numerical orders in day, month, year (DD.MM.YYYY); district; CO; NO₂; O₃; PM₁₀; and CVD hospital admission. A dataset that fulfils statistical and modelling analysis criteria was established to subsequently merge these data. Missing data were imputed through last observation carried forward method. The data was prepared in daily and monthly trends. Descriptive analysis used the IBM Statistical Package for Social Sciences (SPSS) version 26. The result was compared with national air pollutants standard limits (Table 1) (MDE, 2020). Standard limit set was below 0.04 ppm (<0.04 ppm) for NO₂, O₃(<0.05 ppm), CO (<9 ppm), and PM₁₀ (<100 μg/m³). R program software version 4.1 was applied for advanced Pearson correlation coefficient statistical analysis, time series analysis, and ARIMA. The ARIMA model has been widely applied in medical data to identify the data’s cyclic pattern and time series features. Subsequently, the estimated model was established by adjusting the algorithm and reducing the prediction error (Huang et al., 2020). Data were prepared and cleaned to be extracted into the software during the initial phase of analysis. The trend and seasonality of the data were described. Then, the potential model is estimated by comparing Akaike Information Criteria (AIC), Ljung-box test, forecast error (Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE) and Mean Absolute Error (MAE)) and regressors. Finally, the parsimonious model was used to estimate the CVD hospital admission number for the next 12 months (Sato, 2013). Several packages were installed to run the analysis including tidyverse, xts, and forecast package. The tidyverse and xts packages were used to clean data and arrange it in daily trends. Meanwhile, the forecast package was applied to illustrated time series analysis and ARIMA.

### RESULTS AND DISCUSSION

**Cardiovascular disease hospital admission in Sabah 2010–2019**

Kota Kinabalu recorded the highest hospital admission CVD number compared to other districts followed by Sandakan, Tawau, and Keningau (Table 2).

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Table 1: Standard limit for air pollutants

<table>
<thead>
<tr>
<th>Air pollutants</th>
<th>DOE standard limit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>µg/m³</td>
</tr>
<tr>
<td>NO₂</td>
<td>280 (1 h)</td>
</tr>
<tr>
<td></td>
<td>70 (24 hs)</td>
</tr>
<tr>
<td>O₃</td>
<td>180 (1 h)</td>
</tr>
<tr>
<td></td>
<td>100 (8 hs)</td>
</tr>
<tr>
<td>CO</td>
<td>30 (1 h)</td>
</tr>
<tr>
<td></td>
<td>10 (8 hs)</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>100 (24 hs)</td>
</tr>
<tr>
<td></td>
<td>40 (1 y)</td>
</tr>
</tbody>
</table>

**Table 2: Hospital admission for cardiovascular disease in Sabah 2010–2019**

<table>
<thead>
<tr>
<th>District</th>
<th>Mean (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kota Kinabalu</td>
<td>6(3)</td>
</tr>
<tr>
<td>Sandakan</td>
<td>3(2)</td>
</tr>
<tr>
<td>Tawau</td>
<td>3(2)</td>
</tr>
<tr>
<td>Keningau</td>
<td>2(1)</td>
</tr>
</tbody>
</table>

SD = Standard deviation
The yearly average hospital admission was ascending rapidly over the years. Sandakan and Tawau hospitals have had similar admissions for the past 9 years. Meanwhile, a Keningau hospital has the least admission number and was continuous. The higher prevalence CVD hospital admission rate was in Kota Kinabalu (12.45 per 1,000 population), followed by Keningau (5.88 per 1,000 population), Sandakan (4.54 per 1,000 population), and Tawau (4.18 per 1,000 population) for 2019.

**Time series analysis of cardiovascular disease hospital admission and air pollutants in Sabah 2010–2019**

All districts experienced a steady upsurging CVD hospital admission trend over the years. In the interim, air pollutants recorded a fluctuating pattern (Fig. 1a-d). However, the mean air pollutants recorded over the years was below the national standard limit levels (Table 3). Nevertheless, O₃ and PM₁₀ gases intensified in the series' later years, particularly in Kota Kinabalu and Tawau. The number of hospital admission increased drastically in Kota Kinabalu and Tawau during the decomposition of additive time series analysis. Meanwhile, Sandakan started to increase during the middle years of the series (Fig. 2). European countries outlined a similar increasing CVD admission trend as observed in this study. Despite admission increasing steadily, death

![Table 3: Air pollutants in Sabah 2010–2019](image-url)
Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019
Continued Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019

Fig. 2: Decomposition additive time series of CVD hospital admission
rates decreased from 1980 until 2013 (Bhatnagar et al., 2016). A Chinese study 4 years ago demonstrated a spatially clustered pattern with decreasing CVD hospital admission number which is in contrast with the present findings (Amsalu et al., 2021). Seasonal countries had some variation. A higher CVD admissions number and death were seen during winter. CVD deaths were related to acute myocardial infarction, acute left ventricular failure and unstable angina (Khan et al., 2014). Nevertheless, concurrent to the current findings, cases of CVD deaths in Malaysia rose from 14.4% (2017) to 15.9% (2018) in urban and 12.7% to 15.0% in rural areas (DOSM, 2019). Air pollutions study results show a disparity

Fig. 3: Correlation coefficient between the air pollutants and cardiovascular hospital admission in Sabah 2010–2019 (a) Kota Kinabalu (b) Sandakan (c) Tawau (d) Keningau
in the findings in the present study. A study in the United Kingdom reported PM$_{10}$ and O$_3$ were consistently above the WHO limit. Hence, O$_3$ become a major concern for premature death (Sicard et al., 2021). On the other hand, air pollutants expects for O$_3$ surged in China by 9% for a 4-year period (2015–2019). The SO$_2$ reading dwindled by 36–60%, while other pollutants abated within a 3–33% range (Zhou et al., 2020). A time series study in Lahore reported an ascending air pollutants trend (PM$_{10}$, PM$_{2.5}$, NO, NO$_2$, O$_3$ and CO) (Bhatti et al., 2021). In Malaysia, long-term temporal dynamic air pollutant data (1997–2015) from 20 monitoring stations reported large coefficient variations for PM$_{10}$. The central region of Malaysia is identified to have an immense part (Pahang, Terengganu, and Kelantan) illustrated a congruent CO trend, but the NO$_2$ parameter was contrary to current finding (Ibrahim et al., 2009).

Correlation coefficient between the air pollutants and cardiovascular hospital admission in Sabah, 2010–2019

Keningau district illustrated a positive correlation towards all air pollutants (Fig. 3). CO demonstrated a preeminent correlation with CVD admission followed by NO$_2$, O$_3$, and PM$_{10}$. Kota Kinabalu displayed three air pollutants (O$_3$, CO and PM$_{10}$) with a low positive correlation with CVD admission. In Sandakan (CO and PM$_{10}$) and Tawau (CO and NO$_2$), two air pollutants positively correlated with CVD admission. In all districts, CO had the highest CVD admission correlation value compared to other air pollutants. The risk of CVD hospital admission attributed to air pollutants highlighted worldwide. A study in Urmia illustrated a higher correlation between CO concentration and CVD admission incidence. In addition, the study highlighted admission case increase for every 10 µg/m$^3$ (Sokoty et al., 2021). Similarly, a study in Beijing highlighted that exposure to ambient CO increases the risk of hospital admission, especially coronary heart disease (CHD) (Li et al., 2018). Another local study in Kuala Lumpur reported CVD admission increase with the NO$_2$ concentration (Sofwan et al., 2021).

<table>
<thead>
<tr>
<th>ARIMA model</th>
<th>AIC</th>
<th>Ljung-box test</th>
<th>Forecast error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Q</td>
<td>p-value</td>
</tr>
<tr>
<td><strong>Kota Kinabalu</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1(0,1,1)</td>
<td>1240.069</td>
<td>5.4423</td>
<td>0.606</td>
</tr>
<tr>
<td>Model 2(0,1,1)</td>
<td>1240.711</td>
<td>5.4329</td>
<td>0.6073</td>
</tr>
<tr>
<td>Model 3(0,1,1)</td>
<td>1241.596</td>
<td>5.5184</td>
<td>0.701</td>
</tr>
<tr>
<td><strong>Sandakan</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1(0,1,1)</td>
<td>987.6061</td>
<td>13.529</td>
<td>0.09489</td>
</tr>
<tr>
<td>Model 2(0,1,1)</td>
<td>987.6088</td>
<td>13.564</td>
<td>0.09385</td>
</tr>
<tr>
<td>Model 3(0,1,1)</td>
<td>987.612</td>
<td>13.55</td>
<td>0.09426</td>
</tr>
<tr>
<td><strong>Tawau</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1(0,1,1)</td>
<td>992.442</td>
<td>8.3476</td>
<td>0.4003</td>
</tr>
<tr>
<td>Model 2(0,1,1)</td>
<td>992.5319</td>
<td>8.4144</td>
<td>0.3941</td>
</tr>
<tr>
<td>Model 3(0,1,1)</td>
<td>992.5907</td>
<td>8.4477</td>
<td>0.391</td>
</tr>
<tr>
<td><strong>Keningau</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Model 1(0,1,2)</td>
<td>1004.459</td>
<td>3.872</td>
<td>0.4974</td>
</tr>
<tr>
<td>Model 2(0,1,2)</td>
<td>1005.43</td>
<td>2.9679</td>
<td>0.9364</td>
</tr>
<tr>
<td>Model 3(0,1,2)</td>
<td>1005.881</td>
<td>3.9177</td>
<td>0.7892</td>
</tr>
</tbody>
</table>

AIC = Akaike Information Criteria; Q = Q statistic; RMSE = Root mean square error; MAPE = Mean absolute percentage error; MAE = Mean absolute error.

* without regressor; *O$_3$; *NO$_2$; *PM$_{10}$; *CO; *CO and NO$_2$; *CO and O$_3$; *O$_3$ and NO$_2$. 

Table 4: ARIMA model for cardiovascular hospital admission in Sabah 2010–2019 with air pollutants as the regressor
Short term NO₂, SO₂, and CO exposure escalated the hospital admission risk at different lag and gender in Tehran (Motesaddi et al., 2021). Another interesting study reported that air pollutants were associated with higher CVD hospital visits compared to COPD (chronic obstructive pulmonary disease). The hospital CVD visits was predominant among older adults (>65 years old) and females (Yang et al., 2021). Seasonal countries like Mongolia reported a significant correlation between cardiovascular diseases and majority of air pollutants (PM₂.₅, PM₁₀, NO₂, SO₂, CO, and O₃) (Enkhjargal et al., 2020). During the warm season, CVD admission surges after an increase in PM₂.₅ (Lee et al., 2021). Nevertheless, a study involving three hospitals in Isfahan, Iran, demonstrated a positive association between air pollutants and myocardial infarction, but it was not statistically significant (Davoodabadi et al., 2019). A study in Switzerland showed no correlation between PM₁₀ and O₃ with CHD. Only SO₂ and NO₂ positively correlated with CHD admission rates (Filippini et al., 2019).

ARIMA and forecasting cardiovascular hospital admission in Sabah

ARIMA with and without air pollutants as regressor was performed to establish the best model with minimum AIC (Akaike Information Centre) (Table 4). The R program forecast package applied the auto ARIMA function during analysis. Identical model ARIMA was shared by three districts (0,1,1); however, air pollutants in the model vary.
Forecasts from ARIMA(0,1,1) with drift

Continued Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA
Forecasts from ARIMA(0,1,1)

Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA

Countinued Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA
Kota Kinabalu (O3) and Sandakan (CO) resulted single air pollutant to be relevant in the model. Meanwhile, Tawau has two air pollutants (CO and O3) as relevant regressors in the model. Analysis with Keningau data resulted in ARIMA (0,1,2) model with NO2 as the single pollutant regressor. The p-value was more than 0.05 and the null hypothesis was not rejected in the Ljung-Box test. This means the established model does not show any lack of fit. CVD hospital admission forecasting was conducted with the established ARIMA model. Kota Kinabalu and Sandakan showed an increased trend of admission. Meanwhile, Tawau and Keningau noted minimal changes in fluctuation during the prediction (Fig. 4). A limited number of studies are available to illustrate the ARIMA application model to find the relation between CVD hospital admission and air pollutants. A study in Spain projected a similar finding to the current study with the ARIMA model (0,1,1). However, only the Keningau district gave a disparate result ARIMA model (0,1,2). The present study demonstrated three air pollutants (CO, O3 and NO2) might be relevant in the model compared to two air pollutants (SO and NO2) (Artola et al., 2019). Another study in Turkey proposed a contrary Seasonal ARIMA model of (2,1,2) (1,0,0)12, which includes a seasonal CVD admission factor and is estimated to increase mainly in April. During the winter season, healthcare facilities may experience a double burden of hospital CVD admission and respiratory diseases (Mercan et al., 2019). Other weather and social variable are shown to affect cardiovascular disease. This was not included in the current study. A study in Iran highlighted temperature, sunshine, and religious mourning events increase the risk of acute myocardial infarction (AMI). The best predicted model obtained was from the autoregressive moving average (ARMA) model (5,5). (Sharif Nia et al., 2021). Unlike the current study, several studies applied machine learning techniques to predict cardiovascular hospital admission considering air pollutants. LightGBM model with meteorological and air pollutants reading significantly contributed to the CVD hospital admission accuracy in Chengdu, China (Qiu et al., 2020). A nonlinear ANN model with four hidden layers and 49 neurons was described as the best model for PM, NOx, O3, and SO2. The correlation coefficient ranges from 0.78–0.83, and can predict cardiovascular rate in 5 years’ time data series (Jalili et al., 2021). Another local study in Malaysia proposed enhanced long short-term memory (ELSTM) model to accurately predict the cardiorespiratory hospitalization rate based on air pollution (Usmani et al., 2021).

CONCLUSION

This study reported a higher CVD hospital admission prevalence in Kota Kinabalu compared to other districts. Nevertheless, decompressive time series analysis illustrated an increasing hospital admission trend over a 9-year period in all the districts. The CO concentration in ambient air was identified as a potential risk for the increasing number of CVD hospital admission in Sabah from a correlation coefficient analysis. Findings proved that air pollution is strongly corrected with CVD hospital admission. A forecast model was developed to determine CVD hospital admission attributed to air pollutants via ARIMA. ARIMA is widely implemented in predicting environmental health issues. The best model for predicting CVD hospital admission number was established by reviewing AIC, Q statistic, RMSE, MAPE and MAE. Only two district results used the ARIMA (0,1,1) model with single regressor O3 (Kota Kinabalu) and CO (Sandakan). Keningau used the ARIMA (0,1,2) model with NO2. Only Tawau district used the ARIMA (0,1,1) model with two regressors (O3 and CO). Further machine learning program utilization such as logistic regression (LR), support vector machine (SVM), artificial neural network (ANN), random forest (RF), extreme gradient boosting (XGBoost), and light gradient boosting machine (LightGBM) is recommended in future studies to develop better models to predict CVD hospitalization attributed to air pollution. In addition, climate variables such as temperature, wind speed, and radiation can be included during the analysis. Prediction model developed from this study useful for planning on appropriate measures to address the CVD hospital admission and environmental management burden. The study findings provide evidence-based information for the healthcare management team, environment policymakers, and community to sustain clean and safe ambient air in Sabah. Public transport should be efficiently available to the public to reduce city car trips. Affordable renewable energy products such as hybrid cars, solar electric, biomass boiler,
and stove are encouraged for local communities. The green building concept can be implemented in future construction or project development in these cities.

**AUTHOR CONTRIBUTIONS**

L. Salvaraji performed the literature review and the model configuration, analysed, and interpreted the data and results. R. Avoi designed the study, performed data analysis, and prepared the manuscript text. H.R.Toha help in gathering environmental data. M.S. Jeffree helped in the methodology and reviewed the manuscript text. S. Saupin provided technical input and prepared the manuscript. S.B. Shamsudin provide technical input and reviewed the manuscript.

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**CONFLICT OF INTEREST**

The author declares that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors. Ethical approval for this study was obtained from the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia (NMRR ID: NMRR-20-2970-57856: IIR). Secondary data consent was obtained from the Officer-in-Charge of the Health Informatic Centre, Malaysia Ministry of Health and Air Quality Unit, Malaysia Department of Environment. For hospital admission variable, only the daily number of admitted cases with CVD diagnosis were included in this study. The data excluded any information in relation to patient details.
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