Global J. Environ. Sci. Manage. 9(1): 157-172, Winter 2023, Serial #33

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

Podcasts

CASE STUDY

Effects of ambient air pollutants on cardiovascular disease hospitalization admission

L. Salvaraji, R. Avoi*, M.S. Jeffree, S. Saupin, H.R. Toha, S.B. Shamsudin

Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia

ARTICLE INFO

Article History:
Received 01 March 2022
Revised 06 Jnue 2022
Accepted 11 July 2022

Keywords:
Autoregressive integrated moving average
Carbon monoxide (CO)
Forecasting; Sabah

DOI: 10.22034/gjesm.2023.01.12

ABSTRACT

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/m^3) 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.

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
45	4	4

*Corresponding Author:
Email: *richard.avoi@ums.edu.my*
Phone: +6017 893 3977
ORCID: 0000-0002-1957-0965

Note: Discussion period for this manuscript open until April 1, 2023 on GJESM website at the “Show Article”.

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/m^3) increase in fine particulate matter ($PM_{2.5}$) in the long term may increase cardiovascular mortality risk by 11%. Meanwhile, short-term exposure to nitrogen oxide (NO_2) 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 State Dollor (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

Table 1: Standard limit for air pollutants

Air pollutants	DOE standard limit	
	µg/m³	ppm
NO_2	280 (1 h) 70 (24 hs)	0.14 (1 h) 0.04 (24 hs)
O3	180 (1 h) 100 (8 hs)	0.09 (1 h) 0.05 (8 hs)
CO	30 (1 h) 10 (8 hs)	25 (1 h) 9 (8 hs)
PM_{10}	100 (24 hs) 40 (1 y)	- -

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

District	Mean (SD)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kota Kinabalu	6(3)	8(4)	9(5)	12(5)	13(6)	13(6)	12(5)	14(6)	16(6)	16(6)
Sandakan	3(2)	4(2)	4(2)	3(2)	4(2)	3(2)	4(2)	5(2)	5(2)	5(2)
Tawau	3(2)	4(2)	4(2)	4(2)	4(2)	4(2)	4(2)	5(3)	5(2)	5(2)
Keningau	2(1)	2(1)	3(2)	3(2)	3(2)	2(1)	3(1)	3(2)	3(2)	3(2)

SD = Standard deviation

air quality monitoring (CAQM) stations for air pollutants (NO_2, O3, CO, and PM_{10}). 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/m^3, nitrogen dioxide (NO_2) 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; NO_2; O3; $PM_{10;}$ 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 NO_2, O3(<0.05 ppm), CO (<9 ppm), and PM_{10} (<100 µg/m^3). 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).

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 PM_{10} 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

District	Mean (SD)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Kota Kinabalu										
NO_2	0.0129	0.0150	0.0165	0.0155	0.0161	0.0151	0.0142	0.0138	0.0115	0.0079
<0.04 ppm	(0.0050)	(0.0047)	(0.0044)	(0.0045)	(0.0055)	(0.0062)	(0.0051)	(0.0091)	(0.0081)	(0.0049)
O3	0.0244	0.0248	0.0280	0.0211	0.0269	0.0364	0.0323	0.0308	0.0301	0.0311
<0.05 ppm	(0.0078)	(0.0064)	(0.0072)	(0.0093)	(0.0086)	(0.0099)	(0.0092)	(0.0098)	(0.0065)	(0.0099)
CO	0.5834	0.6621	0.6565	0.6223	0.6018	0.6454	0.5930	0.8882	0.7602	0.6050
<9 ppm	(0.1630)	(0.1728)	(0.1778)	(0.2054)	(0.1645)	(0.2488)	(0.1895)	(0.3492)	(0.3472)	(0.2399)
PM_{10}	39.383	37.478	38.474	41.690	38.353	45.019	43.148	40.3190	57.079	57.058
<100 μg/m^3	(10.779)	(9.3347)	(9.7500)	(13.654)	(8.0693)	(13.158)	(11.281)	(18.921)	(55.748)	(135.66)
Sandakan										
NO_2	0.0125	0.0134)	0.0137	0.0126	0.0119	0.0111	0.0100	0.0112	0.0108	0.0108
<0.04 ppm	(0.0034)	(0.0043)	(0.0038)	(0.0038)	(0.0038)	(0.0041)	(0.0031)	(0.0032)	(0.0030)	(0.0034)
O3	0.0235	0.0270	0.0286	0.0270	0.0283	0.0284	0.0295	0.0259	0.0246	0.0266
<0.05 ppm	(0.0067)	(0.0085)	(0.0083)	(0.0085)	(0.0070)	(0.0063)	(0.0066)	(0.0066)	(0.0057)	(0.0065)
CO	0.4720	0.5119	0.4790	0.4798	0.4850	0.5511	0.4984	0.7175	0.7427	0.7421
<9 ppm	(0.1757)	(0.1522)	(0.1503)	(0.1707)	(0.1500)	(0.2221)	(0.1277)	(0.2109)	(0.1760)	(0.1807)
PM_{10}	30.518	36.706	35.585	39.079	35.118	37.208	25.928	41.978	34.339	33.556
<100 μg/m^3	(7.3461)	(7.0990)	(6.5003)	(6.8184)	(8.6860)	(13.692)	(6.0272)	(15.324)	(11.112)	(15.720)
Tawau										
NO_2	0.0128	0.0133	0.0151	0.0143	0.0145	0.0147	0.0130	0.0137	0.0146	0.0140
<0.04 ppm	(0.0033)	(0.0034)	(0.0057)	(0.0035)	(0.0035)	(0.0042)	(0.0032)	(0.0038)	(0.0039)	(0.0039)
O3	0.0252	0.0267	0.0267	0.0265	0.0267	0.0283	0.0258	0.0249	0.0246	0.0272
<0.05 ppm	(0.0096)	(0.0075)	(0.0073)	(0.0075)	(0.0089)	(0.0090)	(0.0077)	(0.0073)	(0.0063)	(0.0077)
CO	0.6456	0.5790	0.5885	0.6166	0.7352	0.7929	0.6275	0.9986	1.0281	1.0027
<9 ppm	(0.2282)	(0.1639)	(0.2046)	(0.2620)	(0.2428)	(0.3806)	(0.1534)	(0.3160)	(0.1845)	(0.2150)
PM_{10}	41.505	41.011	39.281	36.740	33.688	43.324	31.883	37.096	32.560	32.219
<100 μg/m^3	(5.8810)	(8.6202)	(8.4291)	(6.3920)	(9.7958)	(32.468)	(6.8326)	(10.987)	(11.550)	(17.156)
Keningau										
NO_2	0.0071	0.0096	0.0087	0.0092	0.0081	0.0080	0.0090	0.0080	0.0086	0.0089
<0.04 ppm	(0.0031)	(0.0039)	(0.0037)	(0.0043)	(0.0038)	(0.0033)	(0.0038)	(0.0034)	(0.0040)	(0.0040)
O3	0.0204	0.0233	0.0230	0.0209	0.0226	0.0233	0.0271	0.0219	0.0238	0.0253
<0.05 ppm	(0.0061)	(0.0062)	(0.0064)	(0.0053)	(0.0081)	(0.0063)	(0.0082)	(0.0063)	(0.0058)	(0.0065)
CO	0.4202	0.4170	0.5422	0.4850	0.4805	0.4667	0.4889	0.6319	0.8523	0.8702
<9 ppm	(0.1478)	(0.1679)	(0.2140)	(0.1891)	(0.1494)	(0.1751)	(0.1766)	(0.2187)	(0.2248)	(0.2102)
PM_{10}	36.248	35.674	35.660	35.412	35.959	36.944	32.674	38.660	42.212	43.653
<100 μg/m^3	(11.252)	(10.691)	(10.957)	(14.232)	(9.5845)	(14.733)	(10.995)	(17.095)	(18.845)	(22.021)

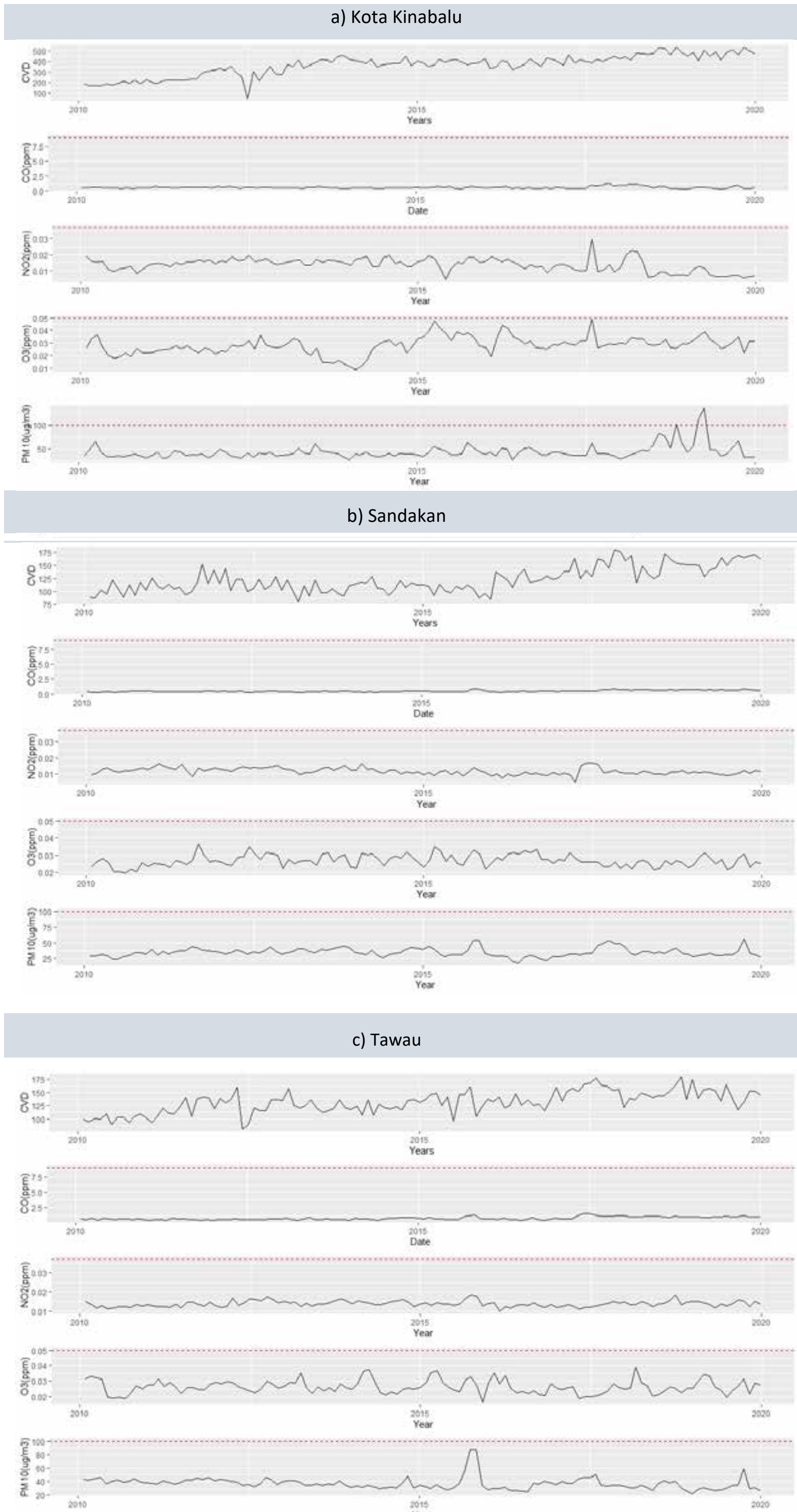
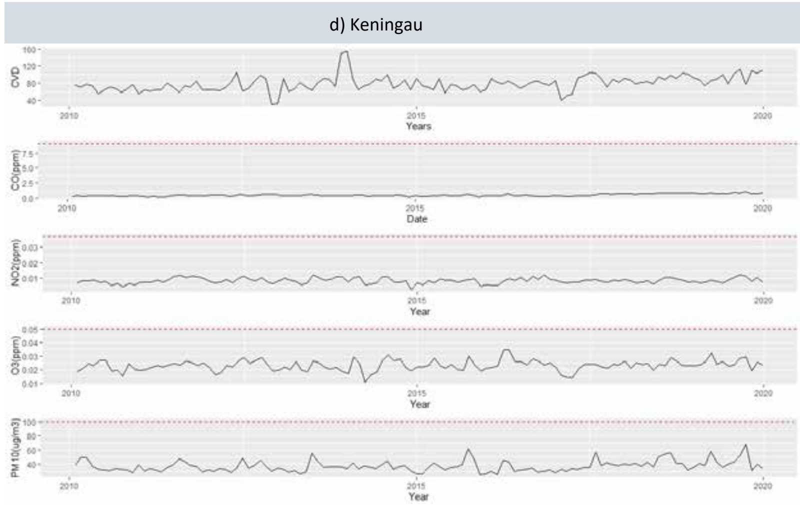
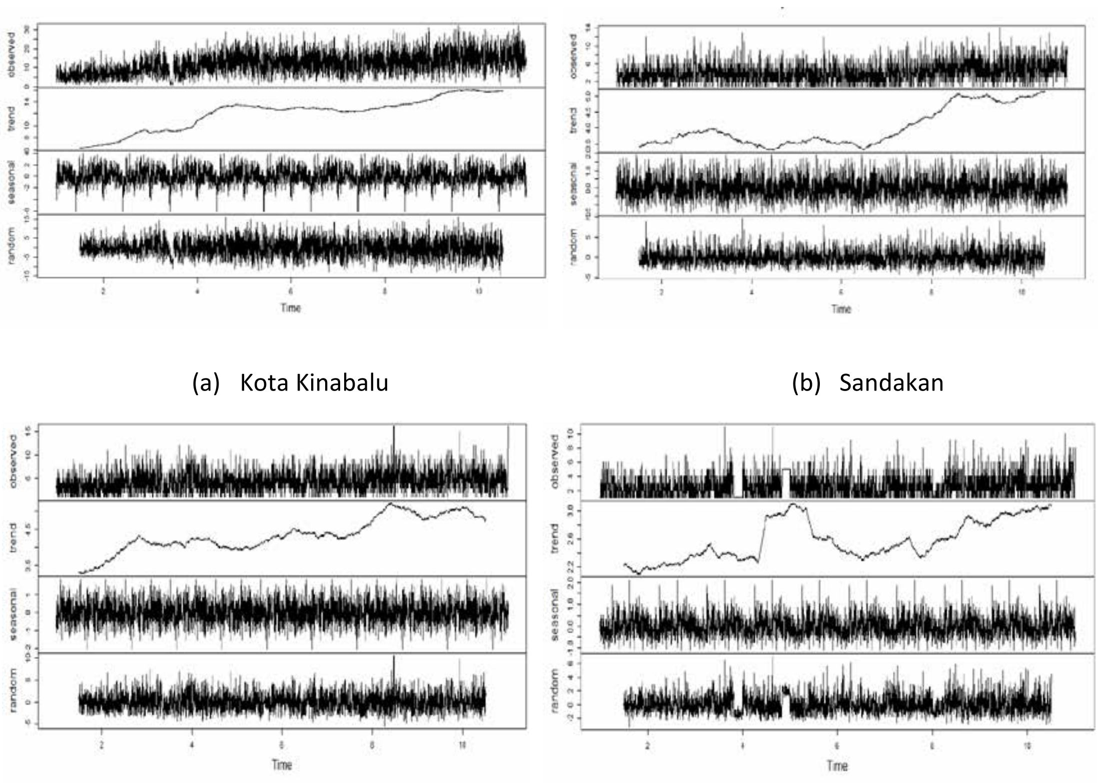


Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019



----- standard limit

Continued Fig. 1: Time series analysis of hospital admission for cardiovascular and air pollutants in Kota Kinabalu 2010–2019



(a) Kota Kinabalu

(b) Sandakan

(c) Tawau

(d) Keningau

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

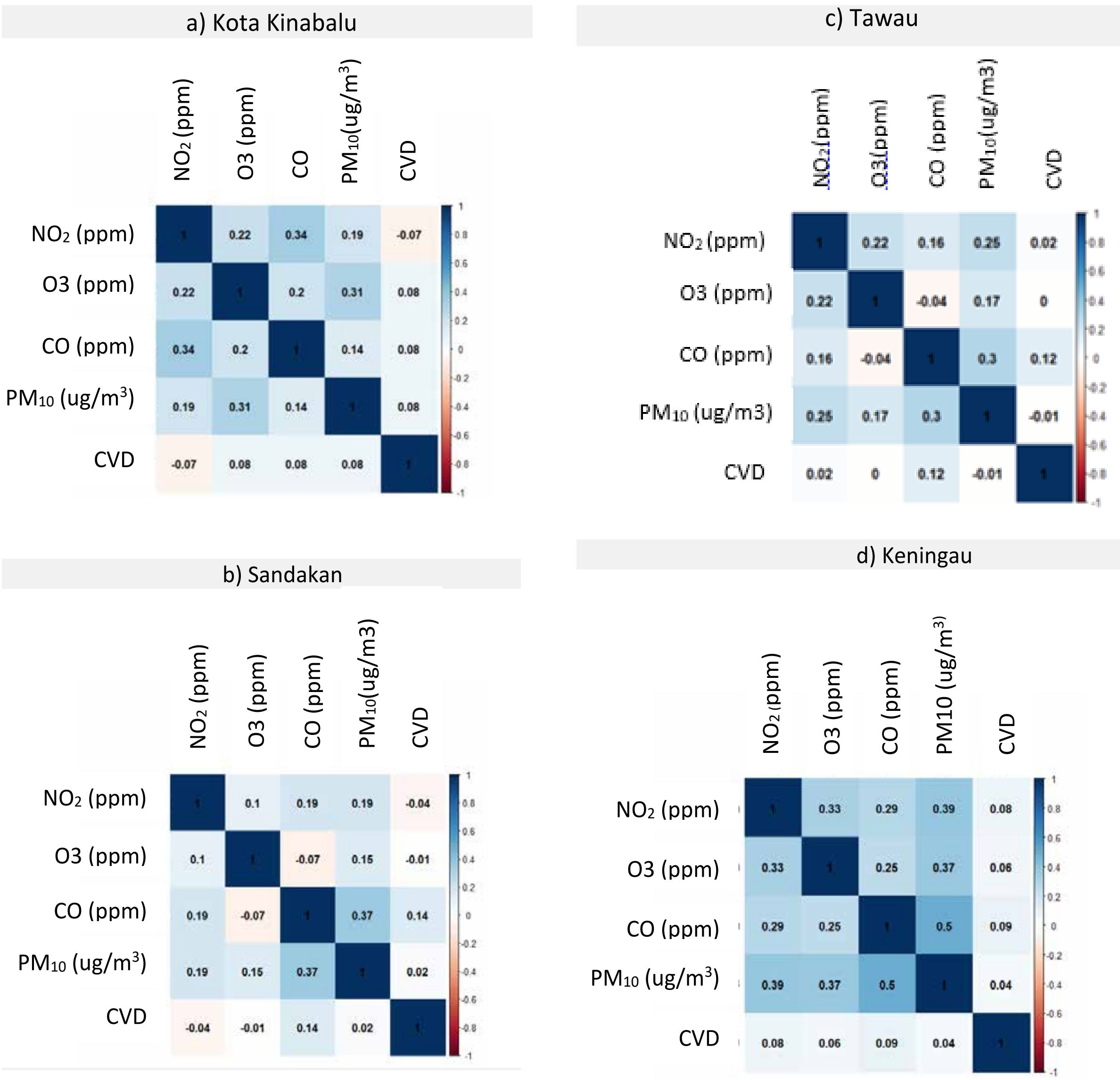


Fig. 3: Correlation coefficient between the air pollutants and cardiovascular hospital admission in Sabah 2010–2019 (a)Kota Kinabalu (b) Sandakan (c)Tawau (d)Keningau

in the findings in the present study. A study in the United Kingdom reported PM_{10} and O3 were consistently above the WHO limit. Hence, O3 become a major concern for premature death (Sicard *et al.*, 2021). On the other hand, air pollutants expects for O3 surged in China by 9% for a 4-year period (2015–2019). The SO2 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}, PM2.5, NO, NO_2, O3 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 air pollutants concentration compared to northern, southern, eastern, and Borneo. Stations in Borneo (Kuching, Bintulu, Miri, and Kota Kinabalu) reported a lower reading compared to stations in peninsular Malaysia. In the current study, the collateral trend was observed for PM_{10} before 2016. However, PM_{10} parameters increased in 2017 and endured a plateau trend until 2019 (Sentian *et al.*, 2019). Subsequent monitoring from the current study illustrated a downward NO_2 trend and rising CO numbers parameters. A distinct forecast study from 1997 until 2016 in the eastern peninsular Malaysia 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, O3, and PM_{10}. Kota Kinabalu displayed three air pollutants (O3, 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 ug/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 4: ARIMA model for cardiovascular hospital admission in Sabah 2010–2019 with air pollutants as the regressor

ARIMA model	AIC	Ljung-box test		Forecast error		
		Q	p-value	RMSE	MAPE	MAE
Kota Kinabalu						
[b]Model 1(0,1,1)	1240.069	5.4423	0.606	42.4823	12.53094	30.04068
[c]Model 2(0,1,1)	1240.711	5.4329	0.6073	42.61948	12.70077	30.57553
[a]Model 3(0,1,1)	1241.596	5.5184	0.701	43.16686	12.87206	30.90907
Sandakan						
[e]Model 1(0,1,1)	987.6061	13.529	0.09489	14.83993	9.353686	11.3033
[f]Model 2(0,1,1)	987.6088	13.564	0.09385	14.84036	9.352232	11.30254
[g]Model 3(0,1,1)	987.612	13.55	0.09426	14.84019	9.355505	11.30518
Tawau						
[g]Model 1(0,1,1)	992.442	8.3476	0.4003	15.07247	9.03198	11.43466
[e]Model 2(0,1,1)	992.5319	8.4144	0.3941	15.0782	9.040969	11.446
[f]Model 3(0,1,1)	992.5907	8.4477	0.391	15.08196	9.042505	11.44757
Keningau						
[c]Model 1(0,1,2)	1004.459	3.872	0.7944	15.74047	15.26077	11.193
[a]Model 2(0,1,2)	1005.43	2.9679	0.9364	15.95171	15.43113	11.2615
[h]Model 3(0,1,2)	1005.881	3.9177	0.7892	15.83803	15.10974	11.10421

AIC = Akaike Information Criteria; Q = Q statistic; RMSE = Root mean square error; MAPE = Mean absolute percentage error; MAE = Mean absolute error.
[a] without regressor; [b]O3; [c]NO_2; [d]PM_{10}; [e]CO; [f]CO and NO_2; [g]CO and O3; [h]O3 and NO_2.

Short term NO_2, SO_2, 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 ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, and O3) (Enkhjargal *et al.,* 2020). During the warm season, CVD admission surges after an increase in $PM_{2.5}$ (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 PM_{10} and O3 with CHD. Only SO_2 and NO_2 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.

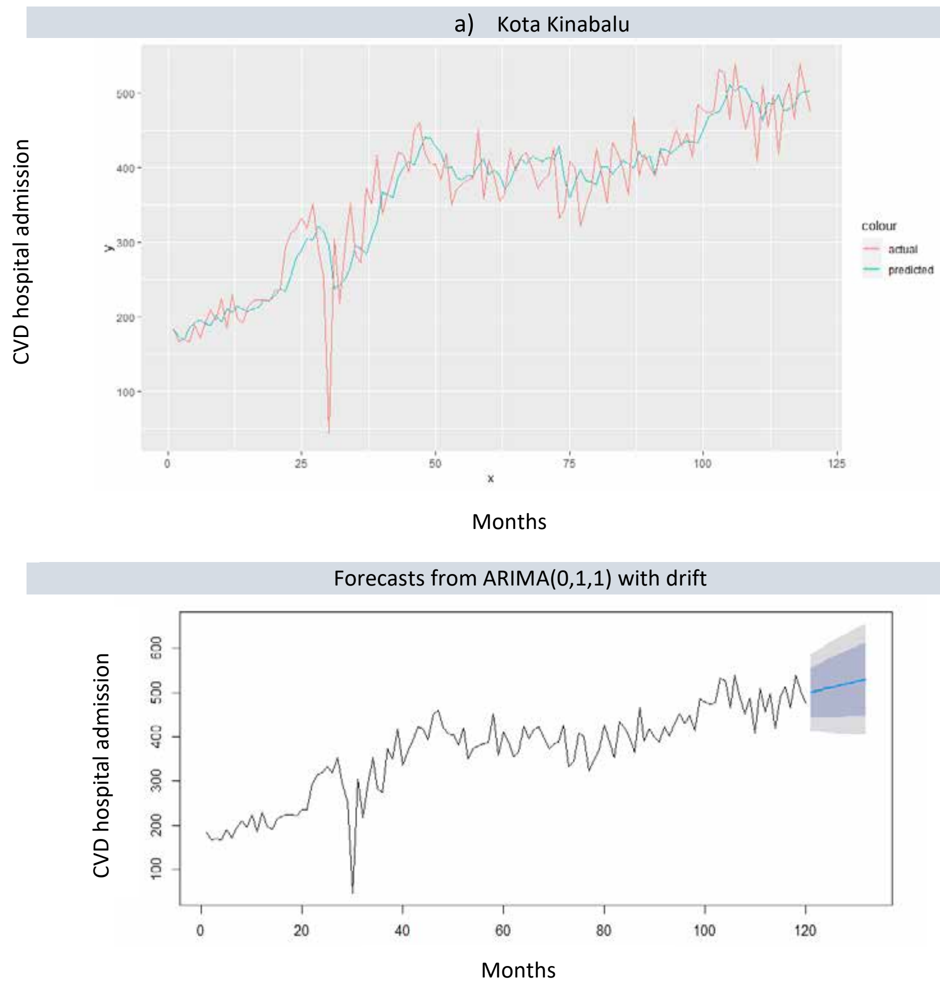


Fig. 4: Prediction forecast of cardiovascular hospital admission in Sabah with air pollutants as regressor in ARIMA

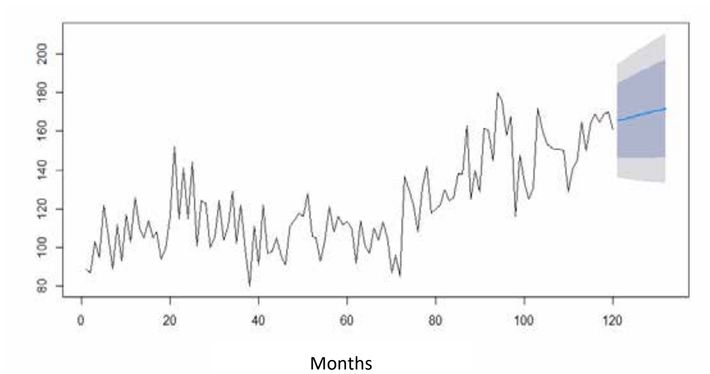
b) Sandakan

CVD hospital admission

Months

Forecasts from ARIMA(0,1,1) with drift

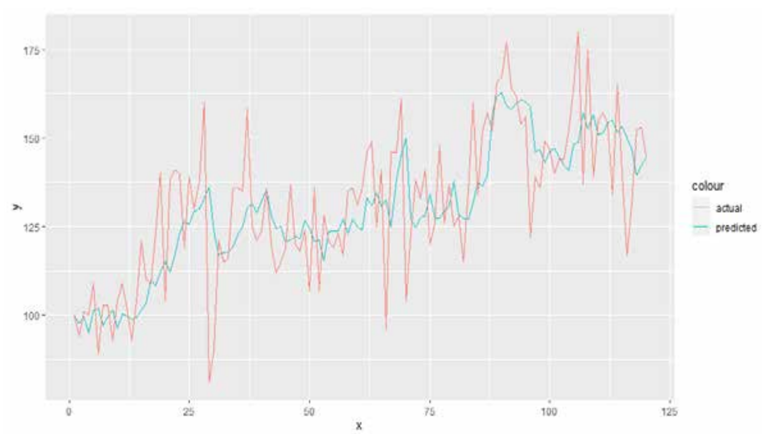
CVD hospital admission



Months

c) Tawau

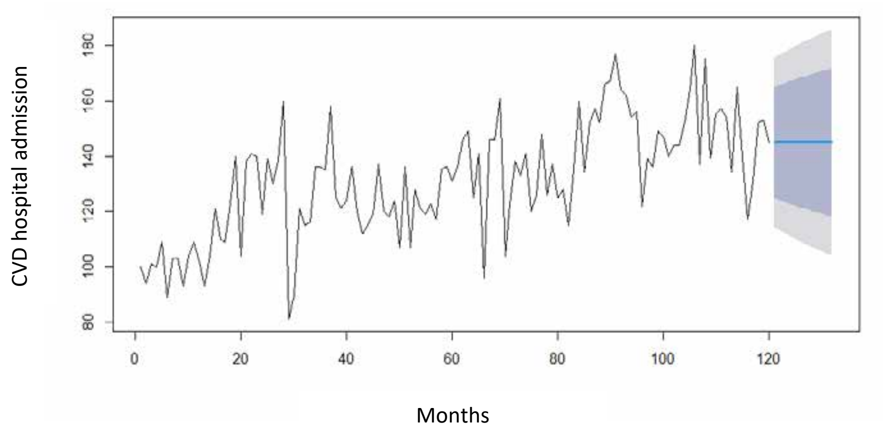
CVD hospital admission



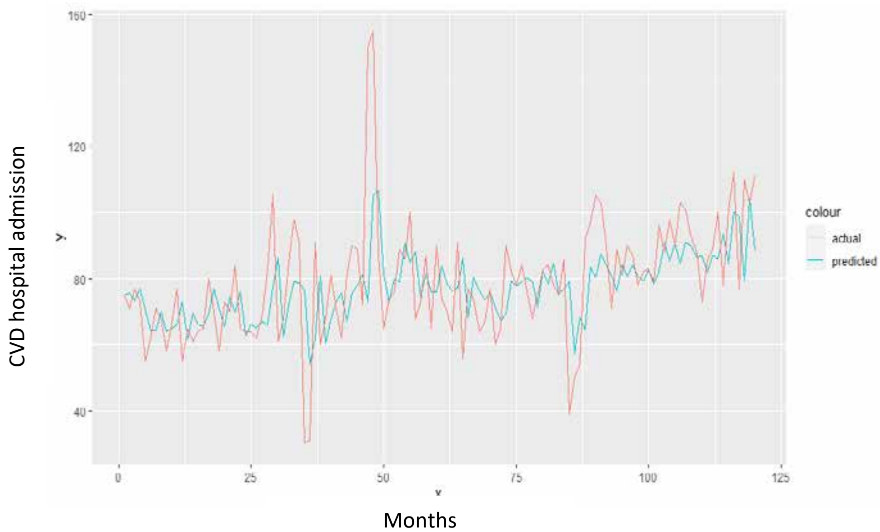
Months

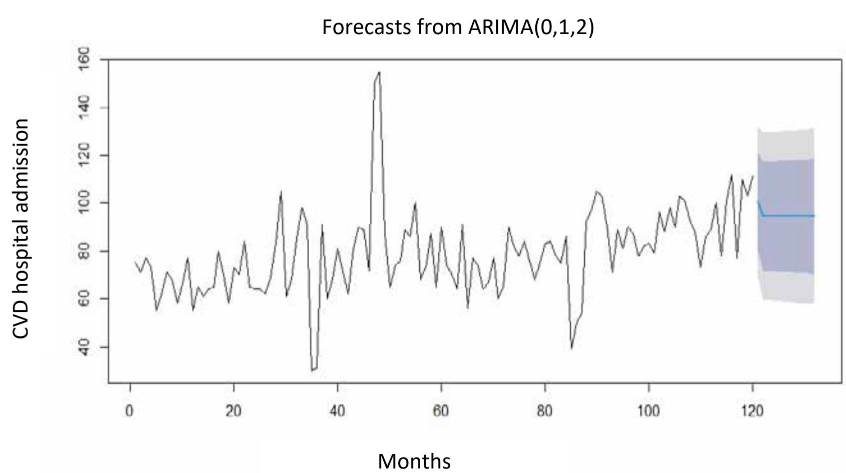
Forecasts from ARIMA(0,1,1)

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



d) Keningau





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 NO_2 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 NO_2) might be relevant in the model compared to two air pollutants (SO and NO_2) (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 infraction (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, NO_2, O3, and SO_2. 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 NO_2. 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.

ACKNOWLEDGEMENTS

The authors would like to thank the Director General of Health Malaysia for the permission to publish this work. Authors also expressed the utmost gratitude to the Director-General of Environment, Malaysia for permission to publish this paper. The authors also give their heartfelt appreciation to the Malaysia Ministry of Health and Malaysia Department of Environment. The authors would also like to thank the Enago for the English language review. This study received no specific grant from any funding agency.

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.

PUBLISHER'S NOTE

GJESM Publisher remains neutral with regard to jurisdictional claims in published maps and institutional afflictions.

ABBREVIATIONS

%	Percent
$\mu g/m^3$	Microgram per cumbic meter
AIC	Akaike Information Criteria;
AMI	Acute Myocardial Infraction
ANN	Artificial Neural Network
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive moving average
CAQM	Continuous Air Quality Monitoring
CHD	Coronary Heart Disease
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CVD	Cardiovascular Disease
DALYs	Daily Adjusted Life Years
DOE	Department of Environment
ELSTM	Enhanced Long Short-Term Memory
EPA	Environment Protection Agency
XGBoost	Extreme Gradient Boosting
LightGBM	Light Gradient Boosting Machine

GAM	Generalized Additive Model
LR	Logistic Regression
MAE	Mean Absolute Error
MAPE	Mean absolute percentage error
MET	Meteorology Department
MREC	Medical Research and Ethics Committee
MOH	Ministry of Health
NMRR ID	National Medical Research Registry Identification
NO_2	Nitrogen dioxide
O3	Ozone
$PM_{2.5}$	Particulate matter 2.5
PM_{10}	Particulate matter 10
ppm	Part per million
Q	Q statistic
RF	Random Forest
RMSE	Root Mean Square Error
SD	Standard deviation
SO_2	Sulphate dioxide
SPSS	Statistical package for social sciences
SVM	Support Vector Machine
USD	United State Dollar
WMO	World Meteorology Organization
WHO ICD	World Health Organization International Classification of Diseases
x	Months
y	Number of CVD hospital admission

REFERENCES

AQPAHO, (2020). Air quality—PAHO/WHO. Pan American Health Organization.

Amsalu, E.; Liu, M.; Li, Q.; Wang, X.; Tao, L.; Liu, X.; Luo, Y.; Yang, X.; Zhang, Y.; Li, W.; Li, X.; Wang, W.; Guo, X., (2021). Spatial-temporal analysis of cause-specific cardiovascular hospital admission in Beijing, China. Int. J. Environ. Health Res., 31(6): 595–606 **(12 pages).**

Artola, G.; Larburu, N.; Álvarez, R.; Escolar, V.; Lozano, A.; Juez, B.; Kerexeta, J., (2019). The impact of environmental factors on heart failure decompensations: Proceedings of the 12th International Joint Conference on Biomedical Engineering Systems and Technologies. 51–58 **(8 pages).**

Bhatnagar, P.; Wickramasinghe, K.; Wilkins, E.; Townsend, N., (2016). Trends in the epidemiology of cardiovascular disease in the UK. Heart. British Cardiac. Soc., 102(24): 1945–1952 **(8 pages).**

Bhatti, U.A.; Yan, Y.; Zhou, M.; Ali, S.; Hussain, A.; Qingsong, H.; Yu, Z.; Yuan, L., (2021). Time series analysis and forecasting of air pollution particulate matter (PM2.5): An SARIMA and factor analysis Approach. IEEE Access. 9: 41019–41031 **(13 pages).**

Bourdrel, T.; Bind, M.-A.; Béjot, Y.; Morel, O.; Argacha, J.-F., (2017). Cardiovascular effects of air pollution. Arch. Cardiovasc. Dis., 110(11): 634–642 **(8 pages).**

Brown, K., (2017). How much does pollution increase as cities grow? Envirobites.

Chauhan, S.; Aeri, D.B.T., (2013). Prevalence of cardiovascular disease in India and its economic impact- A review. Int. J. Sci. Res. Publ., 3(10): 1-5 **(5 pages).**

CVD-WHO, (2020). Cardiovascular diseases (CVDs). World Health Organization.

Davoodabadi, Z.; Soleimani, A.; Pourmoghaddas, A.; Hosseini, S. M.; Jafari-Koshki, T.; Rahimi, M.; Shishehforoush, M.; Lahijanzadeh, A.; Sadeghian, B.; Moazam, E.; Mohebi, M. B.; Ezatian, V.; Rabiei, K.; Sarrafzadegan, N., (2019). Correlation between air pollution and hospitalization due to myocardial infarction. ARYA Atheroscler. 15(4): 161–167 **(7 pages).**

DOSM, (2019). Department of Statistics Malaysia Official Portal.

Enkhjargal, A.; Burmaajav, B.; Tsegmed, S.; Suvd, B.; Norolkhoosuren, B.; Unurbat, D.; Batbayar, J., (2020). Impact of Ambient Air Pollution and Meteorological Factors on Hospital Admission to the Cardiovascular System Disease on Ulaanbaatar City of Mongolia. Open J. Epidemiol., 10(2): 100–114 **(14 pages).**

Filippini, M.; Masiero, G.; Steinbach, S. (2019). The impact of ambient air pollution on hospital admissions. Eur. J. Health Econ., 20(6): 919–931 **(13 pages).**

Forsberg, B.; Bråbäck, L.; Keune, H.; Kobernus, M.; Krayer von Krauss, M.; Yang, A.; Bartonova, A., (2012). An expert assessment on climate change and health – with a European focus on lungs and allergies. Environ. Health. 11(1): S4 **(9 pages).**

Huang, Y.; Xu, C.; Ji, M.; Xiang, W.; He, D., (2020). Medical service demand forecasting using a hybrid model based on ARIMA and self-adaptive filtering method. BMC Med. Informa. Decis. Mak., 20(1): 237 **(14 pages).**

Ibrahim, M.Z.; Zailan, R.; Ismail, M.; Lola,M. S., (2009). Forecasting and time series analysis of air pollutants in several area of Malaysia. Am. J. Environ. Sci., 5(5): 625–632 **(8 pages).**

Imai, C.; Armstrong, B.; Chalabi, Z.; Mangtani, P.; Hashizume, M., (2015). Time series regression model for infectious disease and weather. Environ. Res., 142: 19–327 **(9 pages).**

Jalili, M.; Ehrampoush, M. H.; Mokhtari, M.; Ebrahimi, A. A.; Mazidi, F.; Abbasi, F.; Karimi, H., (2021). Ambient air pollution and cardiovascular disease rate an ANN modeling: Yazd-Central of Iran. Sci. Rep., 11(1): 16937 **(10 pages).**

Khan, R.C.; Halder, D., (2014). Effect of seasonal variation on hospital admission due to cardiovascular disease—Findings from an observational study in a divisional hospital in Bangladesh. BMC Cardiovas. Disord., 14(1): 76 **(6 pages).**

Konovalov, I.B.; Beekmann, M.; Meleux, F.; Dutot, A.; Foret, G., (2009). Combining deterministic and statistical approaches for PM10 forecasting in Europe. Atmos. Environ., 43(40): 6425–6434 **(10 pages).**

Lee, D.W.; Han, C.-W.; Hong, Y.-C.; Oh, J.-M.; Bae, H.-J.; Kim, S.; Lim, Y.-H. (2021). Short-term exposure to air pollution and hospital admission for heart failure among older adults in metropolitan cities: A time-series study. Int. Arch. Occup. Environ. Health. 94(7): 1605–1615 **(11 pages).**

Li, H.; Wu, J.; Wang, A.; Li, X.; Chen, S.; Wang, T.; Amsalu, E.; Gao, Q.; Luo, Y.; Yang, X.; Wang, W.; Guo, J.; Guo, Y.; Guo, X., (2018). Effects of ambient carbon monoxide on daily hospitalizations for cardiovascular disease: A time-stratified case-crossover study of 460,938 cases in Beijing, China from 2013 to 2017. Environ. Health. 17(1): 82 **(11 pages).**

Luz, P.M.; Mendes, B.V.M.; Codeço, C.T.; Struchiner, C.J.; Galvani, A.P., (2008). Time series analysis of dengue incidence in Rio de Janeiro, Brazil. Am. J. Trop. Med. Hyg., 79(6): 933–939 **(7 pages).**

MDE, (2020). Malaysia Department of Environment.

Mercan, Y.; Hapcioglu, B.; Issever, H., (2019). Time series analysis of the admission to the emergency department due to respiratory and cardiovascular diseases between 2010 and 2014 in Kırklareli, Turkey. J. Clin. Anal. Med., 10: 301–307 **(7 pages).**

Meyer, G.; Tanguy, S.; Obert, P.; Reboul, C., (2011). Carbon monoxide urban air pollution: cardiac effects. Advanced topics in environmental health and air pollution case studies. 171-178 **(8 pages).**

Motesaddi Zarandi, S.; Hadei, M.; Hashemi, S. S.; Shahhosseini, E.; Hopke, P.K.; Namvar, Z.; Shahsavani, A., (2021). Effects of ambient air pollutants on hospital admissions and deaths for cardiovascular diseases: A time series analysis in Tehran. Environ. Sci. Pollut. Res., 29(12): 17997-18009 **(13 pages).**

Nichols, M.; Townsend, N.; Scarborough, P.; Rayner, M., (2014). Cardiovascular disease in Europe 2014: Epidemiological update. Europ. Heart J., 35(42): 2950–2959 **(10 pages).**

Pedro Muñoz Miguel, J.; Simón de Blas, C.; Elizabeth García Sipols, A., (2017). A forecast air pollution model applied to a hypothetical urban road pricing scheme: An empirical study in Madrid. Transportation Research Part D: Trans. Environ., 55: 21–38 **(18 pages).**

Plass, D.; Vos, T.; Hornberg, C.; Scheidt-Nave, C.; Zeeb, H.; Krämer, A., (2014). Trends in disease burden in Germany. Dtsch. Arztebl. Int., 111(38): 629–638 **(10 pages).**

Qiu, H.; Luo, L.; Su, Z.; Zhou, L.; Wang, L.; Chen, Y., (2020). Machine learning approaches to predict peak demand days of cardiovascular admissions considering environmental exposure. BMC Med. Informa. Decis. Mak., 20(1): 83 **(11 pages).**

Richardson, J.; Grose, J.; Jackson, B.; Gill, J.L.; Sadeghian, H. B.; Hertel, J.; Kelsey, J., (2014). Effect of climate change and resource scarcity on health care. Nurs. Stand., 28(45): 44–49 **(6 pages).**

Sato, R.C., (2013). Disease management with ARIMA model in time series. Einstein (Sao Paulo), 11(1): 128–131 **(4 pages).**

Sentian, J.; Herman, F.; Yih, C.Y.; Hian Wui, J.C., (2019). Long-term air pollution trend analysis in Malaysia. Int. J. Environ. Impacts. 2(4): 309–324 **(16 pages).**

Sharafi, M.; Ghaem, H.; Tabatabaee, H. R.; Faramarzi, H., (2017). Forecasting the number of zoonotic cutaneous leishmaniasis cases in south of Fars province, Iran using seasonal ARIMA time series method. Asian Pac. J. Trop. Med., 10(1): 79–86 **(8 pages).**

Sharif Nia, H.; Gorgulu, O.; Naghavi, N.; Froelicher, E. S.; Fomani, F. K.; Goudarzian, A. H.; Sharif, S. P.; Pourkia, R.; Haghdoost, A. A., (2021). A time-series prediction model of acute myocardial infarction in northern of Iran: The risk of climate change and religious mourning. BMC Cardiovas. Disord., 21(1): 563 **(11 pages).**

Sicard, P.; Agathokleous, E.; De Marco, A.; Paoletti, E.; Calatayud, V., (2021). Urban population exposure to air pollution in Europe over the last decades. Environ. Sci. Europe. 33(1): 28 **(12 pages).**

Soenarta, A.A.; Buranakitjaroen, P.; Chia, Y.-C.; Chen, C.-H.; Nailes, J.; Hoshide, S.; Minh, H.V.; Park, S.; Shin, J.; Siddique, S.; Sison, J.; Sogunuru, G.P.; Sukonthasarn, A.; Tay, J.C.; Teo, B.W.; Turana, Y.; Verma, N.; Wang, T.-D.; Zhang, Y.-Q.; Kario, K., (2020). An overview of hypertension and cardiac involvement in Asia: Focus on heart failure. J. Clin. Hypertens (Greenwich). 22(3): 423–430 **(8 pages).**

Sofwan, N.M.; Mahiyuddin, W.R.W.; Latif, M.T.; Ayub, N.A.; Yatim, A.N.M.; Mohtar, A.A.A.; Othman, M.; Aizuddin, A.N.; Sahani, M., (2021). Risks of exposure to ambient air pollutants on the admission of respiratory and cardiovascular diseases in Kuala Lumpur. Sustainable Cities Soc., 75: 103390 **(8 pages).**

Sokoty, L.; Rimaz, S.; Hassanlouei, B.; Kermani, M.; Janani, L., (2021). Short-term effects of air pollutants on hospitalization rate in patients with cardiovascular disease: A case-crossover study. Environ. Sci. Pollut. Res. Int., 28(20): 26124–26131 **(8 pages).**

USEPA, (2016). Air Quality—National Summary. United State Environment Protection Agency. Data and Tools.

Usmani, R. S. A.; Pillai, T. R.; Hashem, I. A. T.; Marjani, M.; Shaharudin, R.; Latif, M. T., (2021). Air pollution and cardiorespiratory hospitalization, predictive modeling, and analysis using artificial intelligence techniques. Environ. Sci. Pollut. Res, 28(40): 56759–56771 **(13 pages).**WHO, (2016). Air pollution levels rising in many of the world's poorest cities. Headquarters World Health Organization.

Yang, J.; Liu, M.; Cheng, Q.; Yang, L.; Sun, X.; Kan, H.; Liu, Y.; Bell, M.L.; Dasan, R.; Gao, H.; Yao, X.; Gao, Y. (2021). Investigating the impact of air pollution on AMI and COPD hospital admissions in the coastal city of Qingdao, China. Front. Environ. Sci. Eng., 16(5): 56 **(6 pages).**

Yi, J.; Du, C.; Wang, R.; Liu, L., (2007). Applications of multiple seasonal autoregressive integrated moving average (ARIMA) model on predictive incidence of tuberculosis. Chin. J. Preventive Med., 41(2): 118–121 **(4 pages).**

Zhou, W.; Chen, C.; Lei, L.; Fu, P.; Sun, Y., (2020). Temporal variations and spatial distributions of gaseous and particulate air pollutants and their health risks during 2015–2019 in China. Environ. Pollut., 272: 116031 **(10 pages).**

AUTHOR (S) BIOSKETCHES

Salvaraji, L., M.D., MPH, Candidate, Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

- Email: *logansalv84@gmail.com*
- ORCID: 0000-0003-1160-5243
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://www.ums.edu.my/fpsk/

Avoi, R., MBBS, MPH, Associate Professor, Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

- Email: *richard.avoi@ums.edu.my*
- ORCID: 0000-0002-1957-0965
- Web of Science ResearcherID: T-7650-2019
- Scopus Author ID: 57205744554
- Homepage: https://www.ums.edu.my/fpsk/

Jeffree, M.S., M.D, MComm., Professor, Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

- Email: *saffree@ums.edu.my*
- ORCID: 0000-0002-0373-4451
- Web of Science ResearcherID: NA
- Scopus Author ID: 57190813749
- Homepage: https://www.ums.edu.my/fpsk/

Saupin, S., MBBS, MComm., Associate Professor, Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

- Email: *drsahi@ums.edu.my*
- Orcid ID: 0000-0003-1149-6200
- Web of Science ResearcherID: NA
- Scopus Author ID: 56660609500
- Homepage: https://www.ums.edu.my/fpsk/

Toha, H.R., MBBS, MPH, DrPH, Public Health Medicine Specialist, Public Health Division, Johor State Health Office, Malaysia Ministry of Health.

- Email: *grswd4rj@yahoo.co.uk*
- Orcid ID: 0000-0003-0389-1489
- Web of Science ResearcherID: NA
- Scopus Author ID: NA
- Homepage: https://www.ukm.my/portalukm/

Shamsudin, S.B., Ph.D., Associate Professor, Public Health Medicine Department, Faculty of Medicine and Health Sciences, Universiti Malaysia Sabah, Jalan UMS, 88400, Kota Kinabalu, Sabah, Malaysia.

- Email: *shamsul@ums.edu.my*
- Orcid ID: 0000-0002-9096-2312
- Web of Science ResearcherID: NA
- Scopus Author ID: 56728127500
- Homepage: https://www.ums.edu.my/fpsk/

HOW TO CITE THIS ARTICLE

Salvaraji, L.; Avoi, R.; Jeffree, M.S.; Saupin, S.; Toha, H.R.; Shamsudin, S.B., (2023). Effects of ambient air pollutants on cardiovascular disease hospitalization admission. Global J. Environ. Sci.Manage., 9(1): 157-172.

DOI: https://dx.doi.org/10.22034/gjesm.2023.01.12

url: https://www.gjesm.net/article_253279.html